Some Physical Aspects of Soil Conservation.

THE following paper on "Some Physical Aspects of Soil Conservation" read by Dr. William B. Haines, Soils Divisions, Rubber Research Institute of Malaya, before the Conference of Incorporated Society of Planters held on August 14th and 15th, 1927, is taken from *The Malayan Tin and Rubber Journal*, Vol. XVI., No. 16 :—

Soil conservation means the art of maintaining soil fertility under the exacting conditions of crop production. Under virgin conditions soils reach a stable level of fertility, the level being high or low according to the nature of the soil and of the normal weather to which it is subjected. The balance is disturbed as soon as cultivation begins and for the most part the new factors which come into play tend to reduce fertility, so that the cultivator must constantly apply himself to methods for keeping the fertility from declining.

The subject may be considered in two main aspects, the physical and the chemical. The physical considerations include all methods of improving the soil condition such as mechanical cultivation, drainage, terracing and so on, while the chemical treatments must take in view the actual plant nutrients in the soil, and by the application of additional material as manure must either make up a deficiency or make more easily available the substances already present. The title of my paper when first arranged was limited to the physical aspects of the subject because Mr. Grantham was down to talk to you on the manuring of rubber, but as that paper has been withdrawn I need not apologise if I overstep my bounds and include some of the chemical considerations in my talk. My aim is just to put before you in review the general properties of soil. My contact with rubber-estate problems is too recent for me to attempt to lay down rules or to discuss practical points in great detail, but I shall be satisfied if my talk enables the practical man to understand better the soil changes which the various methods of treatment are designed to produce, and to understand the differences which make one soil so much better than another.

Question of Soil Tilth.

The importance of a proper physical texture in soil is in much more danger of being overlooked in rubber cultivation than in most other cases. In the cultivation of annual crops in temperate climates the question of physical condition becomes of the utmost importance at least once in the year, namely at seed-time, so that it cannot possibly be neglected with impunity. The farmer has the question of soil tilth constantly in mind and makes the work reouired to keep his land in good physical condition his chief item of expenditure. Under rubber there is not the same opportunity to apply soil cultivation methods nor the same apparent necessity to do so. Yet the rubber tree requires the same general conditions for healthy growth as other plants and if the soil conditions are allowed to deteriorate the effects of neglect become cumulative, and recovery may be gained only at great expense of time and money.

First of all let us examine the production of latex from the most general point of view. Suppose that it were being produced as the end-product of a factory process, then a description of its manufacture would entail answering the questions: What is the energy supply? What are the raw materials taken in and consumed? And what is the efficiency of the process? These queries may be applied to the natural process. The last question as to efficiency plainly concerns the production of better yielding trees, and so is outside my scope, but it will be instructive to consider the other two. The raw materials required by the rubber tree for its growth and from which therefore the latex is produced are drawn from the air through the leaves in the shape of carbon dioxide, and from the soil through the roots in the shape of water and various mineral salts. The energy required for elaborating the latex and plant tissues from these raw materials is absorbed from sunlight by the leaves. This intake of energy corresponds to the coal or oil or electricity, which may give motive power to a factory and it may be expressed in the same terms. That is to say, we can express the amount of energy shed by the sun on an acre of land as equivalent to so many tons of coal. I am not aware of many such measurements having been made in the tropics but even in temperate regions the average amount of solar energy received on an acre during a warm day would be the equivalent of several tons of coal. This supply is obviously so liberal that only a small proportion needs to be absorbed by the tree and a still smaller proportion is actually stored in the latex. Thus we may view the rubber estate as a canopy of leaves spread to catch sunshine from the sky and carbon dioxide from the air while a complementary root-system is spread in the soil to collect water and the various plant nutrients. If conditions exist which check a complete development of leaf or root so that part of the sky space is not covered by leaf or part of the soil space is not explored by roots then we may say that nature's latex factory is not exploiting all its opportunities and so is not producing its maximum output.

Limiting Factor.

This brings us to the important concept known as the limiting factor. Wherever there is a chain of inter-dependent processes such as we are considering and which we wish to strengthen, then we have first to find the weakest link and pay attention to that. Abundant supply in one direction is of no value if a check is being imposed by a stringency in another direction. Hence the first step in estate improvement is a correct diagnosis of the limiting factor. For the moment we are to deal with those that concern the soil, the conditions which may hinder proper root development or fail to supply the root system with a proper amount of water or plant food. It may be well to remark that when attention has improved some limiting factor and in this way permanently increased the output, then some other factor assumes importance as a new limiting factor. The focus of attention shifts from one point of improvement to another until the remaining limits are such that it is either uneconomic or impossible to remove them.

Consider first the limiting factor in the soil from the chemical standpoint. The chemical nutrients drawn from the soil by the plant received small attention during the earlier history of agriculture, mainly because in the actual bulk of plant tissue they form such a very small proportion. About the middle of last century Lawes and Gilbert by means of plot Experiments at Rothamsted established an understanding of the main facts regarding the part played by soil in plant nutrition and revolutionised agriculture by the introduction of chemical fertilisers. They showed that there are three chief plant foods taken in from the soil namely nitrogen, potash and phosphate and that a deficiency in any one of these may be a severe check on plant development. These soil constituents are present in relatively very small amounts, and although a crop removes only small quantities a deficiency may be readily brought about by persistant cropping. Under virgin conditions the decaying plant ultimately returns to the soil all the mineral constituents which it has removed, but under cultivation these are taken to market with the crop and sold. Compared with other crops rubber removes from the land relatively small amounts of these essential plant foods although a large amount of sunk capital is represented by the permanent parts of the trees. It has been calculated that on an average estate there is removed in the latex from an acre in one year about 4 lb. of nitrogen and a little more than 1 lb. of phosphate and about a quarter of a lb. of potash. The small proportion of the total soil which is here represented can be realised when we remember that the amount of soil which covers an acre to a depth of 9'' is 3 million lb. Thus a fairly heavy chemical dressing only adds one part in ten thousand to the soil, yet this is enough to make big differences in plant growth.

Nitrogen Deficiency.

Modern research is showing the great importance of the question of the availability of these plant foods. A simple chemical analysis of the soil is not alone sufficient to indicate what fertilisers are to be advised, and an appeal to experiment is often the best method of deciding. Thus the soils which have shown such a good response of rubber to manuring with nitrogen are not notably deficient in this constituent. On analysis one might not have diagnosed nitrogen deficiency , but experiment proved this to be the case as far as availability to the plant was concerned.

The nitrogenous plant foods take the place of first importance, and have a most marked effect upon the leafy growth of plants. While potash and phosphates can only arise from the mineral part of the soil, nitrogen can be fixed from the air by biological activity in the soil. In the particular case of leguminous plants a partnership has been struck up with the nitrogen fixing bacteria of the soil so that the growth of such a crop greatly increases their action and may add to instead of depleting the nitrogen in the soil. Needless to say a good supply of air is necessary to the activities of these bacteria. The nitrogen in the soil assumes various forms but it is only as the soluble nitrate that it is available to the plant. Hence it is easily dissolved out and leached away by rain. Thus questions of aeration and drainage of the soil play a most important part in the formation of and loss of nitrates.

Physical Analysis.

Turning to the physical side of the question it will be necessary first of all to describe what is meant by the physical (or mechanical) analysis of soil. Such an analysis consists in classifying the soil particles into groups according to size and estimating the proportion of each size which is present in a given soil sample. The classes are known as coarse and fine sand, silt, fine silt and clay. The proportions in which they are present will largely determine the physical properties of the soil, particularly that most important property, the rate at which water and air can move through the pores of the soil. Another most important inference can be made from the mechanical analysis, namely the area of the total surface of the soil particles. Some of the most important modern advances in science have been made by the study of surface films, which show properties quite distinct from the substances in bulk. Even under dry conditions the surface of the particles of soil has a very tenuous film of water spread over it and firmly held, while in this film the dissolved salts of the soil which form plant food tend to a greater concentration. The surface is said to absorb these salts and in this condition they are not washed away under excess of water. Hence if these surface films are extensive enough they play an important part in the behaviour of the soil. The increase in the surface area as the particles become finer is a most striking fact. A stone weighing one pound would have a surface area of several square inches but if it be broken down to the fineness of an average soil sample the surface area (for the same amount of material) will be several thousand square yards. It is easy to see that these special film properties, though they may be unimportant in a coarse sandy soil may assume great importance in soils containing a lot of clay. In a wet clay the total particles surface is so large that a large proportion of the water may be bound by its proximity to this surface and this restricts its freedom of movement. In this way the impervious nature of clay as compared with sand can be partly accounted for. A sand may only contain half the amount of pore space for water movement that is present in a clay, yet it is far more pervious. The absorptive properties of these extensive films also account for the good filtering and deodorising properties of soil.

Capillary Attraction in Soil.

A property which is connected with this affinity of clay for water, is the swelling and shrinking of clay as it is wetted and dried. This plays an important part in the formation of a crumb structure in soils. While clay soil in a compact mass is so impervious as to be little use agriculturally, the same clay may be made to form into crumbs or granules and so stimulate the more open texture of a sandy soil. It then has the advantages of both. By alternate wetting and drying of a clay under weathering the swelling and shrinking tends to break it up. This action is of course spoiled by working the clay when wet and plastic and is facilitated by the addition of lime. The author found at Rothamsted reductions up to 15 per cent. of ploughing draft produced by this crumbling effect of chalk on soil. Under the conditions of high temperature and rainfall in the tropics lime is generally deficient in the soil, but it must be a matter of experiment to see whether it will prove advantageous to maintain the lime content at a higher level. There can be little doubt that age-long conditions will be reflected in an adaptation of the indigenous plants.

Great interest attaches to the phenomena of capiliary attraction in soil. By this is meant the action which all porous substances possess of drawing or sucking liquids into their pores. The action of blotting paper or of a lamp-wick are familiar examples. In soil it creates a tendency for water to move from wet regions towards drier regions. Thus movement may take place upwards during dry weather, and it is a common observation that the soil remains wet for some distance above the level of water in a drain. The force of this suction increases as the texture of the soil becomes finer, but on the other hand the rate of water movement falls off with increasing fineness. Hence there is a particular intermediate texture for which the benefits of capillary suction will be most noticed. The soil must be fine enough to give a good suction value, but coarse enough to allow free movement of water both for drainage under gravitational attraction and rise under capillary attraction. The action is always present in soil, although the ideal conditions are rarely approached. When they are the effects are striking. The writer remembers a particular case of a market garden which had one spot which never suffered in drought. On examination it was found that the soil there was a deep silty deposit of just the right texture to draw up the ground water from below at a sufficiently fast rate for the plants. Measurements can be made to show that silt may exert a suction pressure of several pounds to the square inch, which would be equivalent to the power of drawing water up to a point from over ten feet below. These points should be borne in mind in deciding on the depth of drains. Drains are sometimes not cut deep enough for fear that the water table will be lowered too far, such a judgment neglecting to take account of the fact that the moisture in the soil is maintained through a region above the free-water level, by this property of capillarity.

Important Soil Constituents.

When fallen leaves and other decaying vegetable matter get incorporated into the soil they form a most important soil constituent known generally as humus. Its presence has a most marked effect in assisting a crumb-structure and good aeration in the soil and by absoption it considerably improves the water retaining capacity of the soil. But, perhaps the most important role that humus plays may be classed as a chemical effect. Since it represents what was once the living tissue of the plants it has locked in it the plant nutrients which were previously taken from the soil. By its gradual decay these are released again and start once more round the same cycle. The very decaying process itself indicates that the humus is providing food material for a host of tiny organisms in the soil, many of which are playing the vital part of nitrogen fixation which has already been referred to. If the soil is badly aerated, as by water-logging such organisms cannot live and humus decay is prevented so that it accumulates and gives rise to the peaty lands of marshy regions. Hence the importance of proper aeration can hardly be over-estimated for production of fertility, especially in regions of high rainfall. In virgin soil the amount of humus varies according to climatic conditions but it reaches a constant value as a balance between growth and decay, the entire vegetation being returned to the soil. But under conditions of cultivation the tendency is always to a reduction of humus content. Clean weeding and exposure of the soil hasten decomposition and lessen input. While it is probably never economic to endeavour to force up the humus content above the level natural to the soil and climate yet it is often important to prevent its decline by applying organic fertilisers or by green manuring, *i.e.*, the growing of a crop for the specific purpose of returning it to the soil again. A very interesting modern development in regard to organic fertiliser is the synthetic farmyard manure produced by the Adco process. This process was the outcome of research in the problem of utilising waste vegetable materials which if added to the soil direct, would decay so slowly as to be of little fertilising value. Means of treatment were found by which decomposition in the mass is brought about before applying to the soil, and very good results have been obtained.

Green Manure's Double Purpose.

A green manure usually serves a double purpose by keeping the land clean from weeds. In the case of rubber this second service is the protection of the soil from wash under the very high and intense rainfall. The cover crop acts in two ways first by protecting the surface from mechanical erosion from the direct impact of rain and secondly by rendering penetration into the soil more easy and reducing surface run-off. The former action may be seen on estates where erosion has exposed a root but all the soil vertically under the shelter of the root remains. Also small stones and sticks may often be seen standing perched on a pillar of soil which their presence has protected while the surrounding soil has been washed away. A cover crop may be very useful also in preventing a bad soil fault known as capping. This describes a condition in which the soil surface forms a hard and impervious cap, and is apt to occur on clay soil exposed to direct wash from rain. The presence of such a cap lessens aeration and causes rain to run off over the soil instead of into it, with consequent bad effects. The growth of any spreading cover very largely prevents such a condition from arising.

In all these questions of physical changes in the soil the most important feature is the rate at which movement can take place. Thus after heavy rainfall with the soil saturated a drain begins to carry off water from the soil in its immediate neighbourhood, and the area affected gradually spreads out from the drain with the passage of time. The rate of spread will depend upon the permeability of the soil, being faster where the texture is more open. When the spread from two neighbouring drains meet and overlap their function for the time being is fulfilled. This stage must be reached before the next period of saturation by rain arrives. In judging the distance between drains, therefore, one must take into account the frequency as well as amount of rainfall and the permeability of the soil. As the water drains away air is drawn into the soil behind it, and this aeration is of vital importance to the living organisms of the soil, which are in turn of such importance to fertility. If water is allowed to stand in such excess as to exclude air from the soil a stagnant state supervenes which makes it quite unsuitable for most plants. The absence of a tap root in trees growing on poorly drained land is very often remarked. Proper drainage, on the other hand, encourages a deep rooting and greatly increases the available resources of the soil.

The Final Word.

It has already been remarked that with our present limited knowledge of the specific response of rubber to manuring, it is often advisable for estates to experiment under their own conditions. A final word with regard to the lay out of such experiments will not be out of place. It cannot be too strongly insisted that careful planning can greatly increase the value of field tests. Modern statistical examination of the subject shows that a little more elaboration of detail in a trial may often increase its value manyfold. A simple experiment may need to be repeated say for ten or fifteen years before the result can be relied on, while a little elaboration of the same test may give the same degree of certainty in one or two years. The great thing is to be able to eliminate from the results the effects of uncertain factors such as varying skill in the tapper, or varying fertility in different parts of the field under test. The ideal arrangement would be to have individual records, from an equal number of manured and unmanured trees which were dotted about the trial area in a random manner. This would obviously be too troublesome, but a practicable approach to the ideal can be made by dividing up the area under trial into a number of equal strips and making them alternately manured and unmanured. The tapping error can best be got rid of by assigning tasks in strips running across the plots so that each tapper does part of an equal number of manured and unmanured plots. If it is found best to assign tasks along the plots, then the tappers must be moved on to regular intervals from one task to the next in regular rotation. It is also of great advantage if records of yields can be made available, taken from the same plots in the same way, for a period prior to the application of the manures. This gives information as to individual differences in the plots, which can then be allowed for in the final results, thus enabling the effect due to the manures alone to be more clearly discerned.