Centre for Ecology and Hydrology
Bush Estate
Penicuik
Midlothian
EH26 0QB

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SELECTION OF CHARACTERS FOR THE CLASSIFICATION OF SOIL HUMUS TYPES

P. J. A. Howard and C. B. Benefield

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INTRODUCTION

This paper provides a detailed background to Merlewood Project 108 (Selection, development, and testing of methods of examining soil characteristics for classification). In this introductory section we review relevant literature; in the second section we discuss the properties which we propose to study in an attempt to obtain an objective classification of soil humus types. Initially, we are concerned mainly with woodland soils and the first attempts at classification will be made using data from woods in and around the English Lake District. Later we hope to extend the range of soils.

The Danish forester P. E. Müller (1879, 1884) concluded, from his observations on the beechwoods, oak forests, and heaths of Denmark, that their soils could be separated into two types which were quite distinct with regard to their character, origin, and practical significance. These extreme types he called 'muld' (England 'mull') and 'maar' or 'mor' (English 'mor'). He also noted soils with properties intermediate between these extreme types. It is important to note that Müller's descriptions of mull and mor were based not only on morphology but also on biological characteristics. Müller regarded the strikingly different forms which the humus layer assumes in nature as being the result of differences in biological activity in the humus layer. His recognition of these differences has stood the test of time, and his types form the basis of modern humus classifications.

A great deal of confusion was caused by subsequent authors using Müller's terms 'mull' and 'mor' in a variety of different ways, this topic has been dealt with in detail by Howard (1969). For present purposes it is useful to define some terms. 'Humus layer' is used for the top layer of the soil which owes its characteristic features to its organic matter content (Romell and Heiberg, 1931; Hesselman, 1926). By virtue of its organic content the humus layer is a region of high biological activity. Hesselman (1926) used the letters F and H to distinguish parts of the humus layer. The F layer is that in which the plant remains begin to show evident signs of breakdown. The H layer is that which is most heavily transformed, it shows no evident macroscopic plant remains. The unaltered litter is known as the L layer. Kubiena (1953) states that in the H layer intimate mixing occurs between organic matter and mineral particles but this mixing results only in loose binding of organic and mineral materials, unlike the clay-humus complexes which Kubiena considered to be characteristic of every 'true mull' formation. These layers vary in development and thickness in different soils. The term 'humus' is used here to refer to organic residues in all stages of evident decomposition together with accumulating transformation products but excluding undecomposed litter (Romell and Heiberg, 1931). Barratt (1964) regards the term 'humus type' as being logical and analogous to 'soil type'. She thinks that the ultimate aim should be to use 'humus type' in its genetic context which requires the study of the entire organic profile extending into B and C horizons. For this reason she used the term 'humus form' in her classification which is concerned only with the morphologically separable layers of the topsoil.

used earlier.

Barratt proposed a classification of humus forms of grassland soils. Her main divisions (corresponding to Müller's humus layer types) are:-

1. Mull (humus intimately mixed with clay).

2. Mor-like mull (humus intimately mixed with mineral material, but little clay present).

3. Mor (humus not intimately incorporated in mineral soil but may contain non-calcareous mineral grains).

Barratt further subdivided these main types on the basis of micro-morphology. An important feature of this classification is that it separates the gross morphology of the three main divisions from the detailed micro-morphological subdivisions. Failure to do this in many earlier classifications (eg Kubiena, 1953) has led to confusion.

One of the major criticisms of most classifications of humus layers is that they are based on subjective assessment. Another criticism is that a classification based on morphological features alone fails to distinguish between types which have similar gross morphology but have different micro-morphology, chemistry, and profile relationships (e.g. secondary accumulation at depth). It is thus desirable that we should attempt to produce an objective classification of humus layers based on quantitative properties. Barratt (1964) pointed out that the concept of the humus form in isolation from the rest of the profile is obsolete, and that the main reason for continuing to treat the humus form as a separable entity is that it provides a means of phasing soils to show early and local differences in the profile which develop in response to environmental modifications likely to alter the future course of pedogenesis. The ultimate aim is to reveal fundamental relationships between the humus profile and its micromorphology, the soil group in which it occurs, together with corresponding site characters and fertility levels. These relationships shed light on processes occurring in soils under various conditions and under various systems of management. They are thus of considerable interest to the ecologist and soil biologist, and are likely to be of great importance to all concerned with management and conservation.

The observations of Pearsall (1938, 1952) on soils, mostly of woods in northern England, are interesting. Pearsall recognized three main groups in which vegetation, soil biology, and humus layer type were related in a similar way to Müller's observations:

1. Mull, occurring on the more nearly base-saturated (often calcareous) soils, pH above 4.8 to 5.0. Ground flora characterized by Mercurialis and Brachypodium. Nitrates present, earthworms observed. Seedlings of Fraxinus were found on this type.

2. Mor, occurring on base-deficient ('hydrogen') soils, pH below about 3.8. Ground flora characterized by Vaccinium, Deschampsia, and Dicranum. Nitrates absent, earthworms not observed. Seedlings of Betula and Sorbus aucuparia may be present

3. Transitional types within these limits, occurring normally on base-deficient soils, pH between 3.8 and 5.0 to 5.3. Ground flora characterized by <u>Holcus</u> and <u>Milium</u>. Nitrates present and earthworms observed. Seedlings of <u>Quercus</u> may be present.

All these soils were found to be oxidizing, although this will vary with water content. Nitrates were measured in the field, as disturbance and storage cause changes in soil samples (Romell, 1935). No exact relationship was found between soils sampled in the surface layers and the occurrence of mature trees, which are deeper rooting.

Howard (1966, 1969) examined a range of soils, mostly from woods of northern England, and found that the soils falling within Pearsall's 'transitional' range (pH 3.8 to 4.8 approx) were of two types, one representing the acid end of the mull range (pH $\geqslant$ 4.4), the other representing the less acid end of the mor range (pH $\leqslant$ 4.2). These types, referred to respectively as 'transitional mulls' and 'transitional mors', had certain ground flora species in common and similar loss-on-ignition values, but had different C/N values. The C/N values of the transitional mors were somewhat lower than those of the mors, but the C/N values of the transitional mulls were similar to those of the mulls. The carbon content, expressed as a percentage of the estimated organic matter content, was similar in the mors, transitional mors, and transitional mulls, while in the mulls this value was lower than in all the other soils examined. Pearsall found that all the soils in his transitional range showed presence of nitrates, and it is evident that these soils require further study. It seems likely that this range of transitional soils will be particularly sensitive to changes caused by management practices.

PROPERTIES TO BE STUDIED

The properties selected for use in any classification will obviously depend upon the purpose of the classification. We are interested in humus layers for a number of reasons. For example, they reflect the processes which had led to their formation, and so tell us something about their history. Humus layers, because of their organic matter content, are regions of high biological activity. The physico-chemical conditions in the humus layers influence current and future biological activity, and so we are interested in them as an environment and as food material for soil organisms. It is in the humus layers that change in vegetation, either natural or man-made, are likely to show early effects. At the same time we cannot look at the humus layer in isolation from the rest of the soil profile, nor indeed from its environment in terms of climate, vegetation, topography, aspect. With these considerations in mind, a list of physical, chemical and biological properties has been drawn up which we think covers the main aspects. The properties fall naturally into two groups. In the first group, spatial variation makes it impossible to detect significant quantitative variations with season (see e.g. Frankland et al., 1963; Howard, in prep.). The second group contains properties which exhibit marked seasonal fluctuations, these present special difficulties. Merlewood Project 108 gives us an opportunity to [illegible] woodland soils in and near the English Lake District and to attempt to classify the soils using these properties. The woods to be studied are mostly representatives of the 47 groups from association analysis (Bunce 1969, Table 1) for which a considerable amount of information is already available.

The properties to be studied in the first groups are as follows:

Group A

I Field observations at time of sampling:

1. Profile description (sample each horizon and bedrock for analysis)
   (sample each horizon for bulk density)

2. Soil depth

3. Deep-burrowing earthworms observed or not.

II Laboratory measurements on freshly collected samples:

4. pH

5. Bulk density

III Chemical analyses:

6. Extractable iron

7. Organic C, H

8. Loss on ignition (L.O.I.) at 550°C.

9. Total N

10. Extractable Al, (Na?), Ca, K, Mg, Mn, H, P.

11. Free carbonate.

These properties are those which we think, from past experience, are most likely to be useful in characterising the humus layer as an entity, as an environment for soil organisms, and to relate the humus layer type to the rest of the soil profile.

The second group contains certain important properties which show marked seasonal fluctuations and cannot be represented adequately by a single measurement taken at any given time:

Group B

12. Redox/Aeration/Soil atmosphere

13. Respiraton (field and laboratory)

14. Soil moisture

15. Soil temperature

16. Activities of certain enzymes (see below)

17. Nitrification and ammonification

18. Nitrogen fixation.

Dentrification would be of great interest but is beyond the scope of this project. Items 12, 14, 15 in this list are especially important in considering soil as an environment for organisms. Items 17 and 18 and to a certain extent 16, concern processes carried out in soil which are important to plant nutrition. Pearsall (1938) showed that British mors normally lacked nitrates when tested in the field. This absence was observed at times when nitrates were not being used rapidly by plants. At such times, mulls gave a positive test for nitrate in the field. Pearsall's observations agree with those of Heimburger (1934) who found that, in the forest soils of the Adirondacks, nitrifying organisms were normally present only at pH values above 3.8 to 4.0. In mors, the characteristic absence of nitrate is probably due not to oxygen deficiency (Romell, 1935; Pearsall, 1938) but to a negligible rate of formation in the field. Nitrification appears to proceed quite rapidly in mulls (see e.g. Hesselman, 1917, 1917a; Boswell and Gover, 1946) and Pearsall (1938) observe nitrates in mulls and in the transitional soils of pH 4.0 to 4.8. Ammonifying micro-organisms seem to be less sensitive to acid conditions (Small, 1954; Scurfield and Boswell, 1953), but it is possible that this is not simply a pH effect. It seems likely that nitrate-forming organisms are present in at least some types of mor, as rapid nitrate formation may occur when they are disturbed (Romell, 1935). More work needs to be done on the distribution and activity rates of nitrifying and ammonifying micro-organisms in soils, and factors affecting their activity rates. It is known that nitrifying organisms need calcium (Meiklejohn, 1953) and a proper balance of iron, manganese, and copper, as well as adequate supplies of phosphate and a generous oxygen supply (Russell, 1958).

Nitrogen fixation is particularly important in natural and semi-natural ecosystems because nitrogen is the one major nutrient which cannot be obtained from weathering of mineral parent material. Almost the whole of the soil nitrogen reservoir is organic, with only a very small pool of labile inorganic nitrogen. The rate of supply of ammonium ions to the soil, which in turn controls the rate of production of nitrates, depends on the rate of decomposition of plant debris and soil humus. Some nitrogen is brought into soils by rain (Carlisle et al, 1967) and it is likely that ammonia may be absorbed by soils directly from the atmosphere. In certain conditions gaseous nitrogen in the soil air is converted into organic forms by nitrogen-fixing micro-organisms, some of which excrete into the soil soluble nitrogen compounds that are readily available to other organisms. Althoug our knowledge of the rate of production of these substances is imperfect, it is thought that it becomes of increasing importance as the level of nitrate and ammonium ions in the soil decreases (Russell, 1969). Little seems to be known about the distribution and activity of free-living non-symbiotic nitrogen-fixing organism in British woodland soils and there is scope here for much valuable research. There are few, if any, reliable quantitative data on nitrogen fixation in different woodland soil types of Britain.

With regard to item 16, we think that it may be fruitful to study directly the activities of certain enzymes in soils in order to compare the rates of important biological processes in differer soil types. The reason for this lies in the fact that in recent years soil microbiologists have tended to move from the identification of isolates and estimation of populations to the study of the role of micro-organisms in soil processes. This has led to increased interest in methods for estimating the activity of soil micro-organisms. With bacteria there is often a considerable discrepancy between counts obtained by dilution plate methods and by direct observation, which suggests that there are big differences between cells in their ability to grow, and corresponding differences in their physiological activity. Fungi present even more difficult problems (Burges, 1966). Such difficulties have led to attempts to estimate activity by different methods, one of which is the measurement of respiration by carbon dioxide evolution or oxygen uptake, the latter being simpler and more reliable (Howard, 1968). However, the amount of information yielded by respiration measurements is limited as such measurements provide only a general overall value for the biological activity of aerobic organisms in the soil sample. Much more information can be obtained by a combination of relatively simple measurements, including the direct study of enzymes in soil. Some of the biological transformations in soil are catalyzed by enzymes which occur outside living soil organisms. Some of these enzymes are exo-enzymes released by soil organisms as part of their normal physiological activity (e.g. proteinases and cellulases). Some enzymes which normally function within living cells can persist in soil for a certain period in an active state, although most of them are probably quickly metabolized by other living organisms (Skujins, 1967). The enzymes which persist may come from cells of higher plants (e.g. peroxidase), from soil organisms, or both. Peroxidase is important in the biodegradation of aromatic amines and phenols. The latter are also broken down by polyphenol oxidases, which appear to be important in humus transformations. The study of soil enzymes is relatively new, and many aspects are not fully understood. However, methods for the study of certain important enzymes are sufficiently developed for us to use them in the present studies.

Enzyme systems in soil belong to one of two main groups, (a) non-adaptive and (b) adaptive.

(a) Non-adaptive enzyme systems

The most important non-adaptive enzyme systems in soil are the dehydrogenases, which are fundamental to the normal metabolic processes of all organisms so far investigated. Measurements of dehydrogenase activity are therefore capable of given a more reliable estimate of microbial metabolic activity than are most other enzyme systems (Burges, 1966). The measurement of dehydrogenase activity in soil is used to obtain correlative information on the biological activities of microbial populations in soil rather than on the enzyme itself (Skujins, 1967).

(b) Adaptive enzyme systems

Although adaptive enzymes do not provide a true measure of basic activity, they do provide important information on the potential of different soils to carry out certain processes. Enzyme systems in this group which we plan to study immediately are:

Cellulases   These are important because large quantities of plant cellulose are added to woodland soils each year.

Phosphatases   The release of phosphate from organic phosphorus compounds by these enzyme systems is important in nutrient cycling.

METHODS

Samples for chemical analysis can be collected with a trowel. For bulk density measurement we use stainless steel samplers 5 x 5 x 5 cm. Measurement of pH is on samples with water added (soil:water = 1:1) and on samples with N KCl added (cf. Jackson, 1958). At the time of going to press, we are not certain what method will be used for extractable iron, we await a report from the Pedology Section at Bangor on a new method. Organic carbon, hydrogen, loss-on-ignition (550°C), total nitrogen, and extractables are determined by the Chemical Service at Merlewood using the methods described in their handbook ('Chemical Methods for Ecologists').

The properties listed in group B present some problems. Some methods are already available but need further testing and improvement. Some new methods may have to be developed during the course of project 108. A Merlewood Research and Development Paper is being prepared by Mr. K. L. Bocock on methods for measuring soil moisture and temperature. Comparative studies are in hand of methods for examining soil aeration and associated phenomena including evolution of carbon dioxide from soil in the field. Laboratory methods for measuring respiration are well established (Howard, 1968) although with soils the meaning of the results is not always clear. We propose to compare oxygen uptake with dehydrogenase activity as measured by either the method of Lenhard (1956, 1957) modified by Harrison or that of Thalmann (1968) and with phosphatase activity as measured by the method of Hoffman (1968). In each of these enzyme activity measurements the soil is buffered at its natural pH value. The only other enzyme system for which we have an acceptable method is cellulase (Benefield, in press). Other enzyme systems of interest to us are chitinase, amylase, and pectinase, but the methods for these need more developmental work before they can be considered entirely satisfactory. A file is being kept of methods for studying the properties in group B. Development of new methods and improvement of existing ones will continue.

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