THE VERTICAL DISTRIBUTION OF SOIL ACIDITY IN NATURAL SOILS AND ITS RELATION TO THE ORGANIC CONSTITUENTS.¹

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Much has already been done towards the investigation of acidity as it varies between one area and another, but the modifications of this factor in the vertical direction have, up to the present, been almost entirely neglected.

It is unnecessary to emphasise here the importance of distinguishing between the factors which enable a true acidity to be realised and those which actually bring about the acidity itself. With regard to the latter, it is immaterial to the immediate question whether the acidity is due to the ionisation of organic or inorganic acids or to adsorption phenomena consequent upon the presence of colloidal humus.

It is, however, necessary to consider briefly the conditions which bring about the removal of bases and thus permit the development of high hydrogen ion concentrations.

The most important of such factors is the leaching action of carbonated rain-water which, as the Rothamsted results have shown, can remove calcium salts at the rate of 800 lb. per acre, per annum. This rapidity of leaching necessarily diminishes as the amount of calcium becomes the limiting factor and, as a consequence, the gradient of increasing calcium, as we pass downwards, is sometimes very similar in the first few inches whether the natural soil be derived from a highly basic deposit such as the Wenlock limestone or one comparatively poor in soluble salts.

The leaching results in a downward travel, and the curve of increasing bases becomes, as a whole, flatter the greater the capacity of the soil for percolation and the lower the basic content of the subsoil.

There are, however, two factors tending to establish a gradient in the reverse direction, both of which are biological.

The first of these is the influence of earthworms. I shall not enter into details of this here, as the data and experiments on this point will be published elsewhere, but it will suffice to state that the wormcasts deposited at the surface show an appreciably lower acidity, as measured by the hydrogen-ion concentration, than the same soil before its passage through the worm. This is apparently due to the action of the calciferous glands whose supply of calcium is presumably replenished from the subsoil.

The action of worms, then, tends to augment the basicity of the surface, and so with rain action to establish a gradient in the reverse direction to that consequent upon leaching.

The second biological factor, acting in the same sense, is the living mantle of plants. These are constantly exerting a pumping action upon the soil, and the bases brought up in this manner are roughly proportional to the size of the individual constituents of the vegetation though, of

¹ For a fuller discussion of the problems here considered cf. Salisbury, "The Stratification and Hydrogen-ion Concentration of the Soil in Relation to Leaching and Plant Succession (*Journal of Ecology*, vol. ix., pp. 214-234).

course, the amount will vary greatly with the specific character of the plant. With the onset of winter, that part of these bases which is contained in the leaves and twigs of the trees, or the entire overground shoot system in the case of herbs, is returned to the surface which is hence annually enriched by mineral salts. In poor soils overlying rich subsoils the surface may even in consequence show a higher basic content than the layers immediately beneath.

If we are to appreciate the real significance of the relation between the soil and its plant covering, we must distinguish between the herbaceous perennials and annuals on the one hand, which return into circulation the major part of the salts taken up, and the trees and shrubs on the other, in which a large portion becomes demobilised for a long period of years in the overground and underground organs. This is especially true of trees where the plant bodies represent a great storehouse of mineral salts demobilised, so far as the soil and other plants are concerned, until the death of the individual; a condition which is accentuated in the semi-natural woods of civilised countries where there is no continual succession of decaying trees. It might be argued that trees draw upon lower strata of the soil, but this difference is not so great as might be supposed since the actual feeding roots of our forest trees are mostly situated in the top three feet of soil. We may, perhaps, in part relate to this locking up of mineral salts the high acidity characterising many soils permanently covered with ligneous vegetation, a feature which is reflected in the poor fauna of heaths and woods.

From this point of view the decay of the plant remains is important, the contrast in this respect between the organic material derived from the overground parts of most herbaceous plants and that derived from the fallen leaves and twigs of such species as *Ulex europæus* and *Calluna vulgaris* scarcely needs emphasising.

Broadly, acidity and low basic content in natural soils are associated with slow and incomplete decay, whereas, under conditions favourable to rapid decomposition, the contained bases are released and mild humus results. Some years ago I was able to show that the acidity of woodland soils, as measured by their lime requirements, rose after coppicing, but subsequently decreased as the organic constituents diminished.

Under conditions of undisturbed natural vegetation, the covering of plant débris tends to accumulate and so, added to the continued leaching action, we have a continually increasing amount of non-available salts. Such areas tend to become more and more acid, and this increasing acidity is manifest in the tendency for old woodlands to pass gradually into a more and more heath-like condition, and is probably one of the most important factors militating against their natural regeneration.

If we examine a series of samples from a dune system with ranges of increasing age, we find that as we pass from the youngest to the oldest dunes the calcium content decreases owing to progressive leaching. On the other hand, with the increased stability of the older stages there is an augmented plant covering associated with which we find an increasing organic content. As the organic content increases, so too does the acidity. For example, newly formed dunes with practically no organic material will show a hydrogen ion potential of 7.4 to 7.6, whilst an old turf-covered dune with about 10 per cent. of organic material may show a P_H of from 6.6 to 6.8 or lower.

When we examine the acidity in the vertical direction, we find that this diminishes as we pass from the layers rich in humus to the lower layers

poor in humus although the relation to the organic content is only a general one.

A number of estimations in the woodlands of Cornwall, many of which, apart from periodic coppicing at intervals of thirty to forty years, have remained more or less untouched, showed a range of acidity in the humus layer of the *Pteris* Society of from P_H 5.4 to 5.7, whilst at 12 inches the average hydrogen-ion concentration was P_H 6.1 and at 24 inches, 6.5. In the same area the *Vaccinium Myrtillus* Society gave from P_H 3.6 to 5.2 for the humus layer and from P_H 4.0 to 5.7 at 6 inches, whilst at greater depths the gradient was practically the same as under *Pteris*.

These estimations brought out clearly two points. Firstly, the decrease of acidity as we pass downwards, and secondly, the importance of the nature of the plant covering. Considering plants growing on the same soil the humus of *Vaccinium*, for example, appears to be more acid than that of *Pteris*. Similar estimations on lowland woods showed that the same relations obtained whilst the humus formed by *Deschampsia* and *Molinia* showed a much lower acidity.

A number of acidity determinations in a *Quercus robur* wood with a *Pteris-Scilla* ground flora gave an average of P_H 4.8 for the humus layer with a gradual increase to 5.8 at a depth of 9 inches. In the more basic Society of *Mercurialis perennis* and *Ficaria verna* even the surface layer was alkaline, but less so than the underlying soil. In samples from a *Pteris* Society on the Hythe Beds of Surrey the surface inch gave an average of P_H 5.7. In the underlying soil the acidity fell gradually, but even at a depth of 18 inches only attained P_H 6.0. By contrast the gradient on a Beech Wood is very steep, the maximum alkalinity being often attained at from 2 to 6 inches below the surface.

These few examples are typical of all the estimations, and out of several hundreds of these the only exceptions to the decreasing acidity from above downwards have been habitats where (1) the subsoil is highly basic and the humus particularly rich in salts and decaying rapidly, (2) flush vegetation, or (3) where there were corresponding irregularities in the humus gradient.¹

In the first case the high proportion of bases and consequent low acidity is due to the pumping action of the plant, in the second to transport by water.

There are certain species such as *Ficaria verna* and *Adoxa moschatellina* which are shallow rooted species and which normally occur in situations of low acidity. These are sometimes encountered rooted in the surface layers of a flush or elsewhere even though the lower layers are appreciably acid, a condition which is the exception, however, not the rule.

A more striking case of the relation of rooting depth to the acidity gradient is furnished by *Arum maculatum* and *Mercurialis perennis*, both especially met with on soils of low acidity, but sometimes encountered in association with species like *Pteris* which are tolerant of moderately high acidities. It is therefore significant that in the cases investigated the *Pteris* roots were situated in the more acid soil near the surface, whilst the species less tolerant of acidity were rooted at a greater depth where the soil was more basic.

Such layering of the root systems of plants is a common and widespread phenomenon, and it is not improbable that rooting depths are, in part at all events, determined by the acidity gradient described or by the conditions correlated therewith. Broadly, the deeper rooting species such

¹ Cf. Salisbury, *Four. Ecology*, loc. cit.

as *Orchis mascula*, *Allium ursinum*, *Colchicum autumnale*, etc., are more intolerant of acidity than the shallow rooting species such as *Holcus mollis*, *Oxalis acetosella*, etc.

The study of virgin natural soils has not the same economic stimulus that has promoted the mass of accumulated data with respect to the artificially modified soils of ordinary agricultural practice. Nevertheless, the prosecution of their detailed investigation may well throw light on problems which would otherwise remain obscure, and it is therefore to be hoped that more workers will attack the problems they present.