

CSIRO AUSTRALIA
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DIVISIONAL REPORT

**APPLICATION OF CONTINUOUS
METHODS OF SOIL CLASSIFICATION
AND
LAND SUITABILITY
IN THE LOWER NAMOI VALLEY**

J. Triantafilis & A.B. McBratney

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U.S. DEPARTMENT OF AGRICULTURE
BUREAU OF PLANT INDUSTRY

RECORDS OF CONTINUOUS RECORDS
OF SOIL CHARACTERISTICS
AND
STABILITY
IN THE TOWNSHIP OF WINDY HILLS

By H. H. HARRIS & F. E. HARRIS

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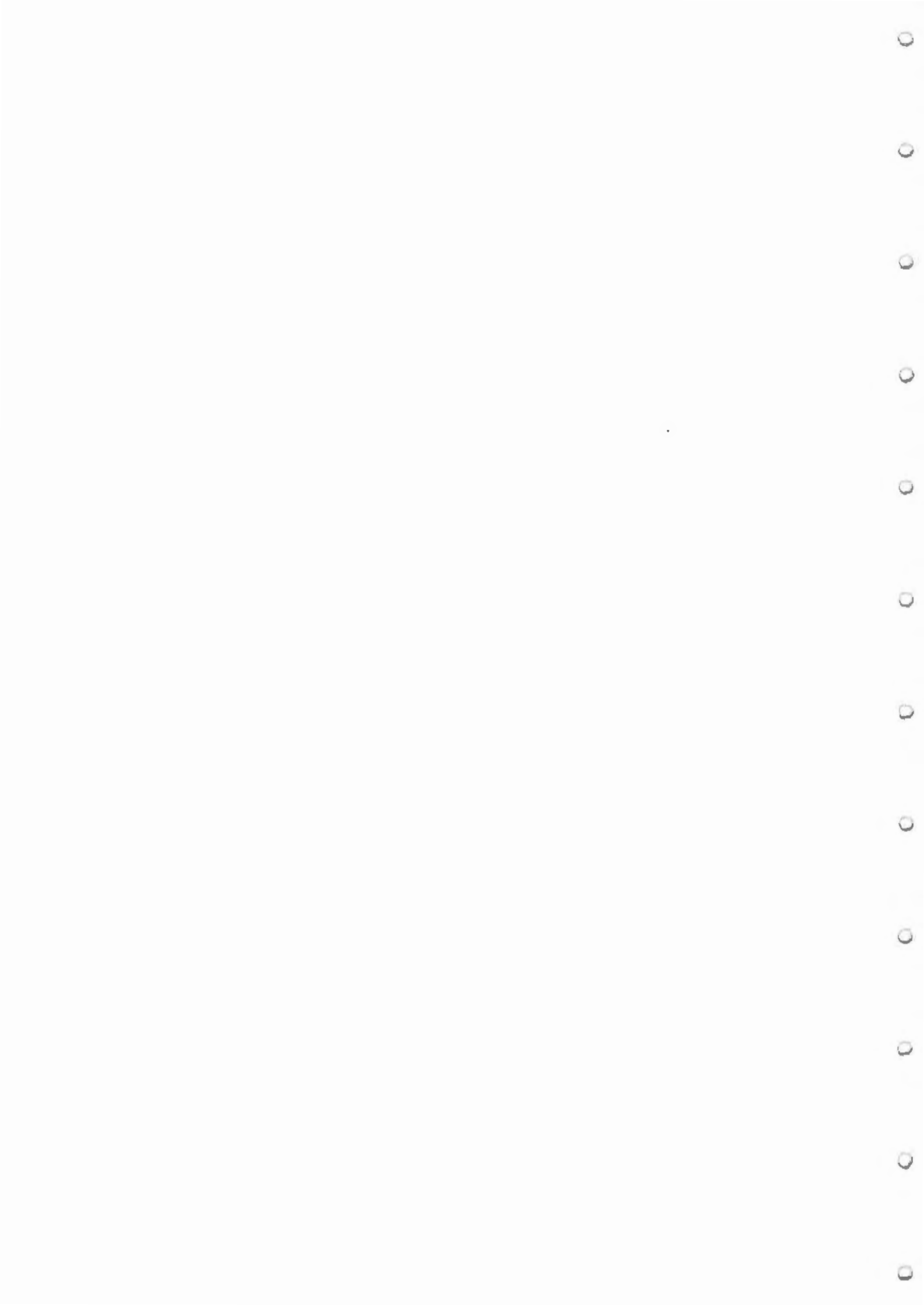


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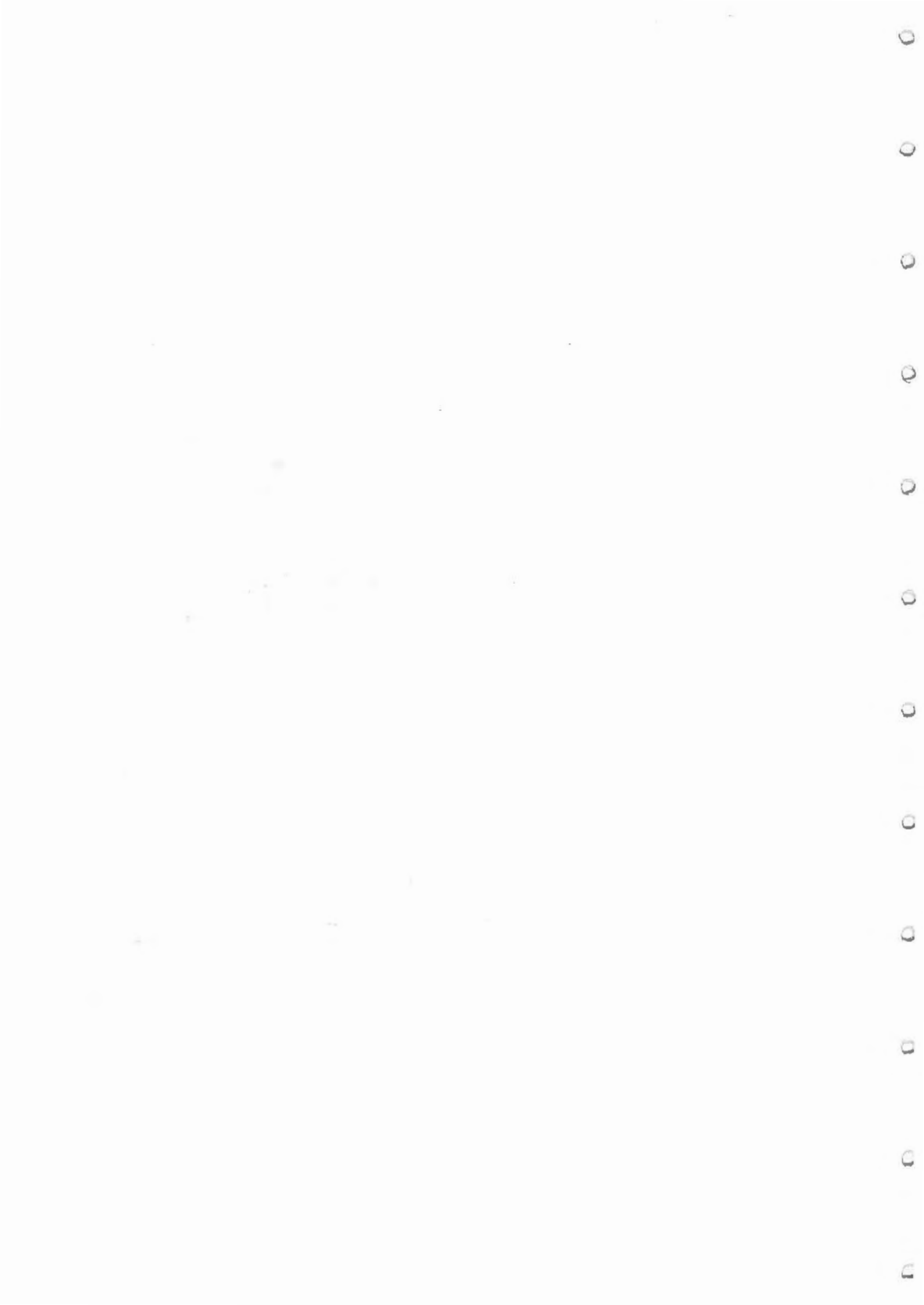
Abstract

The anisotropic nature of the soil continuum does not lend itself to classification schemes constructed as many are by predetermined hierarchical classes. Membership to classes are hard and are hence unable to consider the reality of the continuum, which ultimately manifests itself in the resultant soil map which delineates areas of supposed similarity. Further, the soil profile acts as the individual which itself varies vertically, with depth.

In the following report the rather novel approach of fuzzy classification or continuous classification is used to classify individual soil layers from the lower Namoi Valley in an attempt to better represent the anisotropy of the soil continuum. Essentially 1419 chemical soil layers with particle size analysis data taken from specified depths within 227 soil profiles were classified using fuzzy k-means. Ten soil layer classes or clusters were identified within the data, which were then reclassified to consider an additional extrade layer class or outlier class. When reassembled into their constituent profiles the layers from these classes formed readily identifiable profile sequences which were classified accordingly. The resultant profiles once mapped correlated well with field perceptions of the geology and geomorphology of the lower Namoi Valley.

As with the classificatory difficulties associated with soil classification many land evaluations are constructed in a similar fashion in which subjective cut offs are used to delimit areas or tracts of land which are better suited than others. Continuous classification was applied to a quantitative land evaluation introduced for New South Wales for wide variety of land utilisations by using a function which by its nature produces a continuous membership between two classes, suitable and non suitable to any particular land utilisation.

The following report illustrates the potential of such a classification scheme which could be used in a number of disciplines where the continuous nature of a medium can be expressed and has potentially many practical applications. As a consequence of the work undertaken and presented within this report new directions and technologies are suggested which could be undertaken for further research.





1 INTRODUCTION



1.1 INTRODUCTION

Cracking clay soil makes up some of the most productive land used for cropping in the subhumid regions of northern New South Wales and southern Queensland. Regarded previously as suited to pastoral enterprises, moderate to intensive agricultural development particularly towards irrigated agriculture in the past twenty years have turned these areas into permanent rainfed and irrigated croplands, (Hill, 1984). Evidence of widespread degradation under present land uses is an increasing problem, however (McGarry et al, 1990). Currently, only broad national and international understanding of the characteristics, distribution and variability of cracking clay soil and their potential for agricultural usage are available (Probert et al., 1987). An improved understanding of the characteristics and behavior of these soil types is necessary for agricultural development but would also ensure that the soil resource is conserved.

The CSIRO Division of Soils, Brisbane Laboratories undertook a study to improve the knowledge of cracking clay soil in the lower Namoi Valley, New South Wales. The area chosen was primarily that of the Edgeroi 1:50,000 topographic map sheet. Additional information was gathered from four adjoining sheets, on the landscapes and soil types underrepresented within the Edgeroi sheet. Further, two Agricultural Research Stations situated within the area were also examined because of the lack of knowledge of the soil on these sites. The information was needed to provide a better basis for extending research to the surrounding district, (McGarry *et al.*, 1990).

The major objectives to be addressed by the original study (McGarry *et al.*, 1990) were:

- (i) to investigate the relation of cracking clay soil to landscape and geomorphic history;
- (ii) to test new concepts of soil classification by using statistical techniques to specify meaningful classes for pedology and agriculture;
- (iii) to place soil of the local research stations in context with the soil of the district, (McGarry *et al.*, 1990).

The collected data consists of morphological, chemical and physical data of soil profiles obtained from the grid and free survey within the Edgeroi area. The following report utilises the data collected from the Edgeroi 1:50,000 topographic map sheet and also the information obtained from the I.A. Watson Research Station, to illustrate the fuzzy k-means or continuous method of classification to identify soil layer classes and land evaluation suitability memberships.



2 THE SURVEY AREA



2 THE SURVEY AREA

2.1 BIO-PHYSICAL BACKGROUND

2.1.1 Location of the lower Namoi Valley study area

The Namoi Region occupies an area of nearly 38,500 sq km and is bounded by the Darling-Barwon river system in the west and by the McIntyre River in the north. The south-east boundary is defined by the watershed of the upper Namoi River while shire boundaries form boundaries to the southwest and northeast. The lower Namoi Valley study area is located within the 1:50,000 Edgeroi map sheet area which lies at the centre of the Namoi Region directly to the north of Narrabri and south of Bellata. The map sheet is centred around the small township of Edgeroi on the Newell Highway, (Figure 1.).

Figure 1. (near here)

2.1.2 Physiography

The Namoi Region is dominated by plains of which over 80% have slopes less than 3°. The major relief within the Edgeroi study area is found on the eastern margin associated with the footslopes of the Nandewar Range. The Namoi River and its tributaries which include the Peel, Mainilla and Conadilly Rivers, rise in the rugged country to the southeast of the Region. The Namoi River itself then flows through the southwest corner of the study area. The most prominent features within the region include the Nandewar, Liverpool and Great Dividing Ranges, which form a westward facing semi-circle.

2.1.3 Geology and Geomorphology

During the field examination of the Edgeroi area three broad types of country were identified, namely, sandstone ridges, basalt hills and eroded alluvial plains (i.e., the erosional landscape); dust mantled alluvial lands; and alluvial plains. An excellent discussion of these areas is given by Ward (in prep) of which a brief summary of the geology and geomorphology is given below, (Figure 2). A comparison of these areas is made later which tests current pedological techniques against continuous classification using fuzzy k-means.

Figure 2. (near here)

The basement rocks of the Edgeroi area include Pilliga Sandstone, Nandewar and Garrawilla Basalts, and clayey sands of the Purlawaugh Formation. The eastern margin of the Edgeroi topographic map sheet lies against the Nandewar Range, which is the eroded remnant of an old shield volcano. The rocks of this eroded range consist of alkali basalts and trachytes and are named Nandewar Volcanics. Except for these basalts and those found at Bald Hill, 'Oakvale' and 'Green Timbers', which are thought to be part of the same formation, basalt does not extend very far into this area. Garrawilla Volcanics were also identified in small pockets near Mount Kaputar National Park to the east of the Bingara Road.

The main basement rocks found in the Edgeroi district, form prominent ridges comprised of Pilliga Sandstone and Purlawaugh Formation, both located on the footslope of the Nandewar Range. The latter is an underlying sequence which is relatively soft and clayey. Calcareous clays and marls are also present in the area, however, they are masked by the rounded nodules of calcium carbonate. Soft yellow Tertiary Sandstone with rounded gravels were also identified generally on the same ridges formed by the Pilliga Sandstone but further to the west.

Despite their prominence, most of these basement rocks do not give rise directly to soil, contributing only in a superficial manner in the form of hillside colluvium. The major part of the Edgeroi landscape was formed by the action of various geomorphological processes, mostly alluvial and colluvial deposition. Alluvial deposition has occurred predominantly in the lower lying, flatter, western areas of

§2 THE SURVEY AREA

the Edgeroi sheet, whilst colluvial deposits mantle the gently rising slopes between the Nandewar Range and the western areas.

Much of the alluvial material in the west has been deposited by the Namoi River comprised of material of mixed composition and mostly fine size. The colluvium is produced by weathering and natural erosion of rocks in the immediate catchments. It is poorly sorted and is found on the footslopes. However, there are signs of water sorting, on the lowest slopes. The small creeks which flow in well defined channels in their upper courses in the east flow to the west during intense rainfall events which take up materials into suspension and transport them downstream. In their lower courses they are ill defined and fan out before dispensing the material. Aeolian or parna depositions were also identified in a number of areas particularly on the extensive alluvial plains of the Namoi River.

2.1.5 Soil

Northcote (1966) previously classified the soil of the Edgeroi area as part of the Sydney-Canberra-Bourke-Armidale area identifying a small number of distinguishable mapping units, (Figure 3). In the following section these units are presented as a brief introduction to the soil of the Edgeroi area with the relation to geology and geomorphology briefly discussed.

The extensive alluvial plains of the Namoi River are associated with major and minor functional and non-functional drainageways (CC16). Chiefly self-mulching cracking grey clays (Ug5.24 and Ug5.25) on the open plains and in depressions, better drained brown clays are located on slightly elevated areas (Ug 5.35). These soil profiles may also be slightly gilgaied (few inches). The soil directly to the north and south of the Namoi River, as well as the areas associated with the local drainageways including Spring and Bobbiwaa Creeks in the south and the tributaries of Ten Mile Creek in the North are of such an alluvial nature.

Figure 3. (near here)

Self-mulching dark coloured (Ug5.1) and alkaline non-self mulching profiles are generally associated with the gently undulating plains, also exhibiting gilgai features, (few inches). Mostly dark cracking grey clay profiles (Ug5.16) hard

alkaline dark profiles (Dd1.33 and Dd1.43) occur together as soil complexes in some areas. The surfaces of these (D) profiles do not show the self mulching character common to the (Ug5.16) profiles as their surfaces are hard and slaked, (Kh2), setting hard in many areas.

As mentioned in the previous section only in a few areas is the soil actually formed from *in situ* weathering of the underlying parent material. Rich black earth profiles are often identified near the few outlying basaltic materials including the hills and flat topped ridges of Bald Hill, 'Green Timbers', Oakvale and many areas on the eastern margin of the map sheet associated with Nandewar Volcanics, (Kc5) are derived from dissected basalts. These dark cracking clay and black earth profiles often (Ug5.13, Ug5.15 and Ug5.16) are sometimes littered with surface rocks and boulders.

Mountainous, steep, rugged country is limited within the Edgeroi area to the very edge of the map sheet in small pockets, (Rh8), including much of the area within the Mount Kaputar National Park. The soil associated within these areas are of a friable brown nature (Db3.12) with variable areas of (Um6.2), (Ug5.12) and (Ug5.13).

The undulating to hilly sandstone ledges and rock outcrops on the footslopes of the ranges, with long sandy ridges running out to the plains, give rise to acidic and neutral yellow mottled soil profiles (Dy5.41 and Dy5.42) often with ironstone gravels, (Wa12). These sandy solodic and siliceous sand (Stace *et al.*, 1968) soil profiles are associated with Pilliga Sandstone located on the eastern margin of the surveyed area on the footslopes of the Nandewar Range and are generally located within the confines of the Many State Forests within the area.

Ro2 plain soil chiefly hard alkaline brown soil profiles (Db1.33 and Db1.43) and smaller areas of cracking clays such as (Ug5.15 and 5.16). Associated are:(Dr2.33) on slightly elevated portions of the plain; (Um6.21) profiles on low limestone ridges.

2.1.6 Climate

2.1.6.1 Rainfall

Rainfall across the region is low with a gradient of increasing rainfall from west to east. Heavy rain in the area is associated with weather systems from the northwest and southwest.

Figure 4. (near here)

Rainfall, within the study area, is mostly received during the summer months of December, January and February with a second peak around June-July, (Figure 4). Rainfall within the summer months is also considered to be reliable with intense rainfall in the area almost exclusively a warm month phenomenon, most occurring during the two month period of October and November. Extreme daily falls occur predominantly in the warmer months of January, February and March. Rainfall in all cases within the area generally tends to increase toward the east. Areas with a greater incidence of thunderstorms have a greater incidence of hail. The occurrence of hail on the plains is less than one for any one area while on the footslopes the occurrence could be between 1 and 3 per year, (Bureau of Meteorology, 1972).

2.1.6.2 Temperature

Temperatures are hot and humidity is small in summer on the plains. January is the hottest month with daily maximum averages of 33.7°C and 33.3°C and daily minima of 18.7°C and 19.1°C (Moree P.O. and Narrabri West P.O. respectively). The coldest month is July with daily maxima of 18.3°C and 17.7°C and minimum averages of 3.4°C and 3.2°C, (Figure 5).

Figure 5. (near here)

The seasons of spring and autumn, are the periods of rapid increase and decrease of temperature respectively with changes of monthly averages from the beginning to end of each of these seasons in the order of 10C°. The range in daily temperatures in each month is approximately 15C°, slightly less in winter and slightly more in summer.

July is the most frost prone month, while August and June have only a slightly lower frequency of occurrence. The remaining months of the season have much lower frequencies of frost.

2.1.7 Vegetation

There is a wide variety of native plant species in the Edgeroi area. The largest native stands are located within the Moema, Courrada, Bobbiwaa and Killarney State Forests (Figure 6) located on the footslopes of the Nandewar Rangwe which support mainly *Acacia deanii* (Deane's wattle), *Acacia concurrens* (curracabah), *Callitris columellaris* (white cypress pine), *Cheilanthes tenuifolia*, (rock fern), *Eucalyptus populnea* (bimble box) and *Geijera parviflora* (wilga). The prominent grass species within these areas include *Stipa scabra* and *Stipa verticellata* (slender bamboo grass).

Much of the land to the east of Bald Hill Road and particularly the Newell Highway have been sparingly cleared while the area to the west of Bald Hill Road has been extensively cleared for cultivation and improved pastures. *Stipa scabra* and *Stipa verticellata* (slender bamboo grass) occur also with *Enteropogon acicularis* (curly windmill grass) on the alluvial plains north of the Namoi River. *Bassia quinquecupis* ssp. *semiglabra* (dark rolypoly), *Bassia quinquecupis* (black rolypoly), *Lepidium* (wild turnip), *Silybum marianum* (variegated thistle) and *Lepidium bonariense* (cut-leaf peppergrass) are the common weeds in cultivated areas, (Ward, in prep).

Figure 6. (near here).

On the floodplains *Juncus usitatus* (common rush), *Stipa scabra* and *Asteraceae* are commonly found with *Eucalyptus camaldulensis* (river red gum) prominent near the Namoi River. On the basaltic lands of the Edgeroi district (Ward, in prep) the vegetation has mostly been cleared. The scattered trees and shrubs include *Eucalyptus albens* (white box) and, less commonly, *Eucalyptus crebra* (narrow-leaved ironbark). The weeds *Lepidium* (wild turnip), *Vicia sativa* (common vetch), *Lepidium bonariense*, (cut-leaf peppergrass) and *Bassia quinquecupis* var. *villosa*, (grey rolypoly) are prominent in cultivated areas, (Ward, in prep).

2.1.8 Land use

The land of the lower Namoi Valley has been traditionally used for grazing and dry-land wheat production. The identification of the potential for irrigation of the soil has seen a transformation of many areas to cotton production, practised extensively in the lower lying areas to the west of Bald Hill, north and south of the Namoi River. Other crops such as wheat are used in rotation, however are not frequently irrigated and are used as a management tool for cotton production. Most water for irrigation is obtained from the Namoi River.

Irrigated cotton, dry-land wheat and grazing are the three largest agricultural land uses in the area. The cotton industry is serviced by a gin at Myall Vale. Wheat in the area is delivered to the silo at Edgeroi. Pastures are generally improved in the western corner of the area with native pastures in the east overlapping into uncleared native stands and forests including the Moema, Couradda, Bobbiwaa and Killarney State Forests. Other agricultural crops cultivated within the area include sorghum, soyabeans and sunflower, particularly in rotation with wheat.

2.2 THE EDGEROI DATA SET

The following section is summarised from the two volumes entitled *Soil Studies in the lower Namoi Valley: methods and data 1 & 2'* (McGarry *et al.*, 1990), in which the data set is compiled.

2.2.1 The study area

The data set, generated by the original survey conducted by the CSIRO Division of Soils, Brisbane Laboratories consists primarily of 210 sampling sites, arranged on a systematic, equilateral grid with approximately 2.8km spacing between sites (Figure 7), with additional supplementary transects collected. Each of these sampled sites contained on average six layer descriptions from a soil profile core, based on morphological, physical and chemical soil attributes.

Figure 7. (near here)

In this study, the data from the regular grid were analysed. These all lie within the confines of the 1:50 000 Edgeroi map sheet which covers an area of 1500km² in a 50km x 30km rectangle. The grid placement and site density were chosen to maximise the number of sites on the sheet, yet remain practicable with respect to the number of samples obtained for chemical analysis, (McGarry et al, 1989). Further, by the use of a grid as the basis for sampling, site placement is random with respect to any landscape or soil pattern. This primary data set was extended by data obtained from the University of Sydney's I.A.Watson Research Station, (SUIAWRS). This consists of an additional 17 soil profile descriptions.

2.2.2 Method of sampling

At each grid site a core was recovered for soil profile description and sampled for laboratory analysis. In general a 3m length core (0.1m diameter) was recovered and six layers were described and sampled at 0-0.1m, 0.1-0.2, 0.2-0.3, 0.3-0.4, 0.7-0.8, 1.2-1.3, and 2.5-2.6m. If the sampled depth included a soil horizon boundary the specimen was subdivided, and described above and below the boundary, eg 0-0.004, 0.004-0.1m. If the immediate surface horizon was 0.06 m thick or greater, soil from the lower layer part to 0.1m was discarded. If a soil horizon was found, which was not covered by one of the six sample layers, an additional description and specimen of 0.1m thickness was taken from it.

Sampled sites were assigned an individual profile number, according to its location e.g. ed001, is site 1 of the Edgeroi map sheet whereas na013, is site 13 of the I.A. Watson Research Station of the Narrabri data set. The above mentioned cores with their constituent soil layers were then assigned designated depth numbers, so that for a soil layer designated, 01, 02, 03, 04, 05, and 06 one would most often expect to find these soil layers at the following depths, respectively 0.00-0.10, 0.10-0.20, 0.30-0.40, 0.70-0.80, 1.20-1.30 and 2.50-2.60m.

2.2.3 Profile descriptions

The conventions of McDonald *et al.* (1984) were adopted when describing the site, vegetation and soil morphology. Minor alterations where required are detailed in McGarry *et al.*(1990). The morphological, physical, as well as the chemical

§2 THE SURVEY AREA

information for each site of the 210 grid sites in the Edgeroi data set. The remaining profiles utilized in our classification, which were taken on the I.A. Watson Research Station, are not contained in this volume, but were taken from an electronic data base, (Ward, private communication).

2.2.4 Chemical analysis

Specimens collected for laboratory analysis were subsequently air dried and ground to pass a 2mm sieve, with a small subsample passed through a 0.5mm sieve for total carbon and calcium carbonate analysis. The chemical analysis of the soil layers were performed as follows, (the units for each attribute appear in brackets):

pH and *electrical conductivity* (mS/m) using a combination electrode and conductivity cell on a 1:5 soil:water suspension after shaking for 1hour.

Chloride (mg/kg) was extracted with a 0.1M barium acetate (1:10 for 1hour).and analysed using, an automated ferric nitrate/mercuric thiocynate method (Beech and McLeod, 1984).

Bicarbonate extractable P (mg/kg) was extracted with 0.5M sodium bicarbonate at pH 8.5 and analysed by an automated molybdate method (Colwell, 1963).

Exchangeable basic cations (mmol(+)/kg) were extracted and analysed for Ca, Mg, Na, and K according to the method of Tucker (1974) except that a mechanical leaching device (Holmgren *et al.*, 1977) was used.

Calcium carbonate (%) determined using a Collins calcimeter as described by Loveday and Reeve (1974).

Organic carbon (%) calculated as the difference between total carbon determined using combustion using a Leco furnace (Merry and Spouncer, 1988) and carbonate carbon.

Silt and clay (%) were determined by a pipette method (Coventry and Fett, 1979) following pre-treatment with sodium hypochlorite to remove organic matter and hydrochloric acid in order to remove carbonates.



CONTINUOUS CLASSIFICATION



3 CONTINUOUS CLASSIFICATION

3.1 CONVENTIONAL METHODS OF SOIL CLASSIFICATION

Many conventional soil classification systems proceed by the establishment of a series of subdivisions, which places individual soil profile descriptions into a hierarchically structured scheme, including the United States Department of Agriculture's comprehensive 'Soil Taxonomy', Soil Survey Staff (1975) and Northcote's (1974) 'Factual Key to Australian Soils'. In survey, the experience of the soil surveyor is then utilized to identify the new individual, which is placed into a soil class which has similar attributes, within the hierarchical classification. Soil boundaries are also located in the field. The result of such a classification in terms of a soil survey is the production of a choropleth map, which shows regions of interest divided by parcels each of a particular soil type, (Burgess and Webster, 1984).

These hierarchically arranged classes for individuals are mutually exclusive and for each class defined a central concept is identified by discriminating criteria with sharp boundaries between the class limits (Burrough, 1989). The conventional method outlined above therefore implies that soil classes are discrete with abrupt boundaries, which is represented by a central concept. The distribution of a single property is then assigned to each parcel on the map and a value in which the majority of the sites sampled within the area suggest a typical value for the class, (Burgess and Webster, 1980). Hence the predicted value of a soil attribute at any unsampled location has the value of the typical profile or mean value of the land unit, (Odeh et al., 1990).

§3 CONTINUOUS CLASSIFICATION

The soil map thus produced is a display of the spatial distribution of the classes of the initially constructed classification scheme, where soil boundaries are constructed via the interpolation between points where the soil has been allocated to different classes, (Burgess and Webster, 1984). There are many problems inherent in this type of classification. McBratney and Webster, (1981) ask how homogenous with respect to the soil profile is each land unit, since the precision of any prediction is dependent on the homogeneity of the mapping units and hence on the within-unit variance (Trangmar *et al.*, 1985). Another question we might ask is how well is the spatial variation within the soil continuum has been accounted for?

Webster and Burrough (1974) suggest that a more problematical task involved in soil survey is the allocation of individual profiles to the most appropriate classes in an existing scheme of classification, where the surveyor constructs classifications by judgements based on experience and intuition, the classes defined having polythetic memberships, (i.e. class membership based on several attributes), and are then applied to the soil which has been influenced by many environmental factors. Further, fragmentary information on which much of the survey is based as well as experimental error of the samples collected influence the final classification.

So, according to the existing systems of soil classification any soil individual belongs to exactly one class. The individual therefore is allocated to a single class despite uncertainties in the classification due to errors in data or vagueness of class definitions. Further, no matter how small differences in attributes may be, the classification does not account for the gradational nature of the soil continuum when crossing a class boundary. The boundary tends to be sharp and in a sense discontinuous, (McBratney and DeGruijter, 1992). Another consideration is that some individuals do not fit the description of any of the groups so how best should these be catered for in a classification scheme.

What seems useful is a system of soil classification which takes into account the continuous nature of the soil mantle, both along the surface, and at depth throughout the soil profile. One such technique, which is capable of accounting for the continuous nature of the soil continuum, is the method of fuzzy-k-means analysis, termed continuous classification by McBratney and DeGruijter (1992). Individuals in the conventional method of classification are only allowed

membership to a single class whereas in fuzzy sets an individual may belong totally, partially, or not at all to a class, (Zadeh, 1965).

3.2 CONTINUOUS CLASSIFICATION

In fuzzy or continuous classification, the objects being classified are accepted as having membership, to a greater or less degree, in every class formed (Bezdek, 1981). According to this definition, fuzzy classes are a generalization of the hard or discrete classifications (Odeh et al, 1990). In fuzzy set theory, the membership function ranges from 0 to 1, which replaces the membership of conventional set theory that states, membership is either 0 (no membership) or 1 (exclusive membership), that is an individual has membership to exactly one class. Therefore an individual particularly one which is equally a member of two or more classes can have membership to more than one class in fuzzy set theory.

In conventional or hard classes, the conditions which ensure mutually exclusive, jointly exhaustive and non-empty classes, is considered when a set of n individuals are partitioned into k discontinuous classes where the membership, $\mu=(\mu_{ic})$, is equal to one, when an individual i belongs to a class c and $\mu=0$ otherwise, the following conditions apply on μ ,

$$\sum_{c=1}^k \mu_{ic} = 1, \quad i=1, \dots, n \quad (1)$$

$$\sum_{i=1}^n \mu_{ic} > 0, \quad c=1, \dots, k \quad (2)$$

$$\mu_{ic} \in \{0,1\}, \quad i=1, \dots, n; c=1, \dots, k. \quad (3)$$

Where the third condition implies the all or nothing membership of the hard classification. However, Zadeh (1965) relaxed this condition so that the membership of an individual within a particular class is allowed to be partial and thus can take any value between or including 0 or 1. Hence, condition (3) becomes

$$\mu_{ic} \in [0,1], \quad i=1, \dots, n; c=1, \dots, k. \quad (3a)$$

so that any $n \times k$ matrix μ which satisfies (1), (2), and (3a) represents a fuzzy set partition of n individuals into k continuous classes.

The theory of fuzzy sets introduced by Zadeh (1965) was extended by Ruspini (1969, 1970) as a way of resolving representational difficulties of conventional clustering where stray points and bridges between sets occur. Numerical algorithms were developed by Dunn (1974) and generalised by Bezdek (1975).

The fuzzy-k-means (McBratney and DeGrujter, 1988) or fuzzy-c-means (Bezdek, 1981) is the most commonly used and studied fuzzy clustering method, which is a generalization of hard-k-means (Hartigan, 1975). This generalization minimizes the within-class sum of square errors functional $J(\mathbf{M}, \mathbf{C})$ under conditions (1), (2) and (3):

$$\mathbf{J}(\mathbf{M}, \mathbf{C}) = \sum_{i=1}^n \sum_{c=1}^k \mu_{ic} d^2(x_i, c_c), \quad (4)$$

where $\mathbf{C} = (c_{cv})$ is a $k \times p$ matrix of class centres, c_{cv} denoting the value of the centre of class c for variable v ,

$\mathbf{x}_i = (x_{i1}, \dots, x_{ip})^T$ is the vector representing individual i ,

$\mathbf{c}_c = (c_{c1}, \dots, c_{cp})^T$ is the vector representing the centre of class c , and

$d^2(x_i, c_c)$ is the square distance between x_i and c_c according to a chosen definition of distance, further denoted by d_{ic}^2 for simplicity.

$\mathbf{J}(\mathbf{M}, \mathbf{C})$ is the sum of square errors (expressed as distances) due to the representation of each individual by the centre of its class.

A fuzzy generalization of $\mathbf{J}(\mathbf{M}, \mathbf{C})$ is obtained by involution of the memberships with an exponent f , hence

$$\mathbf{J}_B(\mathbf{M}, \mathbf{C}) = \sum_{i=1}^n \sum_{c=1}^k \mu_{ic}^f d_{ic}^2, \quad (4a)$$

to be minimized under conditions (1), (2) and (3a). The exponent f is selected prior to the application of the functional, and ranges from $[1, \text{infinity}]$. The exponent f determines the degree of fuzziness of the final solution, with the lowest meaningful value $f=1$, is the hard partition solution of (4a), that is the result obtained is not

hard at all. However, the hard partition is simply only one of the many possible fuzzy partitions. Further as f approaches infinity with $m_{ic}=1/k$ for each pair of i and c .

The most commonly used measures of distance frequently employed in cluster analysis include:

$$d_{ic}^2 = \sum_{v=1}^p (x_{iv}-c_{cv})^2 = (x_i-c_c)'(x_i-c_c) \quad (5)$$

in which the variables are given equal weight, therefore, if one or more variables has a much larger variance than the other, the first will heavily determine the result. Where this effect is undesirable, it can be suppressed by standardising the variables to unit variance. An alternative to (5) is the Mahalanobis distance measure defined by

$$d_{ic}^2 = (x_i-c_c)' S^{-1} (x_i-c_c) \quad (5a)$$

where S is the sample covariance matrix X . In this case not only differences in variance but also correlations between variables are taken into account, Bezdek (1981).

McBratney and De Grujter (1992) found that continuous classes by their nature provided a better representation of the intergrades than discontinuous classes, especially where outliers were located between clusters in property space, known as intergrades. However outliers outside the main body of data points termed extragrades, are still not suitably represented by fuzzy k-means analysis.

Ohashi (1984) defined a version of fuzzy k-means to reduce the effects of outliers by partly accommodating them in a special class, whose members are not concentrated in a fuzzy hypersphere around a defined class centre. Instead, they are distributed over regions of larger distances between an individual and the class centres. However, problems arise in the possibility of differentiating intergrades and extragrades, based largely on m_i^* , which applies equally to both types of individuals.

McBratney and De Gruijter (1992), improved this separation between intergrades and extragrades by making the membership to the extragrade class depend on the distances to the class centres:

$$J_{MG}(M,C) = a \sum_{i=1}^n \sum_{c=1}^k m_{ic}^f d_{ic}^2 + (1-a) \sum_{i=1}^n m_{i*}^f \sum_{c=1}^k d_{ic}^{-2}, \quad (6)$$

with the convention that if both m_{i*} and d_{ic} are zero, the corresponding term in equation 6 is zero. The memberships to the extragrade class, m_{i*} are not concentrated in a fuzzy hypersphere around a given class centre, as with regular classes. Instead, they will spread over regions at larger distances from each of the class centres. The larger the distances between an individual and the class centres, the higher its membership m_{i*} .

3.3 APPLICATION OF CONTINUOUS CLASSIFICATION

McBratney and Moore (1985) used fuzzy sets as a possible way of dealing with the continuity of climate, since hard classifications seemed inappropriate for climate because of the continuity of the atmosphere. Fuzzy sets proved to be more realistic, flexible and provided better information to users of the original data.

McBratney and De Gruijter (1992) used the fuzzy k-means technique for soil classification on a forty-eight square kilometre area at Wesepe in the Netherlands and concluded that fuzzy sets were capable of creating a classification which reflects the main pedological features of the area in a continuous way. Their motive for using fuzzy sets was not to deal with a concept of vagueness, but to deal with the soil continuum, as with climate, since the soil changes in a continuous way and suggested the term of continuous classes rather than fuzzy classes.

Odeh *et al.* (1990) used fuzzy k-mean analysis to classify soil on transects within the Mount Lofty Ranges in South Australia to assess methods of designing optimal sampling schemes for mapping soil types. Powell *et al.* (1992) working in the Lockyer Valley in south-east Queensland, examined the application of fuzzy classification and ordination to the characterization of soil units recognized. The

soil attributes used were morphological supplemented by a limited number of soil chemical parameters.

Odeh *et al.* (1990) found that fuzzy k-means classification offered the possibility of data reduction when several soil attributes were considered on two perpendicular transects, as opposed to geostatistical procedures which only allow examination of a single soil attribute at a time. Powell *et al.* (1992) concluded that fuzzy classification and multivariate planing of profile data provided a useful means of evaluating and verifying recognised field units. They found that fuzzy groups matched most soil profile classes and indicated those profiles which may require re-evaluation.

Ward (in prep.) used fuzzy k-mean analysis to classify the surface soil layers in the lower Namoi Valley by first partitioning the area into recognisable geological and geomorphological units. Within these units the soil to a depth of 0.20m was analysed using fuzzy k-means to derive soil units based on clay content and a number of soil chemical attributes including cation exchange capacity, exchangeable aluminium, potassium, sodium, magnesium and calcium. The resultant analysis agreed with field perceptions of soil relationships and drew attention to significant attributes in profiles of deep clayey soil that appeared to show little morphological variation.

In the following report fuzzy classification of individual soil layers based on a wide variety of chemical attributes and particle size analysis data was used to assess the potential for this method as a means of classifying soil. A continuous method of land evaluation is also illustrated by the use of an function which allows the result to be expressed in a more continuous way.

3.4 CONTINUOUS CLASSIFICATION: with and without extragrades

In the following section the "butterfly" data set introduced by Ruspini (1970) is used to illustrate fuzzy k-means classification. The data set, (Table 1), defines the individual site locations for 15 points in a geometrical space, illustrated in Figure Butterfly. Geometrically, the data set consists of two isosceles triangles, separated by a single site, site 8, (Figure 8).

§3 CONTINUOUS CLASSIFICATION

Table 1. (near here)

Figure 8. (near here)

To classify these sites geometrically, we consider the attributes of geometry, that is the x and y co-ordinates of the sites. Geometrically, site 8 would be considered the representative site with respect to geometry if one class were to be defined, due to its location at the centre of the geometric plane (3,2), with a subsequent decrease in membership of those individuals with increasing radii from site 8.

If we consider classifying the area to delineate two classes, site 8 would then become an intergrade between the two probable classes. The allocation of site 8 under any method of classification would be difficult, similar to the situation which may arise in the field during soil survey where an individual soil profile has similar attributes to two closely related groups, however the classification allows only a yes or no membership, that is, it either is or is not a member of a particular soil class. Fuzzy classification however, allows for the possibility that an individual, may have membership to all the classes formed. In this example the site is accommodated by the allocation of equal membership to both of the classes formed, (Table 2). Due to the symmetry of the "butterfly" configuration, in the following discussion only the left hand class will be considered, since the right hand class is implied by symmetry.

Table 2. (near here)

As with any classification scheme, continuous classification using fuzzy k-means produces a central concept, called a centroid which is an average weighted by membership values and to which all prospective members are compared to. The centroid which is not a real individual but a modal individual is in our example expressed by an x and y co-ordinate, which in terms of an analysis of a real data set could be the soil attributes of actual field and laboratory analysis including for example pH, organic carbon percent, exchangeable calcium, sodium, and so on.

The centroid value for the left hand class had the co-ordinates of (0.8548, 2.0). This closely approximates the co-ordinates of site 5, (1, 2), which has subsequently the greatest degree of membership ($\mu=0.999$). Site 5, is called the exemplar, which is the real individual that is most closely related to the central concept, although not the central concept itself.

Considering site 2 we see that due to its geometrical position, it is slightly eclipsed by site 5, the exemplar of this class, with respect to the opposite right hand class, where its membership is only 0.027. The low membership is also due to the position of this site which lies on the outer edges of the geometrical area and is not very close to the centroid of the second hand class. Site 7 is slightly further away from the centroid of the left hand class than site 2 and accordingly has less membership. However, this is also due to the closer proximity of this site to the right hand class, and subsequent higher membership to this class. It behaves as an intergrade between the two classes.

Sites 1 and 3, members of the left hand class have the least membership, since they are the furthest from the centroid. Further membership to the right hand class is greater than that of many other site similar to site 7, which is due to these location of these sites in the outer area of the geometrical plain under consideration. In essence these sites are behaving as extragrades, however the analysis cannot account for them. When the classification is re-analysed to consider the additional extragrade class, these sites are accommodated. Sites 1 and 3, are recognized as having little membership to any of the recognised classes and are therefore allocated to the extragrade class.

If we reconsider site 2 and 7 we see that site 7 has a greater membership to the left hand class than site 2, which has a larger membership to the extragrade group due to its proximity to the edge of the geometric area. The membership of site 5 is also reduced. However, this is a product of a high fuzziness exponent which influences the degree of fuzziness of the individuals classified.

It should be remembered that extragrades are those individuals which do not belong to any of the classes recognized, and do not have a class centroid to represent them. It should also be remembered that an extragrade owes that classification simply due to its poor representation in the area under consideration. In this particular example it is restricted to the sites defined in the "butterfly" configuration and to the confines of the geometrical area considered.



4 SOIL LAYER CLASSES



4 SOIL LAYER CLASSES

4.1 THE SOIL LAYER AS THE INDIVIDUAL

Many notions of what constitutes a soil individual have been suggested including the soil profile, polypedon, pedonit, tessera, pedotop and so on. Holmgren (1988) argued for a point representation of soil which is in accordance with the use of geostatistics in soil description and prediction. From the pedological point of view the use of the soil horizon as the individual is a sensible one since it represents the product of pedological processes, (McBratney, 1991). The question then of "Can different combinations of processes bring about the same result?" can be answered by detailed numerical modelling of soil landscape and processes. An approach which appears not to have been pursued.

FitzPatrick (1967) recognised the fundamental importance of soil horizons and attempted to characterise the universe of them. The classification system recognised some eighty such horizon classes, described in terms of a variety of soil attributes which gives a very flexible approach since horizons can appear in a large multitude of sequences. FitzPatrick (1967, 1971) then recognised certain common sequences of horizon classes, which were then used to define great soil groups.

Independently, soil physicists and surveyors have recently tried to extrapolate point observations of soil physical properties for whole areas with emphasis on land evaluation (Bouma, 1989). The approach deemed to be most effective is defining certain horizon classes characterised physically and which are internally homogeneous enough to allow the use of scaling using similar media concepts. Thirty five such horizon classes have been recognised with defined hydraulic conductivity and moisture potential characteristics (Wosten *et al.*, 1987). These

physical horizon classes have then been called "building blocks" because as above these classes can be combined in soil profiles in many ways.

In Australia, the new South Wales Soil Conservation Service (now part of the New South Wales Department of Conservation and Land Management), morphologically defined soil materials which may correspond to soil horizons or stratigraphic units (Atkinson, 1991). The layer classes defined below may be regarded as soil material classes but the method of their discovery and definition is quite different to that of soil materials.

Numerical analysis of soil profile data is also complicated by the vertical anisotropy of soil properties as mentioned above. In essence, Russell and Moore (1968) suggest that the explicit expression of the significance of various soil layers within the profile as a whole, is necessary before anisotropic soil profile data can be interpreted. Various approaches have been attempted previously in comparing multi level data which have been applied to soil profile data.

In the literature concerning the selection of layers to be compared, some authors (Bidwell and Hole, 1964; Rayner, 1966; Lance and Williams, 1967; Moore, *et al*, 1972) considered the profiles as being made up of three layers, in most cases equivalent to the A, B and C horizons. Associated with their classifications were depth weightings, in which layers of inferred similarity within profiles were compared, however this assumes a similarity between them and may not reflect reality.

Further, horizon classifications have dealt primarily with morphological and physical characterisation of soil. Ward (in prep), attempted to classify soil numerically by considering the surface 0.20m soil layers in terms of properties that have significance to agriculture at the ground surface. Further the attributes used to delineate these layers were chemical rather than morphological, including the use of pH, cation exchange capacity and exchangeable percentages of aluminium, potassium, sodium, magnesium and calcium.

In the following classification this approach of using chemical and not morphological data which may not reflect the true agricultural significance particularly at the ground surface is extended using a larger number of chemical attributes as well as

§4. SOIL LAYER CLASSES

particle size analysis data to illustrate the technique of continuous classification with the use of the soil layer, which closely approximates a soil horizon as the individual. In the next section the most readily identifiable layer sequences are defined and mapped within the Edgeroi area.

4.2 SOIL LAYER ATTRIBUTES

Of the 227 profiles considered in the study, 210 were described as part of the Edgeroi topographic map sheet, which contained 1309 individual soil layers, while the other 17 profiles described and analysed chemically were part of the SUIAWWRC, which includes an additional 110 soil layers.

The chemical attributes which are used to classify these 1419 individual soil layers include pH, E.C., organic carbon, calcium carbonate, chloride, phosphorus, the exchangeable cations of calcium, magnesium, potassium and sodium. Particle size analysis of clay and silt were also considered by the classification. Electrical conductivity, chloride, calcium carbonate, organic carbon, phosphorus and the exchangeable cations of calcium, magnesium, potassium and sodium showed slightly to highly skewed distributions and variates were therefore transformed to logarithms. Nitrate was not included within the classification due to the variable nature of the result, while exchangeable aluminium and sand were omitted due to the lack of exchangeable aluminium data and the inclusion of clay and silt in the analysis respectively. Combined the final raw data matrix as illustrated in Table 3, was 1419 x 12, that is, n=1419 individual soil layers by k=12 soil chemical attributes, (Table 3).

Table 3. (near here).

4.3 CONTINUOUS CLASSIFICATION

4.3.1 MacFuzzy algorithms and metrics

MacFuzzy, the program utilised for soil layer classification, is based on the fuzzy k-means with extragrade algorithm for multivariate analysis of de Gruijter and McBratney (1988). Fuzzy k-means, the simplest of the three algorithms, classifies the data with many individuals given equal membership to all groups formed.

Fuzzy k-means with extragrades recognises these individuals, that is, the possibility that some soil layer descriptions might not be well suited to any of the recognised classes, and places them instead into an additional miscellaneous outlier class, the extragrades (Ward *et al.*, 1991). Fuzzy k-means with variable extragrades, the third algorithm, varies the distance dependence of the extragrade group from the original square law used by de Gruijter and McBratney (1988). Fuzzy k-means and fuzzy k-means with extragrades, were the two algorithms used to classify the soil layers.

Three distance measures are also available within MacFuzzy, including euclidean, diagonal and Mahalanobis (Bezdek, 1981). The Mahalanobis metric was considered most appropriate for our set of data since correlations between variables are taken into account. Further, the transformation results in all attributes having zero mean and unit variance. The other advantages of this metric, is that like the diagonal metric, Mahalanobis distance may produce better separations when large numbers of attributes are used, for measurement of many properties and are likely to provide more distinctions and thus greater dissociation (Ward *et al.*, 1991).

4.3.2 The parameters

Various other parameters are also required by the algorithms, decisions which are based on the data set.

4.3.2.1 Degree of fuzziness

The degree of fuzziness is controlled by the fuzziness exponent. When set near one, the clustering becomes progressively harder as in conventional hard set theory. As the fuzziness exponent is increased the clustering becomes relaxed to the extent that the classification is so fuzzy that no groups are identified. It is suggested that when using the Mahalanobis metric, fuzziness exponents close to one be used (Ward *et al.*, 1991). Three fuzziness exponents (f) were used, including $f=1.1$, 1.2 and 1.3 , to determine the best degree of fuzziness. Each fuzziness exponent was run to classify the 1419 individual soil layers into 8, 9 and 10 soil layer classes, using the attributes of the Edgeroi data set mentioned above. The resultant classifications suggest that of the three fuzziness exponents selected, $f=1.1$ was not fuzzy enough, while that of $f=1.3$ was too fuzzy. The result obtained using $f=1.2$ appeared to be the most appropriate exponent and was selected for further analysis.

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4.3.2.2 How many soil layer classes?

Many authors (e.g. Roubens 1982), have proposed validity functionals as a means of solving the cluster validity problem. McBratney and Moore (1985), Odeh *et al.*, (1990), Powell *et al.* (1992) and Ward (in prep) have all utilised two of the more promising functionals, the fuzziness performance index (FPI) and the normalized classification entropy (NCE). Simply, the FPI is a measure of the degree of fuzziness while the NCE indicates the degree of disorganization within the classification. The FPI is also a measure of the global minimum of the number of classes, while the NCE is a measure of local minimums.

The least fuzzy or disorganized number of classes is considered optimal, which Odeh *et al.* (1990) suggest is rather paradoxical since we reject the idea of hard partitions yet by measuring the amount of fuzziness presume that the least fuzziest partition to be most valid. Odeh *et al.*, (1990) further suggest that it is unlikely to find a wholly satisfactory answer because it is not known if the samples are representative of all the possible entia in either geographical or the taxonomic context.

Nevertheless, the basic fuzzy k-means algorithm was used to assess whether real clusters existed, that is, simply how many soil layer classes exist within the area. This required determining how well the algorithm identified structure in the data by classifying the soil layers from 2 to 25 soil layer classes. The two validity functionals, mentioned above were used to assess the optimal number of groups. Figure 9 indicates a global minimum of FPI occurs when the number of classes equals 10. Further, the NCE indicates a local minimum. The optimal number of classes considered to be present within the data set was taken to be 10.

Figure 9. (near here).

This small number of layer classes would ensure that the ensuing classification would not be too complex to comprehend. The fuzzy k-means with extragrades, using a number of the parameters outlined below, was then run to recognise the ten soil layer classes discussed in detail below and to identify those soil layers which are not well represented by any of the recognised soil layer classes. (For a more detailed discussion of the program and the algorithms refer to Ward *et al.*, 1991).

4.4 DESCRIPTION OF INDIVIDUAL SOIL LAYERS

The following descriptions are of the ten recognised soil layer classes, identified by the fuzzy k-means with extragrades analysis. Each soil layer class has been named after a landholding (e.g. Togo), or a specific land use area (e.g. Couradda State Forest), in which either a large number of the soil layers or exemplars were present. The basis for membership was that a layer with membership greater than 0.50 to any one class was a member of that class. A small portion of the final membership matrix appears in Table 4.

Table 4. (near here)

The following descriptions include the location of many of the layers within the landscape and their relation to geology and geomorphology of the area and also those features which distinguish the different layer classes. Table 6, illustrates the attributes of each recognised soil layer class centroid. During the discussion of each layer class, the centroid as well as the exemplars are presented for comparison. Morphological descriptions are also provided, for each of the soil layer exemplars, (McGarry *et al.*, 1990). The layers are presented in order of decreasing clay content. The layer class names are italicized and are in bold, (e.g. ***Togo***) to distinguish them from the text and in the following section to distinguish them from the profile class names which are in capitals and bold script, e.g. **BELAR**. The following section is also to be used as a key, with the soil layers shaded.

Table 5. (near here)

4.4.1 <i>Togolayer</i> class	
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4.4.1 *Togo* soil layer class

The largest number of layers identified within any class were the 214 of the ***Togo*** layer class. Predominantly located on the lower lying areas of the landscape associated with the Namoi River alluvial terraces, these layers were usually found in succession within half a metre of the soil surface, (Figure 10 and Table 6) and in the A horizon of the 70 profiles in which they were identified, including five from the

§4. SOIL LAYER CLASSES

SUIAWWRC. Consequently, due to their position near the surface these layers characteristically have moderate levels of organic matter and phosphorus.

Table 6. (near here)

Table 7. (near here)

Figure 10. (near here)

Togo soil layers have the largest clay contents (weighted average = 62%), texturally ranging from light medium clay to medium clays. Accordingly, the soil is fertile, high in exchangeable cations particularly calcium and magnesium, (Table 7). Further, low exchangeable sodium percentages and electrical conductivities indicate that these layers are neither sodic nor saline. Their strongly alkaline nature is attributable to the association of this class with **Boolcarrol** layers which usually underly these layers. **Togo** soil layer exemplar, layer ed09904, located at a depth of 0.70-0.80m, acts as an intergrade between these two classes and represents the **Togo** layers of this class which lie at depths of 0.70m which are in close proximity to the underlying **Boolcarrol** layers that are generally more sodic, saline and alkaline.

Morphologically, the **Togo** exemplars were described as follows:

ed09002 (0.10-0.20m) *Very dark greyish brown (10YR3/2) medium clay; moderate >100mm prismatic structure, breaking to moderate 20-50mm angular blocky structure; moderately strong; smooth-ped fabric; <2% distinct fine pale brown (10YR6/3) calcareous nodules; <2% 5-10mm cracks; <2% 0.075-1mm pores; few very fine roots; pH 8.5;*

ed09004 (0.70-0.80m) *Dark grey (10YR4/1) medium clay; moderate 20-50mm wedge structure; moderately strong; weak slickensides, smooth-ped fabric and polished ped fabric; <2% distinct fine pale brown (10YR6/3) calcareous nodules; <2% 5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH 9.0;*

ed09202 (0.10-0.20m) *Dark brown (7.5YR3/2) light medium clay; <2% faint fine light brown (7.5YR4/6) patches of sediment, filling cracks, 50-100 subangular blocky structure; moderately strong; smooth-ped fabric; <2% distinct faint fine very pale brown (10YR8/3) calcareous nodules; <2% 5-10mm cracks; <2% 0.075-1mm pores; few very fine roots; pH 9.0;*

ed109001 (0.00-0.10m) *Dark grey brown (10YR4/2) medium clay; moderate 2-5mm granular structure; moderately weak; rough-ped fabric and polished ped fabric; <2% <5mm cracks; 2-5% 0.075-1mm pores; few very fine roots; pH 8.2;*

ed12502 (0.10-0.20m) *Dark grey (10YR4/1) medium heavy clay; weak 5-10mm lenticular structure; moderately firm; nodular fracture; smooth-ped fabric; 2-5% <5mm cracks; <2% 0.075-1mm pores; few medium roots; pH 8.2; genetic boundary, very diffuse;*

ed14502 (0.10-0.20m) *Very dark greyish brown (10YR3/2) medium clay; moderate 50-100mm sub-angular blocky structure, with moderate 2-5mm granular structure; moderately strong; earthy fabric; <2% <5mm cracks; 2-5% 0.075-1mm pores; few fine roots; pH 8.2.*

4.4.2 Boolcarrol layer class

4.4.2 Boolcarrol layer class

As with the *Togo* layer class, the 152 layers of the *Boolcarrol* layer class are also associated with the alluvial plains of the Namoi River, (Figure 11). However, these layers are exclusively found at depths below 0.70m and are often associated with many of the B horizons containing *Togo* layers, (Table 8). The organic matter and calcium carbonate contents as well as E.C._e, levels of chlorine and the amount of exchangeable sodium differ according to the position these two layer classes occupy within the profile. Characteristically low in organic matter content the amount of calcium carbonate and chlorine present is indicative of a subsoil layer in which salts have, (Table 9).

Table 8. (near here)

Table 9. (near here)

Figure 11. (near here)

Texturally ranging between light medium and heavy clays, these brown to dark brown layers, have the largest exchange capacity of any class. Dominated by calcium and magnesium the layers are also excessively sodic with an average of 20% of the total exchange capacity contributed by exchangeable sodium. The high pH is attributable to the large amounts of calcium carbonate usually identified within these layers but also due to their excessively sodic nature. The slightly saline E.C._e values (as high as 1.90S/m) may be due to either the accumulation of chloride in these layers, which may become significant with rising water tables, affecting the long term viability of these areas or due to the presence of gypsum crystals identified in some layers, during morphological description.

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Morphologically, the *Boolcarrol* exemplars were described as follows:

ed02305 (1.20-1.30m) *Dark reddish brown (5YR3/2); light medium clay; weak >100mm wedge structure, breaking to weak 50-100mm subangular blocky structure; very firm; moderate slickensides, smooth-ped and earthy fabric; <2% distinct fine pink (7.5YR7/4) calcareous nodules; <2% fine manganese stains; <2% <5mm cracks; few very fine roots; pH 8.8; genetic boundary, diffuse, smooth;*

ed04005 (1.20-1.30m) *Dark brown (10YR3/3); medium heavy clay; <2% very fine dark grey (10YR3/1) organic stains; strong 50-100mm wedge structure, breaking to strong 20-50mm subangular blocky structure; very firm; strong slickensides, smooth ped fabric and earthy fabric; <2% distinct medium pinkish grey (7.5YR6/2) calcareous nodules or <2% medium calcareous soft segregations; with <2% gypsum crystals; <2% <5mm cracks; pH 8.5;*

ed04106 (1.20-1.30m) *Dark brown (10YR3/3); heavy clay; moderate 10-20mm subangular blocky structure; very firm; weak slickensides, smooth-ped and polished ped fabric; 2-10% distinct fine black (N2/) manganese stains; 2-10% distinct medium white (10YR8/1) calcareous nodules; 2-5% 5-10mm cracks; <2% 1-2mm pores; pH 8.7;*

ed04205 (1.20-1.30m) *Brown (7.5YR5/4) medium clay; weak 50-100mm prismatic structure, with moderate 5-10mm subangular blocky structure; moderately firm; smooth-ped and polished ped fabric; 20-50% prominent very coarse very dark grey (N3/) manganese veins; <2% fine gypsum crystals; <2% medium calcareous soft segregations; 2-5% <5mm cracks; <2% 0.075-1mm pores; pH 8.5;*

ed04305 (1.20-1.30m) *Dark brown (7.5YR4/2) heavy clay; 2-10% distinct medium very dark grey (10YR3/1) patches of soil, filling cracks; 2-10% distinct fine reddish brown (5YR4/4) flecks produced by faunal mixing; weak 20-50mm subangular blocky structure; very firm; nodular fracture; earthy and smooth ped-fabric; 2-10% fine manganese stains; <2% <5mm cracks; <22% 0.075-1mm pores; pH 8.5; genetic boundary, gradual, smooth;*

ed07505 (1.20-1.30m) *Brown (10YR4/3) medium heavy clay; 2-10% distinct medium yellowish red (5YR4/6) flecks produced by faunal mixing; strong 5-10mm angular blocky structure; very firm; moderate slickensides, smooth-ped fabric; 2-10% prominent medium light grey (10YR7/2) calcareous nodules; 2-5% <5mm cracks; common very fine roots; pH 8.2;*

ed07605 (1.20-1.30m) *Dark brown (7.5YR4/2); medium clay; 10-20% distinct medium very dark greyish brown (10YR3/2) patches of soil filling cracks; weak 20-50mm subangular blocky structure; moderately firm; weak slickensides, smooth-ped and earthy fabric; 2-10% distinct medium very pale brown (10YR8/3) calcareous nodules; <25 fine gypsum crystals; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH 8.7;*

ed00506 (2.50-2.60) *Dark brown (7.5YR4/2); light medium clay; strong 50-100mm wedge structure, breaking to moderate 5-10mm angular blocky structure; moderately firm; strong slickensides, smooth-*

ped and polished ped fabric; 10-20% distinct coarse very dark grey (10Yr3/1) manganese laminae; 2-10% distinct coarse light grey (10YR7/2) calcareous nodules; 2-5% 0.075-1mm pores; <2% 2-6mm rounded quartz fragments; pH8.7;

ed02706 (2.50-2.60) Dark brown (7.5YR4/2); medium heavy clay; 2-10% prominent medium yellowish red (5YR5/8) mottles; moderate 5-10mm wedge structure, with moderate 5-10mm angular blocky structure; moderately firm; moderate slickensides, smooth-ped and polished ped fabric; 10-20% distinct medium very dark grey (N3/) manganese stains; 2-10% medium ferruginous veins; <2% fine calcareous hollow nodules; 2-5% <5mm cracks; <2% 0.075-1mm pores, pH9.0;

ed04006 (2.50-2.60) Dark brown (10YR3/3); medium heavy clay; 2-10% distinct very coarse very dark greyish brown (10YR3/2) organic stains; strong 50-100mm wedge structure, breaking to weak 20-50mm subangular blocky structure; very firm; strong slickensides, smooth ped fabric and earthy fabric; 2-10% prominent coarse pinkish grey (7.5YR7/2) calcareous nodules or <2% medium calcareous soft segregations; with <2% gypsum crystals; <2% <5mm cracks; <2% 0.075-1mm pores; pH8.0;

ed04406 (2.50-2.60) Dark brown (7.5YR4/2); medium heavy clay; 2-10% distinct fine reddish brown (2.5YR4/4) flecks produced by faunal mixing; moderate 50-100mm wedge structure; moderately strong; moderate slickensides, polished ped and smooth-ped fabric; <2% distinct fine pinkish grey (7.5YR6/2) calcareous nodules; <2% fine manganese stains; <2% <5mm cracks; <2% 1-2mm pores; pH9.0;

ed05606 (2.50-2.60) Dark brown (7.5YR4/4); medium clay; <2% distinct fine reddish brown (5YR5/4) flecks produced by faunal mixing; weak >100mm wedge structure; breaking to moderate 10-20mm subangular blocky structure; very firm; granular fracture; polished ped and smooth-ped fabric; <2% prominent medium very pale brown (10YR7/3) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; pH9.0.

4.4.3 Bald Knob layer class

4.4.3 Bald Knob layer class

Bald Knob soil layers are strongly alkaline, non-saline and marginally to moderately sodic, (Table 10). The strongly alkaline nature of many of these layers, is attributable to the large amounts of calcium carbonate and the moderate levels of sodicity associated with them. Slightly lighter in texture than the preceding two layer classes, but similar in texture and exchange capacity to the **Moplain**, **Mayfield** and **Nundi** layers these medium to heavy clays have moderate to large cation exchange capacities of which calcium and magnesium dominate.

§4. SOIL LAYER CLASSES

Table 10. (near here)

Table 11. (near here)

Figure 12. (near here)

Found at depths similar to the *Togo* layers, *Bald Knob* layers are not as prominent at the soil surface, but still lie within the A horizon of the profiles in which they were identified, (Table 11). They are most commonly associated with the layers of the *Nundi* layer class, which are more carbonate rich, strongly alkaline, sodic and generally found at greater depths, than the 74 *Bald Knob* layers. Geographically, they are located in a number of areas particularly near the local drainage ways of Bulldog and Ten Mile Creeks in the north and Spring and Bobbiwaa Creeks in the south, with some layers identified on the alluvial terraces of the Namoi River, (Figure 12). Many layers were also found on the foothills of the Nandewar Range in contact with and containing weathering basalt, similar to the Mayfield soil layers, which is perhaps an indication of the possible parent material of the layers located near the local drainageways.

Morphologically, the *Bald Knob* exemplars were described as follows:

ed02403 (0.30-0.40) *Very dark greyish brown (10YR3/2) heavy clay; moderate 5-10mm lenticular structure, breaking to moderate 2-5mm angular blocky structure; very firm; smooth ped and earthy fabric; <2% faint fine white (10YR8/2) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH8.5;*

ed02303 (0.30-0.40) *Dark brown (7.5YR3/2) heavy clay; apedal massive; moderately strong; earthy fabric; <2% distinct fine light grey (10YR7/2) calcareous nodules; <2% <5mm cracks; few very fine roots; pH8.8;*

ed06203 (0.30-0.40) *Very dark grey (10YR3/1) medium clay; moderate 5-10mm angular blocky structure; very firm; weak slickensides, smooth-ped and polished ped fabric; <2% distinct fine white (10YR8/2) calcareous nodules; 5-10% <5mm cracks; 5-10% 0.075-1mm pores; few very fine roots; pH8.6;*

ed01604 (0.70-0.80) *Reddish brown (5YR4/3) heavy clay; moderate 50-100mm angular blocky structure; moderately strong; smooth-ped fabric; <2% medium calcareous nodules; <2% <5mm cracks; pH8.5;*

ed16204 (0.70-0.80) *Very dark greyish brown (10YR3/2) medium heavy clay; weak 10-20mm lenticular structure; moderately strong; smooth-ped fabric; <2% faint fine very pale brown (10YR7/4)*

calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; <2% 2-6mm subrounded quartz fragments; pH8.3.

4.4.4 *Moplain* layer class

4.4.4 *Moplain* layer class

Most of the 35 profiles which contained *Moplain* layers were mainly associated with outcrops of basaltic parent material at 'Bald Hill', 'Oakvale' and 'Green Timbers' and with the underlying basalt at 'Moplain' on the eastern margin of the surveyed area, (Figure 13). Generally found at successive depths within the same profiles although not characteristically found at the ground surface (Table 12), these layers dominated profiles ed059, 101, 130 and 156 which form the nucleus for a readily identifiable soil profile class. Apart from these outliers, the expression of basalt on soil development in the area is minimal, hence the small number of recognised layers (69) within this the fourth smallest class.

Table 12. (near here)

Table 13. (near here)

Figure 13. (near here)

Due to the basaltic nature of the parent material, these layers are quite fertile medium to heavy clays, high in the exchangeable cations of calcium and magnesium with moderate levels of sodicity, which tends to be greater in those layers identified at depth. The layers are non-saline and are strongly alkaline due to the presence of large calcium carbonate nodules and also the slightly to moderately sodic levels, (Table 13). The very dark grey, black or yellowish brown layers have moderate amounts organic matter.

Morphologically, the *Moplain* exemplars were described as follows:

ed09804 (0.70-0.80) Very dark grey (10YR3/1) medium heavy clay; strong >100mm wedge structure breaking to moderate 10-20mm angular blocky structure; very strong; moderate slickensides, polished ped and smooth-ped fabric; 2-10% distinct medium grey (10YR6/1) calcareous msoft segregations; <2% 5-10mm cracks; <2% 0.075-1mm pores; few very fine roots; pH8.8; genetic boundary, clear, smooth;

§4. SOIL LAYER CLASSES

ed10105 (1.20-1.30) Yellowish brown (10YR5/4) medium heavy clay; 2-10% distinct fine dark grey (10YR4/1) organic stains; <2% prominent medium black (5YR2/1) flecks produced by faunal mixing; weak subangular blocky structure, weak slickensides, rough fracture; smooth-ped fabric; <2% medium calcareous soft segregations; pH8.5; stratigraphic boundary;

ed15604 (0.70-0.80) Very dark grey (10YR4/1); medium clay; weak 50-100mm lenticular structure, breaking to moderate 20-50mm angular blocky structure; very firm; weak slickensides, nodular fracture; smooth-ped and polished ped fabric; <2% prominent fine white (10YR8/2) calcareous soft segregations: <2% fine calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH9.0; genetic boundary;

ed08404 (0.30-0.40) Very dark grey (10YR3/1) medium heavy clay; <2% distinct fine light grey patches of sediment filling cracks; weak 50-100mm subangular blocky structure; rigid; rough fracture; smooth-ped and rough-ped fabric; <2% faint fine white (10YR8/2) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH8.5;

ed09803 (0.30-0.40) Very dark grey (10YR3/1) heavy clay; moderate; 50-100 mm lenticular structure, breaking to moderate 10-20mm angular blocky structure; moderately strong; weak slickensides; smooth-ped and polished ped fabric; <2% distinct fine grey (10YR5/1) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; <2% 2-6mm subangular quartz fragments; pH9.0;

ed06403 (0.30-0.40) Black (5YR2/1) medium heavy clay; moderate 20-50mm prismatic structure, breaking to moderate 5-10mm angular blocky structure; moderately strong; earthy fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; <2% 20-60mm rounded tabular ironstone plates; pH8.5.

4.4.5 Mayfield layer class

4.4.5 Mayfield layer class

The 140 *Mayfield* soil layers, of this the third largest layer class, were identified within 61 profiles none of which were from the SUIAWWRC. Generally these layers were found within the confines of the local drainageways, including Galathera Creek in the north, Spring and areas adjacent to Bobbiwaa Creek in the south, material at the head of Nundi Creek and an arm of Ten Mile Creek, with a large number also identified within the current Namoi River floodplain. A smaller number were also associated with lithosols on the footslopes of the Nandewar Range, with the layers of this class lying in contact with weathered basalt perhaps indicating the origin of these layers, (Figure 14).

Table 14. (near here)

Table 15. (near here)

Figure 14. (near here)

Two distinct profile classes are characterised by these layers the first is closely associated with the Namoi River and the Bobbiwaaa and Spring Creek floodplains where the profiles are dominated by these layers at all depths below the surface 0.10m. The second profile class is characterised by the presence of these layers at depths just below the surface to approximately 0.40m underling *Wewak* soil layers and overlying *Boolcarrol* soil layers. Generally, these layers were located near the surface, (Table 14).

Similar to *Bald Knob*, *Moplain* and *Nundi* layers in terms of clay content, *Mayfield* layers range between light medium and heavy clays. However these layers are characteristically siltier than any of the other layer classes recognised. Typically the layers are dark brown and very dark grey and have moderate levels of exchangeable cations, the exchange complex dominated by calcium and magnesium with little contribution from sodium, (Table 15). Typically slightly alkaline, some layers are slightly acidic with most also low in chloride levels and conductivity.

Morphologically, the *Mayfield* exemplars were described as follows:

ed17003 (0.30-0.40) Dark brown (7.5YR3/2) light medium clay; 2-10% distinct fine brown (7.5YR5/4) patches of sediment, filling cracks; <2% distinct medium black (10YR2/1) flecks produced by faunal mixing; moderate 20-50mm angular blocky structure; very firm; smooth-ped fabric; <2% 0.075-1mm pores; common very fine roots; pH8.5;

ed04402 (0.10-0.20) Dark brown (7.5YR3/2) medium heavy clay; strong 20-50mm subangular blocky structure; very strong; smooth-ped fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; <2% 2-6mm subangular quartz fragments; pH8.0;

ed10303 (0.30-0.40) Dark brown (7.5YR3/2) light medium clay; moderate 10-20mm angular blocky structure, breaking to moderate 2-5mm granular structure; moderately strong; smooth-ped fabric; 2-5% 5-10mm cracks; <2% 0.075mm-1mm pores; few very fine roots; pH8.0;

ed17903 (0.30-0.40) Very dark grey (10YR3/1) medium clay; weak 50-100mm prismatic structure, breaking to moderate 20-50mm angular blocky structure; very firm; smooth ped fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH8.0;

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ed19903 (0.30-0.40) *Very dark grey (10YR3/1) medium clay; moderate 10-20mm polyhedral structure; moderately strong; smooth-ped fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH7.8;*

ed11404 (0.70-0.80) *Very dark grey (10YR3/1) medium clay; moderate 20-50mm wedge structure, breaking to 10-20mm angular blocky structure; very strong; weak slickensides, polished ped and smooth-ped fabric; <2% faint fine very pale brown (10YR7/3) calcareous nodules; 2-5% <5mm cracks; <2% 0.075-1mm pores; common very fine roots; pH8.5.*

4.4.6 *Nundi* layer class

4.4.6 *Nundi* layer class

Nundi layers are commonly associated with many of the local drainage ways of the area including Bulldog, *Nundi*, Curramunga, Galathera, Bobbiwaa and Spring Creeks on the footslopes of the Nandewar Ranges, (Figure 15). Layers were also located within the floodplain and in isolated areas on the alluvial terraces of the Namoi River with many layers also present within the SUIAWWRC. The second largest class containing 194 layers, most were located below 0.30m generally associated with the B horizon of the profiles in which they were identified, (Table 16). Those near or at the surface were present in profiles dominated by these layers at all depths, for example ed030, 046, 182 and 201 which form a readily recognisable profile class.

Table 16. (near here)

Table 17. (near here)

Figure 15. (near here)

Generally low in phosphorus and organic material, these dark brown light medium to heavy clay *Nundi* layers characteristically contain the largest amounts of calcium carbonate, partly accounting for the strongly to excessively alkaline nature of not only these layers but the profiles in which they are present, (Table 17). The high pH, mostly above 9.0, is mainly attributable to the large percentage of sodium found on the exchange complex, contributing as much as 30% in some layers, with an average of 15%. Further, magnesium and not calcium as in most of the other clay oriented layer classes is the dominant cation, which tends to indicate the possibility that these layers may be structurally unstable. Finally, small to

moderate chloride levels contribute to the slightly saline nature of many of these subsurface *Nundi* layers.

Morphologically the *Nundi* exemplars were described as follows:

ed04804 (0.70-0.80) *Dark reddish grey (5YR4/2); heavy clay; <2% distinct medium dark brown (7.5YR4/2) patches of soil, filling cracks; moderate 10-20mm subangular blocky structure; moderately firm; smooth-ped fabric; <2% distinct medium light grey (10YR7/2) calcareous soft segregations; <2% <5mm cracks; <2% 0.075-1mm pores; pH9.0;*

ed20103 (0.30-0.40) *Very dark grey (10YR3/1) medium heavy clay; 2-10% distinct fine light brownish grey (10YR6/3) patches of sediment, filling cracks; moderate 20-50mm lenticular structure to breaking to moderate 5-10mm angular blocky structure; very firm; smooth-ped and polished ped fabric; <2% distinct fine very pale brown (10YR8/4) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH8.8;*

ed03104 (2.50-2.60) *Dark brown (7.5YR3/2) medium clay; weak 50-100mm angular blocky structure; moderately strong; nodular fracture; smooth-ped fabric; <2% distinct medium pale brown (10YR8/3) calcareous soft segregations; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH9.5;*

ed04705 (1.20-1.30) *Dark brown (7.5YR4/4) medium clay; 10-20% faint coarse very dark greyish brown (10YR3/2) patches of soil, filling cracks; weak 10-20mm subangular blocky structure; moderately firm; smooth-ped fabric; <2% distinct very pale brown (10YR8/3) calcareous nodules; <2% <5mm cracks; 2-5% 0.075-1mm pores; pH9.0;*

ed13308 (3.50-3.60) *Brown (10YR4/3) light medium clay; weak 50-100mm wedge structure, breaking to weak 10-20mm angular blocky structure; moderately strong; weak slickensides; nodular fracture; smooth-ped fabric; <2% prominent coarse light brown (7.5YR6/4) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; pH9.0;*

ed17405 (1.20-1.30) *Dark reddish brown (5YR3/3) light medium clay; <2% distinct medium dark brown (7.5YR3/2) flecks produced by faunal mixing; strong 20-50mm wedge structure, breaking to moderate 2-5mm angular blocky structure; very firm; weak slickensides; smooth-ped fabric; <2% prominent coarse reddish brown (5YR5/3) calcareous nodules; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH9.0.*

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4.4.7 *Wewak* layer class

4.4.7 *Wewak* layer class

Wewak layers are predominantly associated with Galathera Creek which flows from the footslopes of the Nandewar Range in the east toward the Namoi River in the south-west before turning northward away from the River, (Figure 16). These layers are also associated in areas related to other local drainage ways, including the Tarlee, Bobbiwaa, Moonbill and Spring Creeks and their associated pediments. Some layers were also identified near and within the Namoi River floodplain. However, unlike the other soil layers associated with the local drainageways, these layers are lightly textured light to medium clays. Similar to the Boolcarrol soil layers which are found at particular depths within the profiles in which they were identified, the 114 *Wewak* soil layers are predominantly a surface phenomenon identified at depths no greater than 0.60m, with most located within 0.20m of the soil surface, (Table 18). Where they were identified at depth, the layers always underlied other *Wewak* layers.

Table 18. (near here)

Table 19. (near here)

Figure 16. (near here)

The presence within local drainage ways, on pedimented slopes, position at the ground surface and the generally sandy nature of these layers suggests that their origin is the sandstone at the foot of the Nandewar Ranges. Most of the soil derived from sandstone has not been utilised for agricultural production because these areas are particularly susceptible to sheet wash. However, some clearing for pastoral purposes has occurred, contributing sand to the pedimented slopes and the drainage ways mentioned above. Fine sand is also readily identifiable in many areas after heavy rainfall, and in many instances the surface soil layers had been washed away, and replaced by these layers.

The layers themselves are neutral containing moderate amounts of exchangeable cations, of which calcium and magnesium dominate, with only a small contribution from sodium, (Table 19). The layers are neither sodic nor saline and have negligible amounts of chloride. These layers have the largest recorded values of

organic carbon, the amount of organic material present on average is equivalent to 2.1% which under Australian conditions is considered to be a satisfactory amount. The soil is also quite rich in available phosphorus, the fourth highest level after *Moema*, *Togo*, and *Mayfield* soil layers.

Morphologically, the *Wewak* exemplars were described as follows:

ed07801 (0.00-0.05) *Very dark grey (10YR3/1) light clay; moderate 2-5mm granular structure; moderately strong; earthy fabric; 2-5% <5mm cracks; few very fine roots; pH7.5; plough sole;*

ed11501 (0.00-0.10) *Very dark grey (10YR3/1) light medium clay; moderate 20-50mm subangular blocky structure; very strong; rough-ped fabric; <2% 5-10mm cracks; <2% 2-5mm pores; common fine roots; <2% 2-6mm subrounded quartz fragments; pH6.8;*

ed13301 (0.00-0.10) *Dark reddish brown (5YR3/3) light medium clay; weak 10-20mm subangular blocky structure, with moderate 2-5mm granular structure; moderately firm; rough-ped fabric; 2-5% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH6.0; plough sole;*

ed07802 (0.05-0.10) *Very dark grey (10YR3/1) light clay; <2% faint fine dark grey 10YR4/1 patches of sediment, filing cracks; moderate 20-50,, angular blocky structure; moderately strong; earthy fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH7.5;*

ed09901 (0.00-0.10) *Very dark grey (10YR3/1) light clay; weak 20-50mm angular blocky structure; very strong; smooth fracture; rough ped fabric; 2-5% <5mm cracks; 2-5% 1-2mm pores; common very fine roots; pH6.5;*

ed04201 (0.00-0.06) *Dark greyish brown (10YR4/2) medium clay; moderate 5-10mm subangular blocky structure, with moderate 2-5mm angular blocky structure; moderately firm; earthy fabric;; 5-10% <5mm cracks; 2-5% 0.075-1mm pores; few very fine roots; pH6.5; plough sole,*

4.4.8 Noelurmalayer class	
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4.4.8 Noelurma layer class

Clayey sand and sandy clay layers dominate this essentially subsurface class, most identified below 1.20m, (Table 20). Generally located on the footslopes of the Nandewar Range and associated with Tertiary Weathered Sandstone, many layers were also located within the SUIAWWRC and identified at depth on the alluvial terraces and within the floodplain of the Namoi River, (Figure 17). One of the smaller groups recognised the 64 *Noelurma* soil layers along with the *Moema* and

§4. SOIL LAYER CLASSES

Couradda layer classes represent the lighter textured weakly structured soil layers within the area.

Table 20. (near here)

Table 21. (near here)

Figure 17. (near here)

Generally, underlying **Moema** layers the morphology and chemistry reflects the position these layers occupy well beneath the soil surface, (Table 21). Weakly structured and mostly apedal massive these layers contain little organic carbon, and have few roots or faunal activity within them. The moderately alkaline pH is usually attributable to their association with clayey layers which have high carbonate contents, with carbonate readily leaching through these sandy layers. The other source of the alkalinity may be due to the moderately sodic nature of these layers which also have low cation exchange capacities. Magnesium and not calcium is the dominant cation. **Noelurma** layers have characteristically low conductivities and contain few chlorides.

Morphologically, the **Noelurma** soil layer exemplars were described as follows:

ed16405 (1.20-1.30) Yellowish brown (10YR5/6); coarse sandy clay; 2-10% distinct medium dark greyish brown (10YR4/2) patches of soil, filling cracks; apedal massive; moderately weak; smooth fracture; earthy and sandy fabric; <2% fine manganese veins; pH8.5

ed16705 (1.20-1.30) Reddish brown (5YR4/4); light medium clay; 2-10% distinct medium dark grey (10YR4/1) patches of soil, filling cracks; weak 5-10 cast granular structure, apedal massive; moderately firm; smooth fracture; rough ped fabric; <2% 0.075-1.00mm pores; pH8.8; stratigraphic boundary, sharp, smooth.

ed10006 (2.50-2.60) Reddish yellow (7.5YR6/6) clayey sand; 2-10% prominent medium grey (N6/1) mottles; <2% faint fine reddish brown (5YR5/4) inherited stains; apedal massive; moderately strong; fabric; <2% <5mm cracks; pH8.0;

ed16006 (1.20-1.30) Dark brown (7.5YR4/4) sandy clay; apedal massive, with weak 10-20 subangular blocky structure; moderately firm; rough fracture; earthy and smooth-ped fabric; 10-20% distinct coarse very dark grey (N3/1) clayey veins; <2% 0.075-1mm pores; few very fine roots; pH8.5;

ed16406 (2.50-2.60) Brown (10YR5/3) sandy clay; 20-50% prominent very coarse yellowish (10YR5/1) inherited stains; weak 2-5mm biscuity structure; moderately weak; smooth fracture; earthy and sandy fabric; <2% medium manganese stains; <2% <5mm cracks; <2% 2-5mm pores; pH8.5;

ed17606 (2.50-2.60) Yellowish red (5YR5/6) sandy clay; <2% faint medium dark brown (7.5YR4/2) organic stains; weak 50-100mm sub-angular blocky structure; moderately weak; nodular fracture; earthy and sandy fabric; <2% medium organic laminae; <2% <5mm cracks; 2-5% 0.075-1mm pores; pH8.5;

4.4.9 Moema layer class

4.4.9 Moema layer class

Moema layers were generally located at the ground surface or within the A horizon of the profiles in which they were identified, (Table 22) although in profiles ed067 and 100 these loamy sand and sandy loam layers dominated to depths of at least 1.30m. Often associated with layers of the Noelurma class many were associated with the small exposure of Tertiary Weathered Sandstone on the footslope of the Nandewar Range to the east of the Pilliga sandstone and the State Forests, (Figure 18).

Table 22. (near here)

Table 23. (near here)

Figure 18. (near here)

Chemically, *Moema* layers have low cation exchange capacities, of which calcium and magnesium dominant, with only a small contribution from sodium, (Table 23). Low conductivities indicate few salts within these slightly acidic to neutral layers which have characteristically the largest amounts of phosphorus recognised within any class. Large amounts of organic carbon are also present with the potential for cropping limited by the light texture and weak structure of these layers.

Morphologically, the *Moema* soil layer exemplars were described as follows:

ed10001 (0.00-0.10) Dark brown (10YR3/3) sandy loam; weak 20-50mm subangular blocky structure, breaking to weak <2mm granular structure; moderately weak; granular fracture; earthy fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH7.5;

ed06702 (0.00-0.10) Dark brown (7.5YR3/2) sandy loam; <2% distinct fine yellowish red (5YR4/6) flecks produced by faunal mixing; apedal massive; moderately strong; granular fracture; earthy fabric; <2% 0.075-1mm pores; few very fine roots; pH6.2;

§4. SOIL LAYER CLASSES

ed10102 (0.10-0.20) *Dark brown (10YR3/3) clayey sand; weak 20-50mm subangular blocky structure, breaking to weak <2mm granular structure; moderately weak; granular fracture; earthy fabric; <2% <5mm cracks; <2% 1-2mm pores; few very fine roots; pH7.5;*

ed19401 (0.00-0.10) *Dark reddish brown (5YR3/4) loamy sand; apedal single grained structure, with weak 2-5mm granular structure; moderately weak; sandy fabric; <2% <5mm cracks; <2% 0.075-1mm pores; few very fine roots; pH6.5*

ed17301 (0.00-0.10) *Dark brown (7.5YR4/4) sandy loam; weak <2mm granular structure; sandy fabric; <2% <5mm cracks; <2% 0.075-1mm pores; common fine roots; pH6.5;*

ed19101 (0.00-0.10) *Reddish brown (5YR4/4) sandy clay; moderate 20-50mm subangular blocky structure; moderately firm; rough-ped fabric; <2% <5mm cracks; 2-5% 1-2mm pores; common very fine roots; <2% >60mm subangular tabular quartz fragments; pH6.5;*

4.4.10 *Couradda* layer class

4.4.10 *Couradda* layer class

A total of 24 lightly textured, predominantly loamy sand layers usually associated with the deeper A and B horizons of the profiles in which they were identified were classified within this the smallest class with the layers derived from Pilliga Sandstone, (Table 24). These *Couradda* layers were identified exclusively within the areas bounded by the Moeama, Couradda, Bobbiwaa and Killarney State Forests which lie on the footslopes of the Nandewar Range, (Figure 19).

Table 24. (near here)

Table 25. (near here)

Figure 19. (near here)

Characteristically the most acidic layers, *Couradda* layers have low base saturations and are often high in exchangeable aluminium, (Table 25). In many layers the dominant cation is magnesium with calcium almost completely leached. The exemplars of this class are all excessively sodic although the centroid indicates a class in which the layers are generally only moderately sodic. The soil is almost devoid of any phosphorus and contains very little organic material. Coupled with these poor chemical attributes the layers lie within poorly drained profiles which are also poorly structured and make these areas unfavourable for any agricultural land utilization.

Morphologically, the *Couradda* soil layer exemplars were described as follows:

ed08604 (0.50-0.60) Yellowish red (5YR4/6) sandy clay; 20-50% prominent very coarse light brownish grey (10YR6/2) mottles; moderate 50-100mm columnar structure, breaking to moderate 10-20mm angular blocky structure; very firm; smooth-ped fabric; <2% fine ferruginous nodules; <2% 5-10mm cracks; <2% 0.075-1mm pores; few very fine roots; pH6.5.

ed12005 (1.20-1.30) Reddish yellow (7.5YR6/8); loamy sand; 2-10% distinct medium white (10YR8/1) mottles; apedal massive; rigid; fabric; <2% <5mm cracks; <2% 0.075-1mm pores; pH6.5.

ed05205 (0.70-0.80) Yellowish red (5YR4/6) sandy light clay; 20-50% prominent coarse brown (7YR5/4) mottles; 2-10% prominent medium light brownish grey (10YR6/2) mottles; moderate >100mm prismatic structure, breaking to weak 20-50mm angular blocky structure; very strong; nodular fracture; rough-ped fabric; <2% medium ferruginous nodules; <2% 5-10mm cracks; 2-5% 0.075-1mm pores; few very fine roots; pH6.5.

ed12004 (0.70-0.80) Light yellowish brown (10YR6/4); loamy sand; 10-20% distinct medium light grey (10YR7/2) mottles; apedal single grained structure; very weak; granular fracture; sandy fabric; <2% fine to medium ferruginous nodules; <2% 5-10mm cracks; <2% 0.075-1mm pores; few very fine roots; pH5.8 abrupt change to

4.4.11 Extragradelayers

4.4.11 Extragrade layers

The extragrades are those individuals which are not adequately represented by any of the soil layer classes identified within our classification. The majority of these individual soil layers are located in the area bounded geologically by the Tertiary Weathered and the Pilliga Sandstone outcrops which occur along the eastern margin of the study area, on the footslopes of the Nandewar Range, (Figure 20). The 123 soil layers were not accounted for in any of the soil layer classes (including 15 from the SUIAWWRC) within a total of 54 soil profiles (including six from the SUIAWWRC). Many of these soil profiles including ed068, ed105, ed172 and ed190 had at least five extragrade soil layers, with the last three profile sites made up entirely of extragrade soil layers.

Table 26. (near here)

Table 27. (near here)

§4. SOIL LAYER CLASSES

Figure 20. (near here)

The extragrades were found to occur at a wide range of depths with no discernable pattern as evidenced with many of the regular soil layers, (Table 26). The number of extragrades which had a value of 1.0, totaled 16 soil layers including two from the SUIAWWRC. A small number of these extragrade soil layers are presented along with their chemical attributes. These exemple extragrade soil layers show a wide distribution of values, across the range of the attributes with no real similarity between any soil layer, except that the majority of tbe soil layers are relatively sandy.

The classification carried out to identify ten different soil layer classes, appears to have adequately accounted for the more popular clay type soil layers, but was unable to account for the large number of sandy type soil layers. However by the same token, these sandy soil layers appear to be very widely distributed in terms of all their chemical attributes. It may well be that these sandier soil layers then would remain unaccounted for even if a larger number of soil layer classes was chosen to classify these layers.



SOIL PROFILE CLASSES



5 SOIL PROFILE CLASSES

5.1 INTRODUCTION

In the previous section the mostly chemical and textural soil layer within the soil profile was introduced as the individual. The classification of these individual layers into ten soil layer classes along with the extragrades were then reassembled into their original profiles and classified into similar soil layer sequence profiles. Similar to a conventional soil profile class, fourteen profile classes were recognised, including an extragrade class for those profiles dominated by extragrade soil layers or which could not be allocated into any one of the recognised profile classes. Many extragrades were identified within the SUIAWWRC.

In the following section, these soil profile classes are discussed in terms of their chemical and morphological attributes, with an example profile selected that best represents the soil layer sequence common to these profiles. Morphological and chemical descriptions of that profile are also presented. The profile classes are named after a parish (eg **WAUGAN** and **COWIMANGHIAH**), a landholding (eg. **GREEN TIMBERS**), or a landmark (eg. **ROMA BORE**) were a small number of these profiles were identified. The figures illustrate the continuity of the profiles vertically as one layer class grades to another (eg Belar profile example), with their respective memberships summing to one at each layer depth.

The soil profile classes presented here are not entirely homogenous, nor are the boundaries between them, sharp. However, as opposed to previous attempts at classification the individual soil layers are very similar, chemically and also morphologically.

5.2 PROXIMAL DELINEATION

Soil boundaries which are used to delineate bordering and similar soil profiles have conventionally been delimited by pattern recognition. A significant factor in the quality of the soil map produced, is therefor the extent to which the surveyor has succeeded in the task of seperating groups of similar soil profiles from others in order to reduce the range of soil properties present within a delineated area, compared with the range over the area as a whole, (Marsman and De Gruijter, 1986).

There are at least two, distinctly different methods of delineating the continuum which include:

- a) field methods, in which the information derived from the soil observation points, plus information on the landscape is used;
- b) mathematical methods, in which a given algorithm computes the position of the soil boundaries solely on the basis of the data from the observation points (Marsman and De Gruijter, 1986).

Figure 21. (near here)

The profile class map, (Figure 22), which indicates the positions of the 14 recognised soil profile classes was generated using the mathematical method of proximal boundary delineation, illustrated in Figure 21. The principal of this method is to allocate each point in the survey area to the class of the nearest observation point that is that every location in a region is nearer to that regions point than any other point. To achieve this, each observation point is initially seperated from neighbouring observation points by the construction of mid-normals or perpendicular bisectors on the lines connecting the point with its neighbours. These perpendicular bisectors meet in threes or terminate at the edge of the boundary. This gives rise to a so-called Thiessen polygon or Dirichlet tessellation. This polygon surrounds all points that are closer to this observation point than to any other observation point, (Marsman and De Gruijter, 1986 and ARC/INFO, 1986).

Figure 22. (near here)

5.3 DESCRIPTION OF SOIL PROFILE CLASSES

In the following section the soil profile classes are described in alphabetical order, and have been named after landholdings, landmarks and parishes in which a large number of the profiles were identified. As mentioned in Section 4.4, the profile class names are in capitals and in bold text (e.g. **BELAR**, **BELBOWRIE**, **COWIMANGHIAH**, and so on...), to distinguish these soil names from the soil layer classes which are italicised and which are also in bold to delineate these names from the text, (e.g. *Togo*, *Boolcarrol*, *Bald Knob*, and so on...).

5.3.1 **BELAR** soil profile class

The parish of Belar which lies in the western third of the Edgeroi area is used to represent the largest number of soil profiles belonging to any profile class. In all 49 slow draining grey clays and slightly better drained brown clays were mostly identified west of Bald Hill Road and associated with Namoi River alluvial terraces, particularly the first, second, third and fourth terraces, with many also located on local alluvial fans. Characterised by *Togo* soil layers which form the A horizon and *Boolcarrol* soil layers forming the B horizon, (Figure 23), the large majority including ed091, the example soil profile were identified within the 'Boolcarrol', 'Togo' and 'Auscott' land holdings, with many also identified within the SUIAWWRC. Smaller numbers were also located north of Bulldog Creek, south of and adjacent to the Namoi River as well as lanholdings adjacent to the abovementioned.

In the northern areas the *Boolcarrol* layers were generally identified within 0.50m of the surface, underlying the A horizon *Togo* layers, while in the southern areas, near the Namoi River, the *Boolcarrol* layers preside at depths below 1.30m. Chemically, the profiles in the south are not as saline as the areas of this class in the north, however, the profiles are all excessively sodic at depth.

Figure 23. (near here)

Table 28. (near here)

Much of the land associated with these profiles has been extensively cleared for cultivation and grazing. Initially, utilised for wheat and pasture, irrigated

§5 SOIL PROFILE CLASSES

agriculture particularly that of cotton is now practised extensively on these fine self mulching profiles which contain adequate amounts of organic carbon and phosphorus. Calcium and magnesium are the dominant cations, within these fertile profiles with the strongly alkaline, very sodic and often saline nature of these profiles attributable to the presence of *Boolcarrol* layers which form the B horizon, (Table 28).

The **BELAR** soil profile class includes profiles ed001, 002, 003, 004, 005, 006, 009, 010, 011, 020, 021, 022, 023, 026, 038, 050, 054, 055, 056, 073, 074, 075, 089, 090, 092, 093, 107, 108, 109, 110, 124, 125, 127, 128, 141, 142, 144, 145, 146, 162, 163, 164, 167, 177, 196 and 197, with profiles na013, 016, 017 and 019 identified within the SUIAWWRC.

5.3.2 BELBOWRIE soil profile class

The homestead of 'Belbowrie' lies to the east of the Newell Highway and to the south of the township of Edgeroi and is used here to describe the profiles which are located on easy to gently sloping country, occupying positions adjacent to but further west of the **DOYLE** profile class on the footslope of the Nandewar Range. As with the **DOYLE** soil profiles much of the land has remained uncleared, due to the generally hard setting surface and sandy nature of the soil which has been left to support *Eucalyptus populneae*, *Callitris columellaris*, *Stipa scabra* and *Bassia quinquecupis*, as well as many other native species.

Figure 24. (near here)

Table 29. (near here)

Classified as either solodic, red brown earths, red earths, red and brown clays, or siliceous sands, the profiles are derived from residual Tertiary Sandstone (Ward, in prep) including ed033, 034, 051, 067, 068, 085, 100, 118, 173, 187, 191, 194, 207 and 210 all of which are characterised by *Moema* and *Noelurma* soil layers. Figure 24 illustrates the example profile (ed100) which is comprised of a *Moema* sandy loam surface layer which overlies *Moema* clayey sands and sandy light clays to a depth of 2.00m where a *Noelurma* clayey sand layer was identified. The large pH in some areas is due to the presence of carbonate nodules usually associated with the *Nundi* soil layers sometimes identified within these profiles. *Wewak* soil layers are

also commonly identified at the surface in profiles of this class associated near local drainage ways.

Chemically, the profiles are generally neutral at the surface grading to alkaline at depth with carbonate held up at the clay boundary. They are rich in phosphorus and in organic material, however, this is due to the virgin state of the soil and would be quickly lost if cultivated. Further, the nutrient status is quite low with few exchangeable cations at the surface, of which calcium and magnesium are dominant, (Table 29). The example profile is neither sodic nor saline, however, the majority of the other profiles within this class are excessively sodic at depth, with as much as 20% of the total exchange capacity contributed by sodium. The profiles are mostly non-saline with a small amounts of salt present within a couple of profiles.

5.3.3 COWIMANGHIAH soil profile class

The parish of Cowimangahiah located on the footslope of the Nandewar Range lies to the east of the Terry Hie Hie Road and is used here to represent brown clay and prairie soil profiles. These profiles are characterised by very rocky coarse to fine self mulching surface *Moema* layers which overlie *Togo* and *Moplain* soil layers, as illustrated by the example soil profile ed176, (Figure 25). *Bald Knob* layers are present in the subsoil at depths greater than 0.40m often in contact with weathering basaltic boulders. Profiles ed053, 140, 157, 175, 176, 208 and na011, na020 are included in this profile class.

Figure 25. (near here)

Table 30. (near here)

Many of the profiles were from uncleared areas utilized for native pasture which had many basaltic boulders commonly scattered on the surface which makes cultivation difficult but not uncommon. As a consequence, these uncleared near virgin sites contain large amounts of phosphorus with organic matter as much as 6% at the surface and consistently large to depth in some areas. Except for ed053 and 175 which are moderately and excessively sodic, respectively, at depths below 2.40m the profiles are generally non sodic and non saline, with small to moderately large amounts of exchangeable cations as illustrated by ed176, (Table 30). At the surface the soil is neutral with alkalinity increasing with depth.

5.3.4 CURRAMANGA soil profile class

Currumunga Creek has its origin within the adjoining map sheet to the east of Edgeroi, which when it joins the Edgeroi sheet flows past the homestead of 'Couradda' before crossing the Terry Hie Hie Road and around the northern outskirts and sometimes within the Moema State Forest. The **CURRAMANGA** profiles are located on low and high terraces almost in an adjacent parallel arc with Currumunga Creek, hence the name of this class, which includes profiles ed015, 016, 017, 032, 035, and 049. Profile ed150 identified near a tributary of Bobbiwaa Creek is also included in this class. The example profile ed032 illustrates the characteristic layer sequence of these well drained profiles, comprised basically of the subsoil, strongly alkaline, excessively sodic *Nundi* layers identified below 0.40m, which underly *Bald Knob* soil layers, (Figure 26).

Figure 26. (near here)

Table 31. (near here)

The soil profiles are uniformly textured medium to heavy brown clays which are moderately well structured with a fine self-mulching soil surface often cultivated with wheat and sorghum. The soil is fertile, with large levels of phosphorus and organic material as illustrated by the example soil profile ed032, (Table 31). Large amounts of exchangeable calcium and magnesium occur at the surface whilst at depth magnesium is tends to be the dominant cation. Further, as much as 32% of this exchange complex can be made up of exchangeable sodium, particularly at depths beyond 0.40m, except at ed017 and ed035 where the soil is non sodic. This may explain the generally weak wedged shape structure at depth within many of the profiles. Profiles ed015 and ed032, and ed049 were the only profiles in which slight to moderately large levels of salt were present respectively.

5.3.5 DOYLE soil profile class

The parish of Doyle located on the footslope of the Nandewar Range is used to describe shallow lithosol profiles which are generally either solodic soil types or siliceous sands. **DOYLE** soil profiles were identified within the confines of the 'Moema', 'Courrada', 'Bobbiwaa' and 'Killarney' State Forests, formed from *in situ* weathering of Pilliga Sandstone. These areas have remained uncleared and left to support a wide variety of native tree species, including *Callitris columellaris*, *Acacia deanei*, *Geijera parviflora*, *Aristida ramosa*, *Acacia concurrens*, *Eucalyptus blakelyi*, *Eucalyptus trachyphloia*, and *Cheilanthes tenuifolia* on easy to gently sloping country.

Figure 27. (near here)

Table 32. (near here)

The profiles identified as part of this class include ed052, 086, 102, 104, 120, 122, 137, 188, 189, 205 and 206, with no profiles identified within the SUIAWWRC. Profile ed086 is the example soil profile, the surface of which is a hard setting **Extragrade/Wewak** soil layer, (Figure 27). **Moema** layers also occupy surface positions within many of these profiles, which are characterised by the **Couradda** soil layers. Exclusive to these profiles, **Couradda** soil layers are generally found at all depths beyond 0.20m. At about 2.00m many of the layers come into contact with the underlying Pilliga Sandstone parent material. In the southern areas, however, within Killarney State Forest the profiles of this class are slightly deeper and better drained with the **Couradda** layers overlying **Noelurma** layers in profiles ed205 and 206.

Acidic in nature, as illustrated by the example soil profile ed086, (Table 32), the exchange complex is dominated by magnesium and sodium, particularly at depth with large amounts of aluminium also present. The exchangeable cation of calcium has almost been completely leached from the profiles with only minor traces of exchangeable potassium. Large levels of organic material are present at the soil surface, however, this is a consequence of the accumulation of such material under a eucalypt forest, which would be quickly depleted if the land was cleared. Coupled with the sandy nature, low fertility and generally poor structure of these profiles,

the soil once cleared is prone to erosion and is not suited to any type of agricultural land utilisation.

5.3.6 GREEN TIMBERS soil profile class

Profiles ed059, ed101 and ed130, are associated with the Basaltic outliers identified at 'Bald Hill', 'Oakvale' and 'Green Timbers' respectively and are characterised by *Moplain* soil layers. These layers often lie in contact with the underlying basalt including profiles ed059, ed130 and the example soil profile ed156 located at 'Moplain'. *Wewak* soil layers were identified characteristically at the surface of these profiles as illustrated by. Some profiles included in this class contained *Boolcarrol* soil layers at depths beyond 1.20m. The profiles within this class include ed060, 065, 081, 096, 097, 098, 099, 117,131 and 204, which are located generally in an areas at the foothill of the Nandewar Range, on flat to gently sloping country. None were identified within the USIAWWRC.

Figure GREEN TIMBERS. (near here)

Table GREEN TIMBERS. (near here)

The profiles consist of lightly textured soil surfaces of a fine to coarse self mulching nature, with some prone to weak surface crusts. Large amounts of organic carbon are also associated with the surface. Further, the profiles have large amounts of exchangeable cations with calcium and magnesium dominant, however, in many profiles below 0.70m, including the exemplar ed156, magnesium becomes the dominant cation. Further, at this depth many profiles are generally very sodic and have slightly to moderately large amounts of salt and chlorides present. As a consequence of the sodic nature of these profiles, the layers at these depths are strongly alkaline and generally weakly structured, often massive, prismatic or wedge shaped.

5.3.7 KEERA soil profile class

The parish of Keera lies to the north of the township of Edgeroi and is used here to describe grey and brown clays, and black earth profiles, including ed061, 063, 064, 078, 079, 080, 082, 083, 084, 095 and na010 which are characterised by the example profile ed062. Profile ed062 consists of a coarse self-mulching *Wewak* surface layer, usually to depths of 0.20m which overly a number of *Bald Knob* and/or *Nundi* layers to a depth of approximately 0.80m, below which rest *Boolcarrol* soil layers.

Figure KEERA. (near here)

Table KEERA. (near here)

Much of the land associated with these profiles has been cleared for cropping particularly for wheat and sorghum, although a small number of profiles lie within uncleared native pasture areas. The soil surface is generally of a fine to coarse self mulching nature, although in a number of areas a weak crust was evident, with large amounts of organic carbon and phosphorus present. The subsoil of these profiles are also excessively sodic and slightly to moderately saline at approximately 0.70m and below, characteristic of the *Boolcarrol* layers identified at these depths. The profiles are also characteristically strongly alkaline.

5.3.8 MANAMOI soil profile class

The 'Manamoi' homestead lies to the north of 'Oakvale' and to the west of the Couradda State Forest and is used here to represent alluvial soil profiles usually associated with the floodplains of the area. Profile ed066 which lies within the 'Manamoi' land holding contains many silty *Mayfield* soil layers which dominate and characterise most of the profiles at all depths, including ed159, 178, 198, 175 and the example profile ed186. However, *Nundi* soil layers are also present within many profiles, including ed066, which lies on a high terrace near Nundi Creek.

The largest number of **MANAMOI** profiles, was identified within the current floodplain of the Namoi River, including profiles ed159, 178, 179, 180, 181, 198, 199, and 200. Other profiles, were also identified within the local floodplains including ed134, 151 and 152 which lie on terraces of Bobbiwaa Creek and profiles ed155, 170,

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186, and 202 which lie within the floodplain or on terraces of Spring Creek. Profile ed103 located on a terrace near Grayvania Creek, at 'Myall Valley West' and ed018 located within the floodplain of Bulldog Creek are also members of this profile class. The example profile is ed186, (Figure Manamoi).

Figure MANAMOI. (near here)

Table MANAMOI. (near here)

The surface layers of these profiles are generally a coarse to fine self-mulching light medium clay, often *Wewak* soil layers, with weak surface crusts evident in some profiles. The profiles, are of an alluvial nature, mostly very dark greyish brown with uniform texture and receive much new material and show little sign of separation into distinct layers, although depositional bands are evident (Ward, in prep). The soil is non sodic nor saline within the Namoi River floodplain except ed200 which is moderately sodic at 2.50m, while the profiles associated with the local drainageways are often sodic and slightly saline at depths beyond 1.20m.

The majority of the profiles particularly within the Namoi River floodplain are periodically susceptible to flooding and/or water ponding, due to the generally low lying nature of the land, with floodwater levels on trees within the Namoi floodplain, as high as 3m. These areas have remained heavily timbered, the extent of agriculture limited to native pasture. In those areas which have been cleared, protection is afforded by the use of levee banks with the principal land uses including irrigated cotton, wheat, cattle and sheep pastures. The areas not associated with the Namoi floodplain are utilised for a wide variety of agricultural practises including native pastures, with the cropping of wheat, sorghum, and sunflower also protected in many areas by floodways.

5.3.9 ROMA BORE soil profile class

Roma Bore which lies within the 'Boolcarrol' land holding is used to represent soil profiles which have the soil layer sequence characterised by the example profile ed019, (Figure ROMA BORE). Generally, *Togo* but also *Wewak* soil layers are found at the soil surface which overly *Moplain* and in ed036 *Noelurma* soil layers to depths of 0.40m. The calcium carbonate rich strongly sodic and alkaline *Nundi* soil layers occupy the layers of these profiles beyond 0.70m. The profiles were

generally located on flat country in small pockets throughout the study area mainly located on the periphery of the **BELAR** profiles including profile ed036 located south-west of Roma Bore, profiles ed143 and 163, north-west of the 'Myall Vale Research Station' and profiles ed166 and 183 at 'Midgee' and 'Blue Hills' north of the Wee Waa Road. Profiles ed174 and 209 were also identified to the west of the Terry Hie Hie Road on the footslopes of the Nandewar Range.

Figure ROMA BORE. (near here)

Table ROMA BORE. (near here)

The profiles identified on the alluvial terraces are generally uniformly textured medium to heavy grey clays whereas the profiles located on the footslopes of the Nandewar Range are slightly better drained, ed174 a brown clay and ed209 a shallow black earth. The profiles although containing large amounts of exchangeable cations are generally quite sodic at depth and also quite alkaline, particularly those located on the alluvial plain indicative of *Nundi* soil layers. Further, small to moderate levels of salt and chlorides were also recorded at depths usually beyond 0.80m at most sites, although salt and sodium levels experienced at ed209, the lithosolic Black Earth, were small.

The soil surface of these profiles are often weakly crusted and trampled in the uncultivated pasture areas, with coarse and fine self mulching surfaces associated generally with the areas cultivated for wheat and sorghum. Most sites are high in organic material usually above 2% at the surface, particularly in the uncultivated areas, with small levels of phosphorus recorded in all profiles.

5.3.10 WAUGAN soil profile class

The parish name of Waugan, which lies to the north of the parish of Gommel and east of Bald Hill Road, is used to describe slow draining grey clay profiles, (Ward, in prep), located on low lying flat areas of the landscape, associated with the alluvial fan of Galathera Creek that envelopes Bald Hill from the north, south and the west. The profiles of this class include ed007, 008, 024, 025, 027, 028, 037, 039, 040, 041, 042, 043, 044, 045, 057, 058, 076, 077, 094, 111, 112, 113, 114, 129, 147, and 165, where ed008 is the example soil profile, (Figure WAUGAN).

Figure WAUGAN (near here)

Table WAUGAN (near here)

The profiles as characterised by ed008 consist of lightly textured neutral, non-sodic, non-saline *Wewak* soil layers which have a tendency to form weak surface seals, that overly dark greyish brown weak to strongly structured medium heavy clay *Mayfield* soil layers which make up the A horizon of these profiles. As with the **BELAR** profiles, the B horizon of those profiles located in the north are found closer to the surface than those located in the south and are dominated by dark brown very sodic and often saline light medium clay *Boolcarrol* soil layers. Hence, the profiles in the south have deeper A horizons, in which *Mayfield* layers can extend to depths of 1.20m, similar to the **MANAMOI** class, before the subsoil *Boolcarrol* layer is identified.

The saline nature of many of the soil profiles including the example profile which is excessively so, is attributable to the presence of large quantities of chloride and although the exchange capacity is large, much of this at depth is accounted for by exchangeable sodium. The sodic, slightly saline and surface sealing properties of many of these profiles limit the potential for extensive cropping with agricultural land utilisation limited to pasture. Most profiles are moderately to strongly alkaline as a consequence of the large amounts of sodium present. Calcium carbonate contents are also quite large.

5.3.11 WOODLANDS soil profile class

Shallow and stony basaltic clay loam and medium clay soil profiles, found on the eastern margin of the map sheet, generally occupying easy sloping and gently undulating positions on pedimented footslopes of the Nandewar Ranges are located on a number of landholdings including 'Woodlands' and 'Montana'. Classified as well draining brown clays, eg ed087, 088, 123, 192 and 193, with ed070 a prairie soil, these profiles often come into contact with the underlying pulverised basalt which lies within 1.5m of the surface. The soil surface is also littered with detached basaltic boulders.

Figure WOODLANDS. (near here)

Table WOODLANDS. (near here)

Many of the profiles were from areas which have remained uncleared commonly supporting *Elaeodendron australe*, *Eucalyptus albens*, *Eucalyptus sp.*, *Stipa scabra*, *Stipa setacea*, *Notoleae microcarpa*, and *Acaccia sp.*, with the extent of agriculture land utilisation limited to native pasture. On the longer flatter slopes of 'Monatana' sorghum, wheat and lucerne are grown, protected from runoff by extensive contouring, with surface rocks avoided during cultivation.

The **WOODLANDS** profiles are characterised by ed193, (Figure WOODLANDS), and are predominantly made up of *Moema* and *Mayfield* soil layers which are of a coarse self mulching nature. Weak crusts are evident in some profiles. At depths beyond 0.30m and approaching the basalt parent material silty *Mayfield* soil layers are present. These layers, are those within the profile which come into contact with underling pulverised basalt previously identified as those of the Nandewar Volcanics. This tends to suggest that the current material deposited by the Namoi River and by the local drainage ways in which this layer class is recognised throughout the area, originates from these areas overlying this type of basalt, as distinct from the basalt outcrops located at 'Bald Hill', 'Green Timbers' and 'Oakvale' and underlying basalt at 'Moplain'.

Chemically, the soil is neutral to slightly alkaline, the profiles neither sodic nor saline. Calcium and magnesium are the dominant cations of this fertile soil, which at the surface has also large amounts of organic carbon and phosphorus which make these soil profiles well suited for cropping, with shallow depths and steep slopes limiting the potential of many areas in which these profiles were identified, however.

5.3.12 WOOLANGABBA soil profile class

The 'Woolangabba' land holding lies to the east of Wee Waa Road and to the west of Bald Hill Road near the Namoi River. The name is used to represent uniform brown clay profiles located on flat to gently sloping and undulating country identified in a number of areas, often associated with past and present local drainage ways in which many profiles are susceptible to minor flooding. A large number, were identified in the north, to the west of the Newell Highway and associated with Boggy, Bulldog and Ten Mile Creeks including ed012, 013, 014, 029, 030, 031, 046,

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047, 048. Profiles ed115, 116, 132, 148, 149, 168, 169, 182, 184, 185 and ed201 which lies within 'Woolangabba' were identified in the south, generally to the west of the Newell Highway. Profiles ed071, 072 and 106 which lie to the north of the Rowena Road on the alluvial terraces of the Namoi River and to the west of the adjacent **BELAR** profiles were also included. Profile na021 was the only profile identified within the SUIAWWRC.

Figure WOOLANGABBA . (near here)

Table WOOLANGABBA . (near here)

WOOLANGABBA profiles are light to medium heavy clays, characterised by ed072, 182, 201 and the example profile ed046 which are dominated by the calcium carbonate rich, excessively sodic and strongly alkaline *Nundi* soil layers. *Wewak* soil layers are often found at the ground surface of these generally fine self-mulching profiles, which are cultivated primarily for wheat. Sorghum and sunflower are the other major cropped species with irrigated cotton practiced on those profiles identified to the west of **BELAR** profiles. Dominated by calcium and magnesium cations at the surface, the profiles become excessively sodic and alkaline with magnesium the dominant cation at depths below 0.70m. Further, large amounts of salt were present at below this depth.

5.3.13 YERI soil profile class

Grey, brown and alluvial clays as well as solodic soil profiles most located south of the Edgeroi township on pedimented slopes associated with the catchments of Bobbiwaa and Spring Creeks, form the **YERI** class. Many profiles within the SUIAWWRC, as well as two profiles located on opposite banks of the Namoi River floodplain were also recognised. The extent of agriculture in these areas has been limited to native forest and pasture species for sheep and cattle grazing on flat to gently undulating country which support native stands of *Geijera parviflora*, *Eucalyptus populnea*, *Enteropogon acicularis*, *Stipa setacea*, *Bassia quinquecupis*, *Eucalyptus camaldulensis*, *Callitris columellaris* and *Casuarina sp.*

Figure YERI. (near here)

Table YERI. (near here)

Profiles ed119, 133, 135, 138, 139, 153, 160, 171, 195, 203, na014, na015, na025. The class is characterised by ed136, (Figure YERI), which consists of a surface hardsetting *Wewak* layer which overlies subsurface Noelurma layers. Where the parent material is derived from alluvial sediments of mixed textured non calcareous sandstone with lime the calcium carbinate rich, alkaline *Nundi* layers were also present. Accordingly, the profiles have alkaline reaction trends and are excessively sodic and moderately saline. The soil is relatively infertile, with low exchange capacities of which magnesium and calcium are the dominant cations. Organic, carbon and phosphorus levels are large, however this is directly attributable to the virgin state of the soil.

5.3.14 EXTRAGRADE soil profiles

As with the soil layer classes, individual profiles which did not appear to have membership to any of the recognised classes during the classification were placed into this class. The individuals included those profiles predominantly made up of extragrade soil layers, that is profiles ed105, 121, 154, 172 and 190. Many other profiles may also have been selected for this class, however an effort was made to place each of the profiles with many different sequential soil layers into a profile class. Of those which could not be placed many were from the SUIAWWRC which lies to the south of the Edgeroi map sheet including profiles na018, na022, na012, na023, na024, and na026.