obtainable by the same expenditure on additional nitrogen. It appears probable that the increase obtained is due to the increased immediate availability of the nitrogenous manures, and is not due to the lowered acidity of the soil. These cases also will be watched and further investigated.

The chief exceptions to these observations come from gardens in the Doom Dooma district where carefully conducted experiments show that liming has an undoubtedly beneficial effect on certain soils. Here a dose of 80 maunds lime per acre generally depresses the crop or gives a small increase but smaller doses of 60, 40 or 20 maunds, give increases varying from 10 to 16 per cent. above the non-limed plots. An application of 10 maunds gives an increase of about 3 per cent.

CONCLUSIONS.

Our opinions, on the evidence available may be briefly expressed thus:

Tea only grows well in soils which are definitely acid, and a relatively high degree of acidity appears to favour rapid growth, a high degree of acidity appears to act as a stimulant to tea, but stimulants in excess may prove harmful and such an excess is reached when very heavy top-dressings of acid peat-bheel are applied to sandy soils very low in lime as are Surma Valley teelas. In such cases the first effect has always been an enormous increase in crop, which is followed in later years by serious deterioration of the tea due to attack by disease. In such cases lime has often proved useful; and although we have no definite experiments in support of the supposition, it is probable that lime would in some cases, prove useful on very acid peat-bheel soils which are suffering from diseases.

Certain root diseases also are encouraged by excessive soil acidity, and will not grow in alkaline soil; these diseases may be usefully treated with lime.

On excessively heavy soils an application of lime will render the soil more permeable to water and to plant roots: in such cases lime may often prove valuable if used in quantities which still leave the soil definitely acid.

With the exception of such cases, lime on tea soils in small quantities is likely to have generally no good effect, while in quantities large enough to reduce the soil acidity greatly, it will cause definite loss of crop.—Quarterly Journal of the Indian Tea Association, Part 1, 1925

THE CONTROL OF THE BIOLOGICAL FACTOR IN SOIL FERTILITY BY IRRIGATION.

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Recent advances in our knowledge of the science of soil biology have led to the general conclusion that the relationship between soil fertility and the bacterial action upon which this depends, is mainly determined by the water-supply in the soil. The aim, generally unconscious, of the cultivator in this respect is in most cases to secure nitrification of the organic nitrogenous matter either present in, or added to, the soil, and the measure of

his success will depend upon the provision of appropriate moisture conditions for the various stages of the process. Under natural conditions, therefore, he is dependent firstly upon the amount, and secondly, upon the incidence of the rainfall, and most of the management of the soil, in which the art of agriculture mainly consists, is directed towards making the most of such rainfall as occurs. In irrigated areas, however, the uncertainty attendant upon this natural water-supply is to a large extent done away with, and it is therefore precisely in such districts that we have an opportunity, not only of making use of such knowledge as we possess of the water requirements of soil bacteria, but of adding enormously to our, at present, comparatively scanty stock of information on this point. The gap in our information comes at present between our knowledge gained in the laboratory and the conditions obtaining in the field, and it is this gap which research, carried out under proper conditions, should be able to fill. The necessary conditions, in my opinion, would involve the close collaboration of an experienced laboratory worker (a soil bacteriologist) and an agricultural expert fully experienced in irrigation methods, and the chances of successful and rapid advance in this line of research would be greatly increased by the inclusion in this collaboration of a soil physicist on the one hand and probably an irrigation engineer on the other.

The importance of this line of research is overwhelmingly great; it may be partly gauged from the large volume of discussion ranging round about such subjects as soil aeration, drainage, and irrigation, and based almost entirely on empirical experiment or more dogmatic statements of the water requirements or air requirements of crops. Of real knowledge, even of optima, we have at present but little, and although research on soil biology is continually adding to it, such advance is necessarily slow, very largely on account of the small number of centres where such research is being carried out, and the small number of workers on the subject. In India we are especially well situated for such work in respect of the high soil temperature obtaining in most districts, with the consequent greatly increased rate and amount of bacterial action going on in the soil; in addition to this we have enormous irrigation areas where knowledge of the optimal conditions of soil moisture is of incalculable importance because of the possibility of approximating to them by means within direct control.

Not only is it of great importance to know how best to secure nitrification of organic nitrogen present in the soil, but the actual increase in the amount of the latter by natural fixation processes may be said to be of equal consequence, especially in India. There can be no doubt that such processes, whether symbiotic or asymbiotic, depend largely upon proper water conditions being maintained in the soil, and I am at present of opinion that the amount of nitrogen fixed by a soil is largely determined, *coeteris paribus*, not so much by the amount of water in the soil as by its continuous movement therein. In any case it is of prime importance to ascertain, as nearly as possible, the optimal methods of applying water to a soil so as to secure nitrogen fixation therein, as, in practically every Indian soil with which I am acquainted, the supply of nitrogen and the exhaustion of that supply by over-cropping or intensive cultivation, is the most important problem to be

dealt with. It may be of interest to mention here some of the particular problems arising out of investigations dealing with the relation between bacterial action and water-supply in soils.

(*a*) In the conversion of buried organic matter such as green manures, oilcake, etc., into available plant food, the various stages of decomposition are carried out by different classes of bacteria requiring different soil conditions for their successful operation. Thus during the earliest stage when it is advantageous to provide for the breaking down of the cell walls of the vegetable tissues present, a high moisture percentage will conduce to completeness of this action; later, ammonification is promoted by a smaller amount of soil water, and lastly nitrification of the ammonia and amino acids will be secured by a still further reduction of the water-supply. Such control as this implies could only be secured under irrigation, although a well-distributed rainfall would produce similar results. In the above operation it is necessary for success to avoid certain extremes, such as the loss of nitrogen as gas under excessive flooding, the formation of soil colloids due to prolonged high moisture conditions, and the reduction of nitrates during the later stages due to the same cause. It is obvious not only that further research is necessary to determine more fully the conditions underlying such results, but to apply the knowledge gained to soils of varying type. It is also obvious that at present we are not possessed of sufficient information to lay down any hard and fast rules as to the number of waterings which will give the best results for any particular crop or soil. It has been demonstrated at Pusa that the transpiration requirements of various crops may be modified by adequate provision of plant food; such provision is partly dependent upon bacterial action, so that proper control of the water supply not only implies provision of the minimum requirement of the crop, but the possibility of reducing this amount by proper attention to that of the soil bacteria.

(*b*) In unirrigated soils of the Gangetic alluvium the growth of cold weather crops is sometimes considerably prejudiced by the undue concentration of nitrates in the surface layer, leading to the formation of a highly superficial root system incapable in many cases of obtaining sufficient moisture from the subsoil to secure complete growth. In Pusa soil this phenomenon is sometimes so marked as to lead to the concentration in the first inch of soil of over 90 per cent. of the total nitrate nitrogen in the first eighteen inches, with the result that careful cultivation is necessary to avoid the formation of a highly superficial root system in the *rabi* crop. With irrigation it is possible to keep down the nitrate to a suitable level and to secure its more even distribution, but it will be necessary to make careful experiments in order to determine the best manner of securing this result, without incurring the danger either of removing the nitrate out of root range or of promoting its reduction by bacteria.

(*c*) An interesting case in point is the practice, known in the Shahabad District as "Nigar," of running off the water from the rice fields some time before maturation of the crop; it appears probable that this method results in the formation of nitrates which are supposed to conduce to proper ripening of this crop although fatal in the earlier stages. This case is cited

as one of many which proper investigation would help to place on a sound basis of scientifically ascertained fact. In this connection it may be pointed out that problems of great economic importance are connected with the irrigation of rice, and should be included in any scheme of scientific investigation of the biology of soil under irrigation.

In considering the possibilities of controlling nitrification by suitable irrigation practice it is important to realize the fact that the amount of nitrate actually accumulating in a soil is the algebraic sum of two opposite sets of bacterial processes, namely, those producing nitrate as their end reaction and those either preventing the nitrification of nitrogenous organic matter or reducing nitrate already formed. The balance of these opposite processes is largely determined by moisture conditions in the soil, and so irrigation practice must be regulated in accordance with the information on this point obtained by biological investigation. Furthermore, the importance of such regulation lies not so much in the ability to produce large total amounts of nitrate during the season, but in the possibility of ensuring their presence in sufficient quantity at definite points in the growing period of the crop. It is well known to agriculturists that the success of a crop so far as nitrogen supply can secure it, depends upon such supply being present in an available form at certain stages of growth. It is obvious therefore that incalculable advantage must accrue from the combination of knowledge of how to obtain and regulate this supply of nitrate and the power of doing so. It is such knowledge as this that can be obtained by researches in soil biology as applied to irrigation practice.

It may then be emphasized that an investigation into methods of irrigation, if it is to have any chance of providing really fundamental information, must include, and indeed mainly depend upon, research into the biological conditions obtaining in the soil.—The Agricultural Journal of India, Vol. XX, Part 4.

THE SOIL WITH SPECIAL REFERENCE TO SOME OF ITS INORGANIC CONSTITUENTS.*

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From the earliest times till some sixty or seventy years ago agriculture was carried out by crude methods which had been handed down from father to son with little improvement. The latter half of last century, however, brought tremendous changes so that now agriculture is universally regarded as a science requiring all the skill and knowledge of a trained research worker to unravel the many factors affecting the production of crops.

The whole business of agriculture is founded on the soil, and on the skill in making use of its inherent capacities depends the outturn of crops which the cultivator will obtain.

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