DETERMINING SOIL PATTERNS IN SINGLETON TRAINING AREA NOT IDENTIFIED BY GEOLOGY AND CATENARY POSITION

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ABSTRACT

A prior soil survey of the Singleton Training Area identified and mapped significantly different categories of soils by stratifying sampling according to geological formation and catenary position. Geology was shown to be the prime determinant of soil properties with catenary position showing relatively minor effects. However, vegetation patterns indicated the existence of additional soil patterns not identified by the first study.

Sampling in this study was stratified according to three vegetation categories within one geological formation, old woodland, young woodland, and grassland. Samples were obtained for the catenary positions of levee, mid slope and crest. The presence of *Casuarina glauca* (swamp oak) was also recorded.

Soils were sampled in boreholes with field descriptions as recommended by Northcote (1979). Soil properties measured for the A1, A2 and B2 soil horizons were pH, field texture and Munsell colour. The thickness of the profile was also measured for the A1 and A2 horizons. Generalised linear modeling was used to statistically analyse relationships between vegetation categories, catenary position, and soil properties.

There were no significant differences in soil properties between areas of old and young regeneration, but B horizons under grasslands were finer textured than under the woodlands, the A1 horizon much thicker, and the A2 horizon more basic. Soils with coarse textured B horizons essentially never support grassland whereas there is a 26% probability of grassland occurring on a medium clay.

The probability of the occurrence of swamp oak (*Casuarina glauca*) was related to catenary position and pH of the A1 horizon. Swamp oak was essentially always present on levees, lower slopes and mid slopes and never present on upper slopes and crests. The A1 horizon under *Casuarina glauca* was always acid.

Soil colour descriptions analysed as a pseudo- continuous variable indicated a significant relationship between soil colour and geology, and lighter colours for coarse textured soils than light textured soils. This analysis confirmed current knowledge that the B horizon is generally darker than the A2 , and that the A2 horizon is darker on the upper slopes and crest than on the lower slopes and levees.

The discussion addresses interpretation of relationships between of patterns of soils and vegetation, the value of colour in analysing patterns in soils for environmental management, as well as the adequacy of mapping soils by reference to geological formations.

INTRODUCTION

A prior soil survey of the Singleton Training Area (STA), (Tunstall and Gourlay, a), identified and mapped significantly different categories of soils by stratifying sampling according to geological formation and catenary position. Most of the significant differences observed in soil properties were attributable to geology with catenary position having relatively minor effects. The study was significant in demonstrating the relative importance of geology and catenary position, and in providing statistical significance for the mapped soil categories, but the study contained limitations. The overall percent variance accounted for by the statistical analyses was low, and vegetation patterns indicated that additional soil patterns existed that were not attributable to geological formation or catenary position.

One geological formation (Pmm in Table 1, Appendix 1) covers about 40% of the northern part of STA. This entire area had previously been cleared for grazing but now contains extensive areas of tree regeneration. The regeneration includes a block of dense old regrowth woodland that could associated with a major reduction of armoured vehicle training in the 1950's, and more widespread young regrowth that could be associated with the removal of sheep grazing in 1970. This tree regeneration exhibits distinctive spatial patterns, some of which appeared to be related to hydrology, and some to prior paddock boundaries. However, some regeneration patterns appeared to be due to differences in soils that were unrelated to geology, topography or past land use.

The primary objective of this study was to demonstrate the existence of spatial patterns of soils that could not be determined by stratifying sampling according to geological formation and catenary position. Given apparent relationships between vegetation and soils, this was achieved by sampling according to vegetation and catenary position within the one geological formation.

A secondary objective was to demonstrate the usefulness of colour as a field description in soil survey. Soil colour is invariably measured during soil surveys and is commonly used in the description of soils. For example, colour is used to distinguish between the A1 and A2 horizons, and in some classifications is used to discriminate between soil types (eg. Northcote, 1979).

Colour as a physical property of soils has little effect on soil behaviour other than influence the gain or loss of radiant energy (Hausenbuiller, 1985). However, colour can be an indicator of local soil conditions, and spatial patterns of colour can be used as indicators for land use suitability. The crest or upper slope soils are usually well drained and usually display a reddish-brown colour related to the presence of non-hydrated ion oxides. The midslope positions are usually slower to drain because of water accessions from upslope, and the associated increase in the hydration of the irons produces a yellowish soil colour. The lower slopes and levees can have poor drainage, where this increases the hydration and produces greyish coloured soil (Gerrard, 1981).

The focus on colour arises because of its ease of observation and it being symptomatic of processes important in soil formation such as leaching, hydration and accumulation of organic matter. However, interpretation of the significance of colour is difficult because of the confounding between effects of parent material, leaching, hydration, and the accumulation of organic matter and ions. While some of this confounding can be avoided by restricting comparisons to within profiles, there is still considerable uncertainty as to the value of colour in soil description.

Much of the uncertainty as to the value of colour arises because colour has been used more descriptively than analytically. For example, soils may be described as red or brown where the dividing line between red and brown is artificial. Also, where colours are analysed as categories all differences are equivalent, and this limits the determination of relationships. As these limitations arise through analysis of colour as a category rather than a variable, this study investigated the value of representing colour as a pseudo-continuous variable.

METHODS

The study area, and the methods of soil sampling and description used in this study are described by Tunstall and Gourlay (a). The sampling for the initial study located three transects within each of 6 geological formations, with boreholes located at 5 catenary positions along each transect. Data collected in the initial study for the Pmn geological formation (Beckett, 1988) were used in this study, but were supplemented by additional data to provide the required stratification and replication.

Sampling for this study involved further measurement in the Pmm geological formation for the catenary positions of levee, mid slope and crest. Sampling was additionally stratified by age of regeneration to give 5 replicates for each catenary position in each of grassland, young eucalypt regeneration (approx 25 years) and old eucalypt regeneration (more than 40 years). An additional 46 sites were sampled to complement the 25 sites previously sampled. These data were further stratified for some analyses according to the presence of *Casuarina glauca* (swamp oak).

Soil properties measured for the initial phase were the A1, A2 and B2 soil horizons, pH, field texture and Munsell colour. The thickness of the profile was also measured for the A1 and A2 horizons. Soils were sampled in boreholes with field descriptions as recommended by Northcote (1979). Soil pH was determined using a meter on 1:5, soil:water suspensions. The soil properties measured for this phase of the study were the same, except that Munsell colour was not collected because at the time of sampling no simple procedure for statistically analysing colour had been developed.

Generalised linear modeling was used for statistical analysis with geology being treated as a factor and catenary position being treated as a variable.

The colour data collected for all sites in the initial soil survey (Tunstall and Gourlay, a) was converted to a pseudo-continuous variable for statistical analysis using the scheme in Table 2, Appendix 1. The Munsell scheme is a hue, intensity, saturation representation of colour where these variables are referred to as hue, value and chroma. Value is the intensity in grey scale, hue is the dominant spectral character, and chroma the degree of colour saturation.

The pseudo-continuous measure of colour derived here is given by the value, less the hue equivalent, less chroma x 10^{-1}. This colour conversion relates to equivalence between the colour categories used in the Northcote (1979) classification. The Northcote categorisation places most emphasis on the grey scale intensity and little on chroma. In the numerical conversion, dark soils or strong colours have low values while light coloured soils have high values.

RESULTS

The significant relationships between soil properties and age of tree regeneration are given in Table 1. There were no significant differences for soil properties between areas supporting young and old tree regeneration, but B horizons under grasslands were finer textured than under woodlands, the A1 horizon much thicker and the A2 horizon more basic. This is further illustrated in Table 2 as the probability of a site supporting grassland rather than woodland changes from 3% where the pH of the A2 is 4, to 94% at pH 8. Soils with coarse textured B horizons essentially never support grassland whereas there is a 26% probability of grassland occurring where the B horizon is a medium or heavy clay.

Table 1. Relationships between vegetation type and the texture of the B horizon and thickness of the A2 horizon within the Pmm geological formation.

Vegetation	Texture B	SE	Thickness A1	SE	n
Grassland	16.1	2.3	6.1	1.3	17
Young woodland	13.1	2.3	2.1	1.3	18
Old Woodland	12.1	3.1	1.3	1.7	10

Table 2 Probability of occurrence of grassland in relation to the pH of the A2 horizon, the texture of the B horizon, and the thickness of the A1 horizon.

pH A2	Probability of grassland	SE	Texture B-horizon	Probability of grassland	SE	Thickness A1, cm	Probability of grassland	SE
4	0.03	0.03	10	0	0.01	0	0.13	0.07
5	0.13	0.07	15	0.02	0.07	5	0.63	0.14
6	0.4	0.09	20	0.26	0.08	10	0.95	0.07
7	0.76	0.15						
8	0.94	0.08						

These results indicate relationships but do not separate cause from effect. It could be argued that the vegetation is changing the soil pH, and that grasses have a preference for heavy textured soils, but such causual relationships cannot be determined from the statistical analyses.

The probability of the occurrence of swamp oak (*Casuarina glauca*) was related to catenary position and the pH of the A1 horizon (Table 3). Where trees were present, swamp oak is essentially always present on levees, lower slopes and mid slopes, and always absent from upper slopes and crests. The A1 horizon was always acid under swamp oak on the Pmm geology.

Table 3 Probability of the occurrence of swamp oak (*Casuarina glauca*) in relation to catenary position and pH of the A1 horizon when adjusted for catenary position.

pH A1	Probability of Oak	SE	Catenary Position	Probability of Oak	SE	n
5	1	0.01	7	1	0	3
6	0.48	0.08	9	0.98	0.14	8
7	0	0	10	1	0.03	15
			11	0	0.09	4
			12	0.01	0.06	9

The analysis of colour indicates that the B horizon is darker than the A2 (Table 4). This result accords with expectations given that the A horizon is defined as a zone of leaching and the B horizon a zone of accumulation, but is significant in that the A2 and B horizons were discriminated in the field by texture and density rather than colour. The results in Table 6 also indicate that coarse textured soils are lighter coloured than light textured soils with this difference being evidenced in the A2 and B soil horizons.

Significant relationships between soil colour and geology are given in Table 5. Soils are darkest in geological formations 1 and 2 and lightest in the conglomerate formation 4-1. Relationships between the A2 and B horizons are generally similar with the B horizon always being darkest, and the differential between the A2 and B averaging 1.4 or 1.5. However, the colour differential in geological formation 5 is significantly lower at 1.

The significant relationships between catenary position and colour are given in Table 6. The A2 horizon is darker on the upper slopes and crest than on the mid and lower slopes and levees.

Table 4 Relationship between colour and the texture of the A2 and B horizons across all geological formations.

Texture	Colour A2	SE A2	Colour B	SE B
10	5.4	0.15	4.8	0.41
15	4.8	0.1	4.2	0.21
20	4.2	0.24	3.5	0.11

Table 5 Relationship between geology and colour of the A2 and B horizons.

Geology	Colour A2	SE	Colour B	SE	n
1	4.3	0.21	2.9	0.26	15
2	4.3	0.21	2.9	0.26	15
3	5.1	0.22	3.7	0.27	14
4	5.3	0.22	3.8	0.27	14
4.1	5.6	0.23	4.1	0.33	12
5	5.1	0.21	4.1	0.23	16

Table 6 Relationship between catenary position and colour of the A2 horizon across all geological formations.

Catenary Position	Colour, A2	SE	n
Levee	5.4	0.23	13
Lower Slope	5.3	0.18	19
Mid slope	5.1	0.19	18
Upper slope	4.4	0.19	18
Crest	4.7	0.19	19

DISCUSSION

The results demonstrate the existence of soil patterns that were not determined with a sampling strategy based on geological formation and topography, and that some of the variation in soil properties not associated with geological formations and catenary position is reflected in vegetation patterns. The soil map produced in the initial study (Tunstall and Gourlay, a) will therefore be limited for aspects of environmental management, such as revegetation, despite the mapped soil patterns being spatially detailed and statistically significant. This result has general applicability because the development and/or maintenance of vegetative cover are the most widespread objectives in land use and management.

Application of mapped information

The stratification according to geological formation and catenary position by Tunstall and Gourlay (a) represents a detailed implementation of the soil landscape mapping approach that allowed spatially explicit mapping of discrete soil categories rather than simply identifying soil types that could potentially be present. Another significant improvement was provided by the analysis of soil properties to determine the reliability of the mapped information. As the results provided much greater spatial resolution than with soil landscape mapping, and an improved assessment of reliability, the limitations for application in management identified here are significant.

The deficiencies in the results from the first study relate to stratification of sampling rather than the soil descriptions. The information provided by geological formations was inadequate for defining all patterns relevant to soil development and land management.

The benefits of the method relative to conventional soil landscape mapping of soil types are:

a. Higher spatial resolution.
b. Test of reliability.
c. Direct applicability of soil properties to land use and management.

The definition of soil properties associated with vegetation regeneration demonstrates the utility of the analytical methods in identifying patterns of soil properties relevant to management, but the stratification based on vegetation does not provide a generic method for mapping results. This limitation is addressed in the third phase of the study.

Interpretation of soil-vegetation interrelationships

The usefulness of statistical analyses of relationships between soil properties and vegetation characteristics is limited by the inability to separate cause and effect. For example, it is not clear why the A2 horizon was generally neutral or basic under grassland. The deduction of likely causes depends on the interpretation of differences in responses between the measured properties based on information from other sources.

It is likely reasonable to conclude that the deep A1 horizon in grasslands is caused by the abundance of grass as high levels of organic accumulation are a characteristic of grasslands. These high organic levels could be associated with the slow breakdown of grassland organic matter, and/or grassland humus having darker colours than woodland residues (Hausenbuiller, 1985) thereby making the A1 horizon more readily discernible.

The statistical analysis cannot test whether swamp oak prefers acid soils, or whether it makes them acid, but patterns for the pH of the B horizon suggest the latter. The lack of any effect on the pH of the B horizon indicates that the acidity of the A horizon under swamp oak is likely caused by the occurrence of that species.

It is clear through general observation that dense stands of swamp oak are associated with drainage lines and seepage areas, but the results indicate that swamp oak has an equal and high probability of being present on levees, lower slopes and mid slopes, albeit at different densities. The inference is that while swamp oak may be associated with leachates, saturated flow or waterlogging, the density of swamp oak in better-drained areas is suppressed by the occurrence of eucalypts.

This sampling of soils according to vegetation patterns demonstrates that eucalytpus species have established preferentially on coarser textured soils as there has been the opportunity for trees to establish across all soil types since 1950. Some tree regeneration has occurred on fine textured soils within the Pmm geological formation but this regrowth is limited compared with the regeneration on coarse textured soils. As the texture of the B horizon is unlikely to have been changed by vegetation within 40 years, this tree regeneration is likely to responding to patterns of soil texture. A program of revegetation of eucalyptus trees on the STA would achieve therefore best results on coarser textured soils.

Application of colour estimates

Results from the colour analyses are as would be expected, as with the B horizon being darker than the A2, and the lower catenary positions being lighter coloured than the upper slopes and crests. While such patterns would be expected, they and are not a consequence of the sampling procedure, and therefore do not arise through definition. The results therefore illustrate that soil colour can be reliably analysed to provide useful results.

The distribution of colour within profiles is influenced by patterns of leaching. The concept of principle profile form is based on the A1 horizon being a zone of accumulation of organic matter, the A2 a zone of leaching, and the B a zone of accumulation. This pattern is evidenced in Tables 6 and 7 where the colour of the A2 horizons are lighter than the B. However, the expected colour difference between the A1 and the A2 was not found to be statistically significant. This indicates that the sensitivity of the analysis was limited by the scheme used to convert the Munsell colour description to a pseudo-continuous variable.

Soil colour is affected by a number of factors, but the results demonstrate that separate effects can be evaluated with an appropriate sampling design with differences within and between profiles being separately identified. The results substantiate the value of colour in differentiating between soils, and hence for identifying patterns in the field. Colour has similar value to other soil properties in discriminating between soils when used in an appropriate analysis. Given its ease of measurement it can be useful in soil survey, and the numerical analysis of colour assists such application.

One result for colour was unforseen. Results from all phases of this study show that the colour of the A2 and B horizons provided better discrimination between soils than the colour of the A1. However, the difference in colour between the B and A1 horizons is more significant in the discrimination of radiometric patches than the difference between B and A2 (Tunstall et al., a). A similar pattern was observed in the first phase of this study for pH (Tunstall and Gourlay, a) where the pH of the A1 showed no significant differences related to geology but the pH of the A2 and B horizons did. However, the ratio of pH for the A1 and B horizons showed significant differences between geological formations whereas the ratio for the pH of the A2 and B did not. The reason for this result is unclear, but it appears that pH and colour are providing similar indications of effects that are likely related to soil chemistry.

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APPENDIX 1

Table 1. Number codes used for geology, soil texture and catenary position

Soil Texture

1	**Gravel**	coarse
2		medium
3		fine
4	**Sand**	coarse
5		fine
6		loamy
7		clayey
8	**Sandy Loam**	
9		fine
10		clay
11	**Loam**	fine sandy
12		
13		silty
14	**Clay Loam**	sandy
15		silty
16		
17	**Clay**	sandy
18		silty
18		light
20		medium
21		heavy

Catenary Position

2	Plain - impeded
3	Seepage zone
4	Non-incised drainage
5	Saddle
6	Incised drainage line
7	Levee
8	Plain - drained
9	Lower slope
10	Mid slope
11	Upper slope
12	Crest

Geological Formations

	Code	**Lithology**
1	Pmm	Siltstone, claystone
2	Pswc	Sandstone, siltstone
3	Pswv	Coal seams, siltstone, tuff
4	Pswj - 1	Sandstone, siltstone, tuff
4-1	Pswj - 2	Sandstone, claystone, conglomerate
5	Psw	Conglomerate, claystone

Table 2 Scheme used to convert Munsell colour codes to a pseudo continuous variable.

Level = Value - Hue Equivalent - Chroma x 10^{-1}

Weightings given to Munsell Hue

Munsell Hue	**Hue Equivalent**
7.5 R	1.8
10 R	1.6
2.5 YR	1.4
5 YR	1.2
7.5 YR	1
10 YR	0.8
2.5 Y	0.6
5 Y	0.4

Example

Munsell Colour	**Level**
7.5 R 3/3	0.9
10 R 5/3	3.1
2.5 YR 4/4	2.2
5 YR 5/3	3.5
7.5 YR 6/4	4.6
10 YR 7/3	5.9
2.5 Y 6/2	5.2
5 Y 7/3	6.3