# Soil classification for soil survey

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# Editors' Foreword

The grouping of phenomena into classes that can be talked about or used as the basis for further generalization is an activity so fundamental that in most instances we do not realize that we are doing it. The classification of soils, that is the recognition and definition of groups of soil individuals with properties in common, has proved more difficult and controversial than most. Much is claimed; little is proved. The best schemes of classification have provided useful frameworks for generalizing the results of research and experience so that identifying the class to which a soil individual belongs automatically tells us something about its properties and behaviour. The worst have divided soil on irrelevant properties without proof that the groups created share any useful properties. Some of them require more information about a soil individual to put it into its class than could ever be gained from knowing to which class it belongs. One voice urges the student to classify, another tells him not to bother since crop yields or management practices are poorly correlated with soil classes; neither shows him how to judge.

Bruce Butler, a past President and Honorary Member of the Australian Society of Soil Science, is probably best known outside Australia for his elucidation of the control of soil development by landscape processes, as expressed in the concepts of prior streams and K-cycles. He has been a soil surveyor throughout his career and has faced the problems of finding usable and useful soil classifications.

Here he approaches the problem of classification head-on. Why do we classify? What do we hope to get out of it? To what extent can existing classifications meet this need? Should we use an international scheme of classification or create a local one? These questions must be asked. He introduces the principles of the 'Taxonomic Chop' and the 'Taxonomic Hiatus'. Finally he tackles the crucial problem – what the soil surveyor should do – and offers a tentative procedure, which the surveyor may follow as it stands, or use as a framework for his own analysis of his particular project.

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V.C. Robertson

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# Contents

# 1. Introduction: the nature of soil survey

This is a book about soil classification and how the soil surveyor creates a list of soil classes that will comprise all the soil in the area he is to map.

It will be simplest to start by describing what the soil surveyor does in a soil survey and why it is usually necessary for him to produce a soil classification; then to discuss the problems that in some circumstances make it difficult if not impossible to produce a useful classification; and finally to propose a procedure that, in its essentials, can be applied to any survey and (we hope) minimize the risk of producing a classification that is useless. At the very least he would wish to know before he begins mapping that the soil of his area is in fact classifiable and mappable and that the classes and mapping units he proposes are relevant to the particular problems of management or planning that the survey is to help solve.

Throughout the book we can discuss the broader classes of a national or regional classification to which the surveyor may relate his own local soil classes so that he can draw on the experience of managing similar soils elsewhere.

Soil survey is one of the basic technologies of soil science and it has a long and respected record. But even though the procedures for recognizing soil groups and determining the positions of soil boundaries on the ground are well established and basic to soil survey, there has been remarkably little examination of their theoretical basis. Although the *Soil survey manual* (U.S.D.A. 1951) has been and still is a standard reference in its field and the parent of many national handbooks, most of it is taken up in the definition of classes, the formalization of soil and site descriptions, and the techniques of making a map. It offers little discussion of the basic philosophic questions that are implicit in so many of the decisions the soil surveyor has to make. *Soil taxonomy* (U.S.D.A. 1975) is subtitled 'a basic system of classification for making and interpreting soil surveys' but it offers little discussion on the philosophy of soil survey. According to Blackburn (1960) the Russian conventions of soil survey also fail to relate the craft of soil mapping to the philosophic principles of classification.

## Soil survey

A soil map should have a purpose; for example, to help solve a particular problem or to provide information on which to plan the location of a particular land use or the development of a region. It should either provide information on those properties of the soil that affect an intended use of the soil itself, or serve as an index to a separate library or store containing such information.

If there is no-one in the survey area who thinks he has a soil problem it is unlikely that a group of eager users of soil information will spring up merely because a soil map has been produced. This would seem axiomatic, but a surprising number of soil maps has been produced for no better reason than an unfocused if benevolent interest on the part of the central government or equivalent. So the surveyor's first responsibility is to confirm that a knowledge of the distribution of different kinds of soil within the area of interest, which is what he would contribute if he were to produce a soil map, is in fact required by one or more significant groups of users.

Assume that there is a specific problem. The soil surveyor will try to ascertain which soil properties or aspects of soil behaviour are causing the problem or appear to be related to it. In his context these are the *useful* or *relevant properties* of the local soil. There will be no point in mapping the whole area in intricate detail before discovering, for example, that the problem had arisen only from excess soil acidity, which could have been mapped by itself in much less time.

At the same time the surveyor must recognize his own limitations. He is not trying to solve the problem–that is a matter for the agronomist, engineer, or veterinary surgeon. What he can do is to ascertain the distribution in his area of the soil properties that affect the problem and to record and present them using a classification map and its legend. His role is to *predict*, that is to provide a means or a tool with which the problem-solver can inform himself about the relevant soil conditions at all sites in the area *without having to go there to see*. How he is to do this is the subject of this and other volumes in this series.

This concept of prediction is important. Webster (1977) has discussed it also. The point is that there is only one way of ascertaining, with total confidence, the state or the attributes of the soil at a site and that is to go there to measure or observe them. The average user of the land, or planner of competing land uses, is unable or unwilling to do this; the soil surveyor is brought in to do it for him, and more specifically to employ all the skills he has to provide soil information about the whole area of interest without the cost of visiting every point in it. In short, the surveyor is being asked to provide a tool (his map, memoir, key etc.) from which the user can inform himself about the soil conditions at any site without having to go there. This is what is meant here by prediction. In the same way the success of the surveyor's work will be judged by the extent to which his predictions about the soil at sites of interest prove to be correct. Terms such as the *predictive power* of a classification or map, or the *predictability* of soil attributes in an area covered by a classification or map, will recur frequently in this book. Indeed the author is convinced that several of the most elegant classifications have very little predictive power outside the limited areas from which their component classes have been derived.

Ideally the surveyor would map the values of all relevant properties all over the area. In practice, this is rarely done. In expensive irrigation schemes, for example, it may be economic to map the variations in exchangeable sodium, soluble-salt content, clay content etc. over all the irrigation area. Even in this case the survey is usually simplified by creating classes in these properties; for example, by representing exchangeable sodium as 0–7½%, 7½–15%, > 15% of the cation exchange capacity, conductivity of the saturation extract as 0–2, 2–4, 4–8, 8–16, > 16 mmhos/cm, and clay content as 0–18%, 18–35%, 35–60%, > 60%. The surveyor then need not look for and map all values, but only the class limits. This is not unreasonable; if the farmer or the irrigation engineer, for example, cannot conceive of applying gypsum in finer grades than 500, 1000, or 1500 kg/ha, there will be no point in mapping the corresponding values of exchangeable sodium more finely.

Relevant properties are often expensive or laborious to determine, and many of them can only be determined in the laboratory, so that the surveyor has to collect samples, have them analysed, and then interpolate class boundaries between his observation sites some time afterwards. His boundaries would probably be better if he were able to interpolate them between successive observation sites on the evidence of local changes in vegetation, relief, or surface appearance.

Usually he looks for soil properties that may or may not be useful in themselves but are easily assessed in the field, preferably by hand or eye; these include the morphological properties of colour, texture, rootedness, gleying, or so on. He then defines soil classes from some of these properties. The classes may be defined by the limiting values of their morphological properties (definitional classes) or by their central concepts (typological classes) (Gilmour 1962). The surveyor exerts himself to produce a list of classes (a *classification*) that is complete enough to identify all the soil in the area. When the surveyor *classifies* the soil of an area, he erects a classification or a system of classes; when he *identifies* a soil entity he decides to which of these classes it belongs, or *allocates* it to a class, or gives it its class name.

The soil mantle is a continuum that extends over a range of conditions and its properties vary accordingly. It often lacks sharp discontinuities, so it is not always clear what exactly are the objects or *entities* that are to be identified. Much energy has been devoted to discussing this, and terms such as profile, pedon, or worse have been much bandied about, but the discussion has had remarkably little effect on what soil surveyors actually do. Let us say that in most circumstances a column of soil of 1 m in diameter is large enough to comprise adequately most of the short-range variability characteristic of any soil area without being too large and encompassing a range of soil variation that common sense requires to be divided into two or more soil classes. In this case, it will be convenient and pragmatically justifiable to treat such 1 m columns as soil individuals or soil *entities*. We shall not be pedantic either about the more general terms 'soil', 'the soil', 'soils', and 'a soil' of which the common usages are inevitably confused, and may refer to soil as a material ('soil is a good rooting medium' or 'the soil in my garden'), to the whole range of soil variability in an area ('the soils of Berkshire are mostly calcareous' or 'most of the soil in Berkshire is calcareous'), or to indicate soils of particular but unspecified kinds or profiles ('some of the soils in the Canberra area are acidic'; 'this research was mainly applied to soils in the Western Tablelands'). The reader will find no difficulty in distinguishing between soil as a material, all soil material, all soil profiles, some of all kinds or types of soil material, or soil profiles, from their context.

There are situations in which important soil properties vary rhythmically with periodicities of 1–20 m, where perhaps the units are too finely recurrent to justify the creation of two classes but the contrast in behaviour is too great to be encompassed within one class. The surveyor will probably be inclined to map such an area as a defined combination of two or more defined subclasses.

Given a list of soil classes, defined on their morphological properties, any entity may be identified on its values for these *definitive* properties. If, as is hopefully assumed, other soil properties are associated or correlated with these, then the classes will also be found to group soil entities according to their values of *associated properties* (e.g. it may be that all soils with mor humus (a morphological property) have surface pH less than 5). If, in addition, the classes group soil entities according to their values of relevant properties, then the classes will usefully separate soil entities according to the differences in management that they require. It cannot be assumed, though it often is, that the definitive properties and the useful properties of a set of soil classes are associated.

In a limited area it is often possible to identify the members of a soil class on less than the full range of its definitive properties. For example, if a group of deep, sandy, and acid soils with a textural *B* horizon that contains high exchangeable aluminium also comprises all the red soils in an area, this class may be distinguished from all other classes from the red colour alone. This single character may then be used in an *identification key* to separate the members of this class from those of all other classes, on the assumption that this *keying property* is uniquely associated with its other definitive properties, and in the hope that it is also associated with its other useful properties. A *keying property* should be unambiguous. All members of the class must exhibit the character; members of all other classes should not, unless the classes are distinguished on more than one character, e.g. the four classes defined on the possession of two attributes: *AB*, *A*-, *B*-, --. In this case there are two taxonomic chops (p. 19) employing the criteria *A*/ not *A* and *B*/ not *B*. The class limits could also be numerical, e.g. $A > 100/A \leq 100$. At the same time a key must be local. If the survey area were enlarged till it included two kinds of red soil, the first group would no longer be uniquely distinguished on its redness and the key would break down.

Once he has developed a classification–his gallery of conceptual soil classes–the surveyor can start to map them. Two points quickly emerge. First, their pattern of distribution is usually intricate and the boundaries that separate different classes are correspondingly tortuous. He will have to simplify them to some extent and the boundaries on his maps will be simpler than those in nature, so the areas or *mapping units* that they enclose will not be completely pure but will contain inliers of other classes.

Secondly, if the surveyor can locate these boundaries only by repeated soil borings he will never be able to make enough borings to locate correctly all of even the simplified boundaries he wishes to record. Usually he tries to find features of the landscape (e.g. changes in relief, natural vegetation, colour of soil surface that he can see continuously on the land surface) that correspond to the soil differences he wishes to represent, and he then uses these to interpolate the boundaries between his borings. Indeed, unless he is mapping on a large scale, his decision on how to split up the whole soil continuum into soil classes may be influenced by the extent to which the classes in alternative classification systems correspond to mappable surface features. Where two or more classes occur in irresolvable intricacy he will probably map them together as a *complex* or *compound unit* especially if the differences between them are of little significance for the purpose of the survey.

The final result then is a map made up of simple or compound mapping units, accompanied by a *legend* which records the soil class(es) to be expected within each mapping unit and explains any symbols or inscriptions, and a *memoir* which states definitive characters, perhaps offers an identification key, and summarizes the associated characters of the classes. This is offered to the user who requested the survey or to others so that they can put names to every kind of soil in the survey area.

The users may wish to do this for several reasons:

(a) They wish to see as much soil data as possible arranged in one orderly compilation: a tidiness of structure in the organization of their thoughts;

(b) They wish to put a *name* to any soil entity so that it may be discussed and related to other soil entities already identified;

(c) They believe that once a soil entity has been identified it will be possible to *predict* things about it by associating it with the fund of experience and information belonging to its class, and, with modification, to other similar classes. *In short, they expect to be able to predict certain things of the identified soil which they could not have done before going through the exercise of identifying it.*

The surveyor's classification relates specifically to the local realm of soil experience. Probably soils with the same definitive features will occur immediately outside the survey area, and these can be given the same class name, but the surveyor should not expect his local classes to extend over a great area. Nor, if he finds distant soils that match the definitive features of his classes, should he assume that they necessarily share the same associated or useful properties. Nevertheless, it will usually be possible to group them into higher more comprehensive classes, and then into yet higher. Some national classifications have five or six hierarchical levels, in which the classes at each higher level become progressively more comprehensive in concept and wider in their geographical extent.

# 2. Problems: the concept of orderliness in the soil population

Chapter 1 outlined what the soil surveyor does, and what he hopes to achieve by it. Specifically he is attempting to provide a means or tool by which the user of the land may predict the soil conditions at any site in his area of interest. Now we must consider the problems and the difference between the ideal and reality.

Most soil surveys are done because there is a *problem*: there is some soil-use proposition in the area on which a soil attribute has a large influence. The soil survey is done to show where particular management options should be exercised to make the best use of the area or to avoid expensive failures.

This need to establish and analyse the relationship between the problem and soil attributes in the project area must be emphasized. In its absence, many a soil survey after its publication has lain unused either because there was no soil factor to 'the problem' or because its association with the classification and legend had not been worked out and demonstrated. By working out the soil associations of 'the problem' during the planning and development of a soil survey, it is possible to assess how effective the survey may be at solving the problem, before the major operation of soil mapping is undertaken. It is quite possible that in some cases the mapping will not be done because it has become apparent that there is a better way of handling the problem.

In coping with 'the problem' in relation to soil surveys there has been a tendency in the past to assume that the relationship between soils and problems which have been established in one locality may be 'exported' and used in distant places with the same success and efficiency as at their place of origin. Indeed national and world soil-classification systems are developed to exploit this supposed advantage. But when we reflect that the connection on the soil side depends on a few keying properties (usually morphological) and the connection on the problem side depends on one or two associated edaphic properties, it will be realized that the connection is often tenuous and unreliable.

'The problem' requires serious investigation. In particular it is necessary to ascertain that it has a soil factor and that there is an association between that soil factor and mappable soil characteristics in the survey area. In the past this has not been clearly recognized as either the soil surveyor's or the agronomist's responsibility, and often the result has been that the job has not been properly done.

In some cases a soil survey has no particular problem but is made to provide a general stocktaking of the soils of the project area. Undoubtedly such a survey can provide interesting information about the main soil variables and how they relate to each other and to the landscape; it may also be helpful in broad resource planning. Often the boundaries coincide neither with those required for detailed planning nor with the boundaries of management options for some particular problem. Indeed, an unfocused survey may produce too many boundaries, and it will require comprehensive investigations to show which are the relevant ones for particular problems.

We shall start then from the stage when the surveyor has identified the problem that he is to help solve and has made at least a mental list of the soil properties that are relevant to the problem. If the survey is to be part of a general stocktaking of a natural resource, then he has established a list of the soil properties that at least determine the main anticipated uses of the land. It is his intention that his survey will predict the probable values of these relevant soil properties at any site of interest, or their predominant values within any management area in the survey area.

The surveyor's soil classification is a means to this end. It would be extremely useful if every soil entity belonged to a soil class, and if, for all the members of each class, the soil properties relevant to the problem lay within defined ranges. If so, experience could be passed on from one entity to another in the same class; merely to identify the class to which a soil belonged would specify its main properties. To achieve this the surveyor would try to match his classes to the natural 'modalities' of his area; there is no point in defining classes for ranges of property values that do not exist, nor in defining classes that do not correspond to the differences which the farmer or other users perceive to be important.

The soil surveyor is also concerned with the correlations which he can establish to assist him to locate soil boundaries, so he is interested in the correlations between soil profiles and the topographic features of slope, shape, stoniness, and various features of land use and vegetation, or indeed the correlation between soil profile and the appearance of the soil surface and its vegetation cover on air photographs or on the line-scanning printouts of remote sensors. In general then, the soil surveyor's main technical repertoire is his ability to develop and utilize correlations. He seeks to correlate useful properties with features of the soil profile and to relate them to a shortlist of keying attributes. He then allocates unknown soil entities to their classes on the basis of their *keying* attributes and uses the fact of their class identity as the basis on which he can *predict* what the status of other attributes will be. This prediction is an extrapolation from his original correlation.

The concept of the soil key was briefly introduced on p. 5, and may now be elaborated a little. We have already established that one of the purposes of making a soil classification system is to enable unknown soil entities to be identified and hence acquire a name, be better understood, and have predictions made about them. The identification is achieved by searching through the classification to find the lowest class into which the unknown soil will fit. This can be done laboriously and with possible uncertainty by matching the soil description to class descriptions, but it may be done much more quickly and confidently if the classification system is supported by a soil key.

The maker of the soil-classification system probably has a more complete awareness of the associations and variations of properties throughout a given population of soils than anyone else and is therefore usually best able to produce the sequence of yes/no questions which will bring the unknown soil to its proper class in the system. Such a key will be monothetic (i.e. a necessary and sufficient condition for the membership of a class is that an entity possesses the attributes specified in the key). The success of the key at putting entities into classes depends on a firm association between the keying characteristics of a soil class and its other definitive characteristics.

The growing trend toward the development of keys as part of soil-classification systems is motivated by the need for precise and quick identifications of new soil entities. A good key will achieve this, but in itself can achieve no more. There is no certainty as to what the associated properties of the created classes will be nor that they will be consistent from place to place. Since our interest in the study and use of soils usually lies among their associated and useful properties rather than their keying properties, the service provided by keys is often of doubtful value. Their facility is deceptive. Since they are usually bifurcating in operation, they can be applied to any population of soil entities but they will not necessarily produce groups of soil entities that show consistency in their useful properties for any soil population other than the one for which they were developed.

This leads us to the main problems of classification in soil survey. Notably it reminds us that there were implicit assumptions at every stage in the exposition of the 'normal' soil survey in Chapter 1. If the survey is to be of any substantial help these assumptions must have been met; namely that

(a) the individual entities belonging to each class are more or less continuous so that most classes can be mapped in mapping units that are both coherent and not too impure;
(b) a reasonable proportion of the boundaries to be drawn possess external expression to guide their delineation;
(c) the definitive properties of the classes are either themselves relevant to the land uses being considered or else are associated with useful or relevant properties;
(d) the relevant properties are in fact relevant and between them account for most of the management problems that gave rise to the survey.

All these assumptions relate to what may be called the '*orderliness*' of the soil mantle in the survey area. This is a difficult but useful concept. If the local soil is 'orderly' then classification and mapping are likely to be straightforward and may be useful; if it is not then they are unlikely to be useful and may be very difficult.

This chapter now discusses and brings into the open various facets of this concept of orderliness.

## Attributes

All soils have a great many properties and attributes and, while this enhances their likely points of interest and use, it increases the problem of generalizing about them and of classifying them. It is convenient to think of soil information in terms of the three groups of soil attributes shown as the three parts of Fig. 2.1. The properties of the soil as we see and handle it comprise the most common facet. This is the descriptive facet of soil morphology as described horizon by horizon. These attributes include the colour, texture, structure, and consistency of soil material; the arrangement and thickness of the soil horizons; micro-morphological attributes; and some descriptive analytical data.

The second facet comprises the soil-forming processes by which the