EFFECTS OF NATIVE PLANT SPECIES AND SOIL TYPE ON SOIL NITROGEN MINERALISATION

Brian Tunstall
2005

Abstract

Field nitrogen mineralisation in brigalow and poplar box communities was the reverse expected from the relative levels of soil organic matter. This was investigated by examining mineralisation rates for disturbed soils in the laboratory where relative rates were the reverse of the field and effects of plant species were much greater than soil type. The results are discussed in relation to natural patterns of dark soils occurring alongside light coloured or red soils and the impacts of agriculture on soil carbon.

Introduction

Levels of soil organic carbon have declined with agriculture. Most of the decline is generally attributed to disturbance associated with ploughing, and for some soils the decline is manageable. However, around 75% of Australian cropping soils are identified as having organic levels less than 1.75% when 2% is regarded as the minimum desirable level.

The decline in soil organic matter reflects a loss of fertility where this has been compensated for by the addition of fertiliser. However, grazing and tree killing cause a decline in soil structure (Tunstall & Webb, 1981; Tunstall & Cunningham, 2005) and changes in soil structure are identified as the prime cause of dryland salinity (Jones, 200 a, b, 2001; Tunstall, 2001). This structural decline reduces yields as well as producing adverse environmental impacts and cannot be corrected using mineral fertilisers alone.

While the levels of soil organic matter have unquestionable generally declined with agriculture the causes are not always clear. This uncertainty partly arises because several factors are implicated but it also reflects limited understanding of how the natural systems functioned. Comparisons are usually between different managed states because of a lack of a natural reference system. The objective here was to identify the factors that naturally produce large differences in mineralisation rates in soils derived from common materials, and to evaluate their significance for dryland agriculture.

The observations reported were obtained at different times and were initiated following an apparently anomalous observation that nitrogen mineralisation was higher in a poplar box (*Eucalyptus populnea*) woodland than an adjacent system brigalow (*Acacia harpophylla*) system. Soil nitrogen levels are higher under brigalow than poplar box due to nitrogen fixation, and brigalow soils have high organic contents (Moore et al. 1967, Webb et al., 1981). Poplar box soils have low organic contents and eucalypts are not known to fix nitrogen.

The initial results presented here derive from a study by Tunstall & Walker (1975) that examined the effects of tree killing and grazing on soil water in poplar box and brigalow systems. That study was initiated to identify the cause of the rapid grass growth following tree killing in poplar box lands compared with the slow response on brigalow soils. Soil nitrogen mineralisation was measured along with water content but the nitrogen observations were not reported because one value prevented the effects of land use from being significant. However, nitrogen mineralisation was much higher for the poplar box soil than for brigalow.

A subsequent laboratory study reported here was conducted to examine this apparent anomaly of higher mineralisation in the poplar box soil. The study examined effects of plant species as well as soil type on soil nitrogen mineralisation. The results are interpreted in relation to observations of terra rossa and rendzina soils at Coonawarra in South Australia.

The terra rossa / rendzina and poplar box / brigalow soil comparisons are equivalent as in both situations the soils derive from the same materials but differ considerably in the accumulation of organic matter. This pattern of red soils (poplar box and terra rossa) occurring adjacent to dark soils (brigalow and groundwater rendzina) is common in semi-arid Australia. The dark soils typically occur in accession areas along drainage lines and the red soils on runoff areas upslope. The red indicates oxidation as well as prominent iron oxides. Dark or black colours are generally associated with an accumulation of organic matter.

Methods

Field nitrogen mineralisation

Site

The field data were obtained on the Wycanna property (lat. $28^0$50'S, long. $149^0$50'E) near Talwood in Southern Queensland as part of the study described by Tunstall and Walker (1975). That study investigated effects of tree killing and grazing on soil moisture in adjacent brigalow and poplar box systems. The previously unreported results relate to measurements of soil nitrogen mineralisation obtained following tree killing.

The brigalow soil is a grey self-mulching clay with a gradational texture profile (earth). Soil salt contents are appreciable. The soil in the poplar box system is duplex, with red clay loam around 20 cm deep overlying a mottled clay. Salt contents are generally low. Brigalow systems in the region tend to occur in low lying parts of the landscape and receive accession of water during periods of intense or prolonged rainfall. Poplar box generally occurs in runoff areas. Belah (*Casuarina cristata*) occurs around the interface between the brigalow and poplar box communities.

Measurements

Observations were obtained at fortnightly intervals for 18 weeks following the killing of trees by injection of herbicide in brigalow and poplar box woodlands. Replicate surface (10 cm) soil samples were obtained randomly across plots in the treated and undisturbed systems. The soil samples were obtained using a 5 cm diameter corer, with three cores being bulked for each sample. The nitrogen was extracted from 100 gm of soil with 200ml of two molar K_2SO_4, and the levels of NO_3- and NH_4+ determined using an auto-analyser.

Laboratory nitrogen mineralisation

Soil samples were obtained from the surface 10 cm of soil from under the canopies of different plant species in poplar box and brigalow systems when the surface soil had been dry for several weeks. The experimental design separately examined the effects of vegetation and soil type, but also allowed examination of soil/species interactions.

Soil effects

Soils were effectively identified by the dominance of plant species. Brigalow and poplar box communities in the region tend to have a monospecific tree layer and are associated with characteristic soils.

The plant communities are defined by the abundance of the dominant species but brigalow, poplar box, and belah can occur within each community. While either brigalow or poplar box usually dominates, isolated plants of the other two species can also occur. This allows soils sampling beneath each tree species within each of the communities. The effect of soil type was addressed by obtaining soil samples from under the tree species of brigalow, poplar box, and belah within brigalow and poplar box communities.

Plant species effects

More detailed information on the effect of species was obtained for the duplex soil associated with poplar box woodland. Soil samples were obtained from under the tree species poplar box, brigalow and belah, the shrubs false sandalwood (*Eremophila mitchellii*), *Acacia deneai, and Cassia nemophila,* and in cleared communities of grazed and ungrazed grassland.

The experimental design for soil and species effects provides a replicated block (2), with three replicates for each species within each block. One block was located in the area reported by Tunstall & Walker (1975) and the other was on the Fairymont property around 1km distant.

Each soil sample was sieved, mixed, and 100 gm placed in a cylindrical plastic container 60mm diameter by 50mm deep. Sufficient water was mixed with each sample to achieve approximately 30cm tension, the container sealed with plastic film and incubated at 25^{o}C. Replicate samples (2) were analysed at time zero and at 4 day intervals for 28 days to determine levels of nitrate and ammonia using the method described above.

The effects of soil type, plant species, and incubation time were determined using analysis of variance.

Coonawarra

The soil patterns in the Coonawarra region were mapped by classification of airborne gamma radiation data with field observations undertaken to determine the soil properties associated with those patterns.

The soil properties of depth, texture, pH, oxidation-reduction potential, electrical conductivity, and colour were measured for three red soil profiles on the Coonawarra ridge, and three red profiles at Wrattonbully around 10km to the north east. Samples were obtained at four depths in the profiles. General profile observations were made in a large pit at the northern end of the Coonawarra ridge (terra rossa), and in boreholes on the plain to the west of Coonawarra (groundwater rendzina soils).

Results

Field mineralisation

The field mineralised nitrogen (Fig. 1) average 2.7 ppm for the clay earth associated with the brigalow community, and 7.9 ppm for the duplex soil associated with poplar box. The duplex soil exhibits three times the level of mineralisation of the clay, and high fluctuations related to water availability. The levels of NH_4 are generally high (Fix. 2), and average around the same as for NO_3. The effects of tree killing were not statistically significant due to the variability resulting from occasional very high values for individual samples in undisturbed systems.

Growth of vegetation was not monitored during the six month experiment but grass growth was pronounced on the poplar box soil where trees were killed, and little growth occurred on any area of brigalow soil. The results suggest there may be an effect of killing trees on nitrogen mineralisation but any effect is small compared with the difference between soil types.

Laboratory mineralisation

The level of mineralised nitrogen increased over time with many samples appearing to have reached a maximum within 28 days (Fig. 3, Table 1). Samples with highest final levels of mineralised nitrogen show the highest initial rates of release. The levels of ammonia were generally less than 0.2 ppm except for the first sampling when they averaged 1.9 ppm.

The average and final mineralised nitrogen levels vary between species (Table 2). The species divide into three groups of high (acacias), medium (Casuarina/Eremophila/Grazed Grassland), and low (Cassia/Eucalypt/ungrazed grassland). Mineralisation in the low group is less than half that of the acacias.

Mineralisation for the clay earth was significantly higher than for the duplex soil but the average difference of 1ppm is much smaller than the average difference of 8 ppm between the eucalypt and acacias (Table 3). The vegetation/soil interactions were insignificant.

Table 1 Temporal patterns of nitrogen mineralisation (ppm) in laboratory incubated samples.

	Time **(days)**									
	0	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**SE**	**n**
NH4	1.93	0.20	0.13	0.01	0.06	0.12	0.06	0.14	0.074	32
NO3	3.15	9.25	10.11	11.66	12.21	13.82	17.75	16.45	0.931	32
Total N	5.07	9.44	10.24	11.67	12.27	13.95	17.82	16.60	0.916	32

Table 2 Vegetation effects on soil nitrogen mineralisation (ppm). Total N (1) represents the means across the 8 sampling times, Total N (2) represents the average of the last two samples.

	Vegetation									
	Acdea	**Achar**	**Cacri**	**Ermit**	**Gr_G**	**Canem**	**Eupop**	**Gr_Ug**	**SE**	**N**
NH4	0.42	0.30	0.33	0.50	0.30	0.28	0.25	0.28	0.518	32
NO3	16.70	15.86	13.32	12.460	12.14	8.57	7.96	7.39	0.581	32
Total N (1)	17.12	16.16	13.64	12.95	12.44	8.85	8.21	7.66	0.583	32
Total N (2)	22.90	23.60	20.30	18.50	17.30	12.20	12.80	10.60	1.650	7

Acdea = Acacia deneai, Achar = Acacia harpophylla, Cacri = Casuarina cristata, Erimt = Eremophila mitchellii, Gr_G = grazed grassland, Eupop = Eucalyptus populnea, Gr_Ug = ungrazed grassland.

Table 3 Soil effects on laboratory nitrogen mineralisation (ppm), and soil x vegetation interactions.

	Soil				
	Clay Earth	**Duplex**		**SE**	**N**
	12.66	13.66		0.041	96
Soil		**Vegetation**			
	A. harpophylla	**E. populnea**	**C. cristata**	**SE**	**N**
Clay Earth	12.11	13.30	12.58	0.973	32
Duplex	13.00	13.96	14.02		

Coonawarra

Origin of formations

The rendzina, terra rossa and podzolic[1] soils around Coonawarra derive from the same materials, and essentially represent a mix of clay, sand and limestone. The Coonawarra ridge represents the remnant of a series of lunettes developed on the eastern edge of a shallow ephemeral lake. The lake bed is now a plain with groundwater rendzina soils. The podzols to the east of the Coonawarra ridge have high sand content in the surface as aeolian deposits of clay and calcium have been eluviated through the profile.

Airborne gamma radiation data differentiate these soils through the thorium and potassium associated with the clay. The sand and limestone have low emissions. The high thorium level compared with the total radiometric emission indicates a marine origin for the clay. Potassium levels are high in young clays and decline with weathering and leaching.

Soils where the clay has been leached through the profile have low radiometric emissions. Emission levels are moderate for the terra rossa soils and highest for the rendzina soils. The terra rossa and rendzina soils are further discriminated by the relative levels of potassium. These are lower in the terra rossa soils indicating higher a level of leaching than in the rendzina soil given that the clay in both soils has the same origins. The distributions of these materials relative to the Coonawarra ridge are illustrated in Fig. 4.

Soil properties and native vegetation

Properties for three profiles of red soils at Coonawarra (Table 4) indicate a gradational texture profile of red clay. The soil is underlain by limestone but the calcareous material at the base of the profile is nodular or powdery.

A profile for a terra rossa soil (Fig. 5) illustrates the occurrence of lenses of clay between layers of powdery/nodular lime, and pipes in the limestone associated with leaching. Lateritic nodules can occur in the B horizon. The profiles are not uniform and exhibit profile differentiation in texture that is not necessarily gradational. The terra rossa profiles are typically more than 30 cm deep.

The rendzina soils to the west of the Coonawarra ridge have a uniform black clay profiles less than 20 cm deep. Limestone nodules occur on the surface and throughout the profile. The shallow soil is underlain by limestone and becomes waterlogged during winter.

The native vegetation has been cleared from the Coonawarra ridge but equivalent soils nearby support open eucalypt shrub woodland (woody vegetation) with scattered grass tussocks. The native vegetation on the rendzina soil is grassland.

Discussion

The laboratory results identify large variation in the potential for nitrogen mineralisation related to vegetation and small differences associated with soil type. Mineralisation rates and levels appear commensurate with levels of soil organic matter. This contrasts with the field observations with large differences related to soil type but with mineralisation inversely related to levels of soil organic matter.

[1] Described by Laut et al respectively as (a) red, non-cracking, coherent sub-plastic clays, (b) black self-mulching cracking clay, and (c) mottled, sandy, pedal, duplex soils.

Nitrogen mineralisation is low in undisturbed brigalow soils but high when the soil is disturbed by the sampling for the laboratory studies. Nitrogen mineralisation is high in poplar box soils but, compared with the brigalow soil, is little affected by disturbance.

Stace (1956) determined that the only significant difference between physical and chemical properties of the terra rossa and rendzina soils related to the ratio of organic matter to free iron oxides. Terra rossa soils are oxidised, and hence well aerated. Rendzina soils are hydrated through being seasonally waterlogged. The level of aeration appears to have a pronounced effect on the nitrogen mineralisation, and hence on the accumulation of organic matter. The main difference between the soils derives from hydration/oxidation producing differences in the accumulation of organic matter.

The rate of carbon breakdown can depend on the carbon nitrogen ratio as nitrogen levels in litter generally limit the rate of breakdown. High soil nitrogen due to microbial fixation can potentially increase the rate of breakdown of organic matter, but this high potential for breakdown is not realised in brigalow soils.

Breakdown rates can be affected by chemical characteristics of the organic matter apart from nitrogen content, and grasses are regarded as introducing more organic matter into soils than woody plants. This could help explain the difference in organic levels of rendzina and terra rossa soils, but not for brigalow and poplar box. Grass production is higher in poplar box than brigalow communities and grasses are essentially non-existent in many intact brigalow stands.

Low rates of nitrogen mineralisation in undisturbed brigalow soils appear to reflect soil factors other than the levels of nitrogen, carbon, temperature, or water. For rendzina soils, carbon accumulation appears to be strongly dependent on the inhibition of microbial activity by poor aeration. For the clay soil associated with brigalow, poor aeration can arise through the fine soil texture.

Woody vegetation competes best on well drained soils and hence tends to occur on coarser textured soils that often contain low levels of organic matter. Grasses tend only to dominate on heavy textured soils, and grasslands typically exhibit high levels of accumulation of soil organic matter (Tunstall, 2005).

The nitrogen requirements when cropping in the brigalow and poplar box soils are inversely related to the levels of organic matter and positively related to mineralisation rates. Within brigalow soils the nitrogen requirements with cropping are identified as being related to the rate of nitrogen release rather than the soil store (Graham et al., 1981).

The implications for land use relate to enhanced rates of nitrogen mineralisation, and hence the breakdown of soil organic matter with dryland agriculture. The enhancement can be due to:

- Disturbance, such as ploughing.
- Increased water availability due to reduced water use by vegetation.
- Increased soil temperatures due to increased exposure of the soil surface to radiation.

When combined with the reduced input of organic matter due to the degradation of the vegetation, the enhanced rate of breakdown would tend to reduce the levels of soil organic matter. As soil organic matter is a prime determinant of soil structure and the availability of nutrients for plant growth, its loss adversely affects agricultural production. The decline in soil structure is manifest as soil compaction, and is recorded as an increase in bulk density by Webb et al. (1977).

The potential rapidity of the structural decline is evident from experience on the Fairymont property. The depth of ploughing immediately following clearing of a poplar box woodland on a duplex soil was 30cm. The depth with the same implement was 5cm after 5 years of continuous cropping.

The implications are that the impact of land use depends strongly on soil type, and that management procedures are required to maintain levels of soil organic matter.

References

Moore, A. W., Russell, J. S. and Coaldrake, J. E. (Dry matter and nutrient content of a sub-tropical semiarid forest of *Acacia Harpophylla* F. Muell. (brigalow). Aust. J. Bot. 15:11,24

Stace, H. C. T. (1956). Chemical characteristics of terra rossas and rendzinas of South Australia. Journal of Soil Science 7:280-293

Jones, C. E. (2000). The great Australian salinity debate Part 1:Controlling the salinisation processes. Holistic Management Aust. Quarterly Newsletter, July 2000.

Jones, C. E. (2000). The great Australian salinity debate Part 2: why the recharge:discharge model is fundamentally flawed. Stipa Native Grasses Newsletter 14, 6-11

Jones, C. E. (2001). The great Australian salinity debate Part 3: Soil organic matter: past lessons for future learning. Stipa Native Grasses Newsletter 15, 4-9

Tunstall, B. R. (2001). Scenario for dryland salinity. *On* www.eric.com.au

Tunstall, B. R. (2005). Soil Factors Affecting the Competition between Trees and Grasses. *On* www.eric.com.au

Tunstall, B. R., and Walker, J. (1975). The effect of woodland disturbance on soil water. Proc. Ecol. Soc. of Australia Vol 9. Ed J. Kikkawa and H. A. Nix, Symposium Brisbane.

Tunstall, B. R. and Webb, A. A. (1981). Effects of land use on the solodic soils of the poplar box (*Eucalyptus populnea*) lands. Aust. Rangel. J. 3: 5, 11.

Graham, T. W. G., Webb, A. A and Waring, S. A. (1981) Soil nitrogen status and pasture productivity after clearing brigalow (Acacia harpophylla). Aust. J. Agric. Anim. Husb. 21:109,18

Webb, A. A., Crack, B. J. and Gill, J. Y. (1977). Studies on the galgaied clay soils (Ug5.2) of the Highworth Land System in eas-central Queensland. 1. Chemical characteristics. Qld. J. Agric. & Anim. Sci. 34:53-65

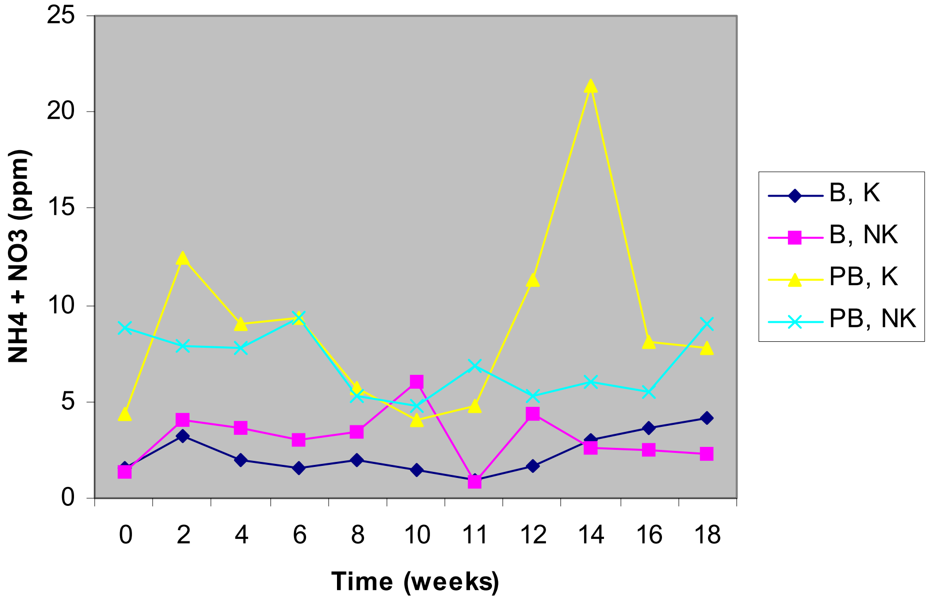

Fig. 1 Temporal pattern of nitrogen mineralisation (NO_3 + NH_4) in brigalow (B) and poplar box (PB) systems following killing of trees by injecting herbicide. K = trees killed, NK = trees not killed.

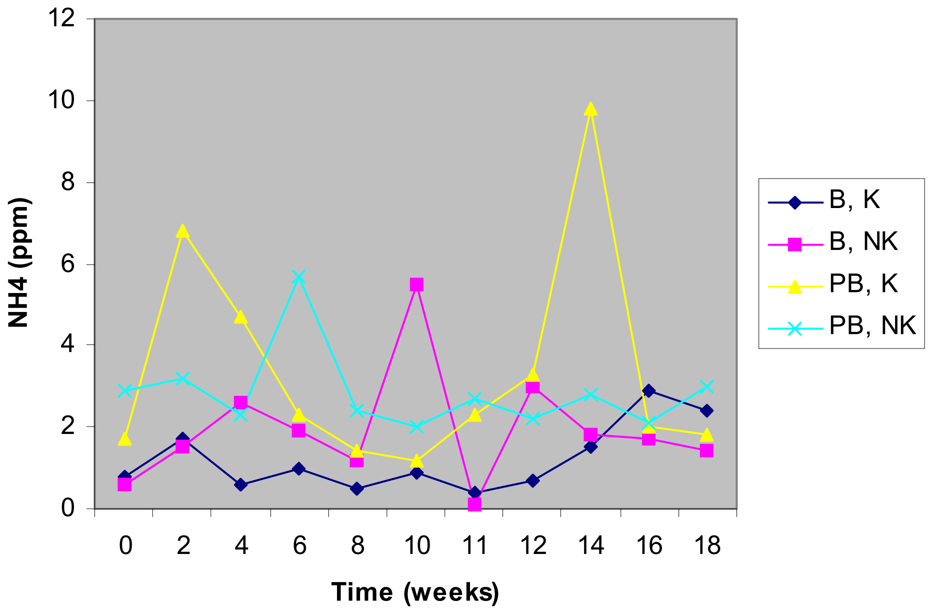

Fig. 2 Temporal pattern of ammonia (NH_4+) mineralisation in brigalow (B) and poplar box (PB) systems following killing of trees by injecting herbicide. K = trees killed, NK = trees not killed.

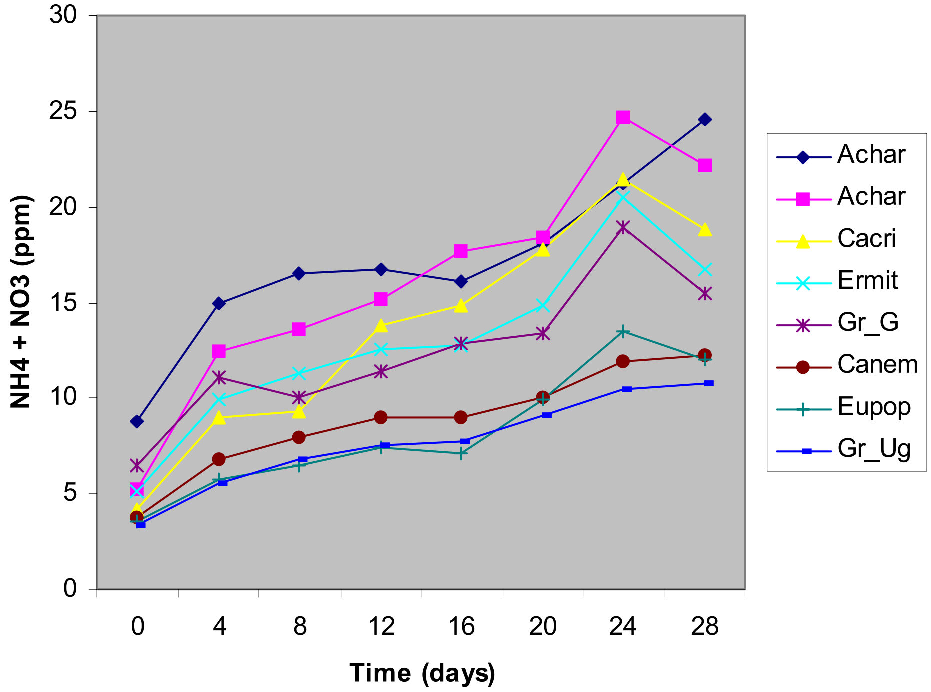

Fig. 3 Temporal pattern of nitrogen mineralisation ($NO_3 + NH_4$) in laboratory incubated soil samples obtained from under different species / vegetation types. Acdea = Acacia deneai, Achar = Acacia harpophylla, Cacri = Casuarina cristata, Erimt = Eremophila mitchellii, Gr_G = grazed grassland, Eupop = Eucalyptus populnea, Gr_Ug = ungrazed grassland.

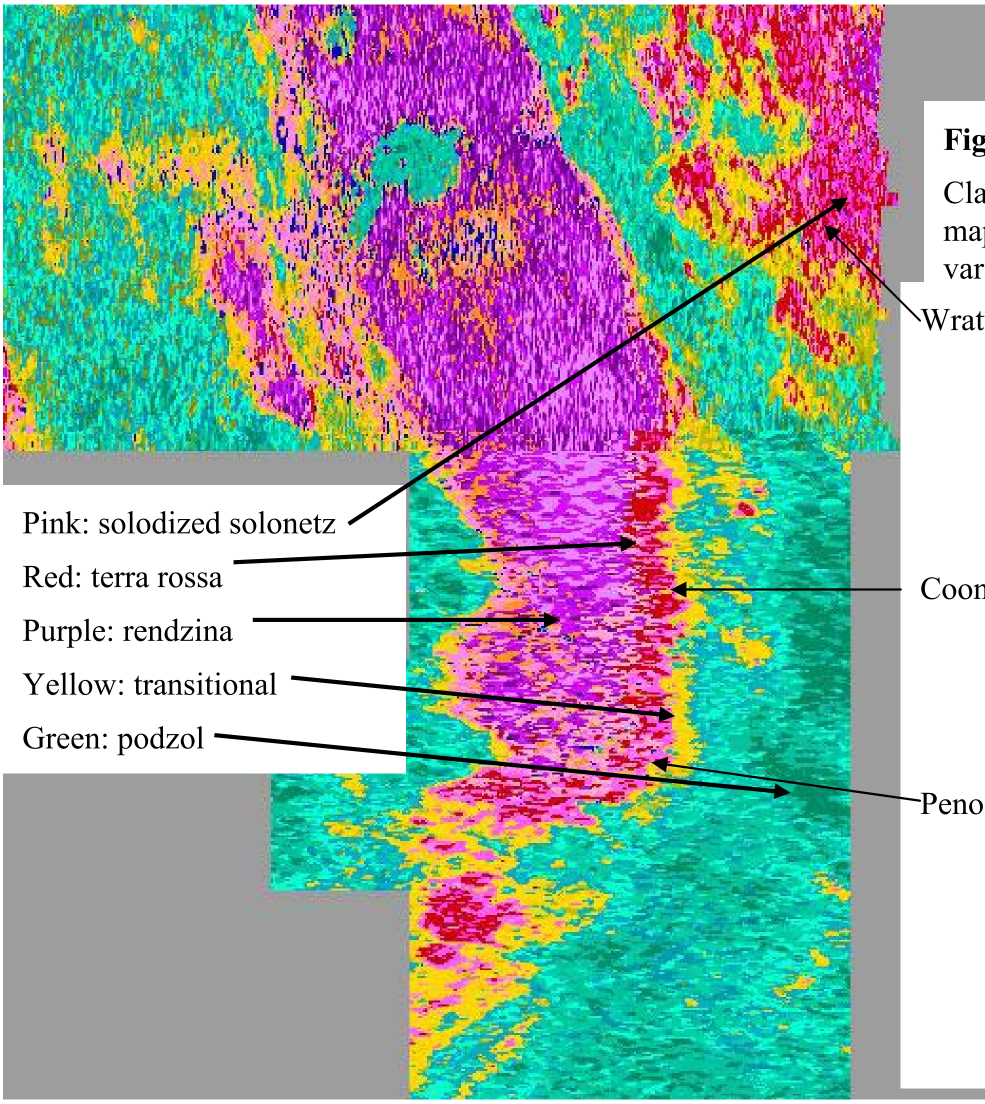

Fig. 4

Classified radiometrics mapping patterns of soil variation around:

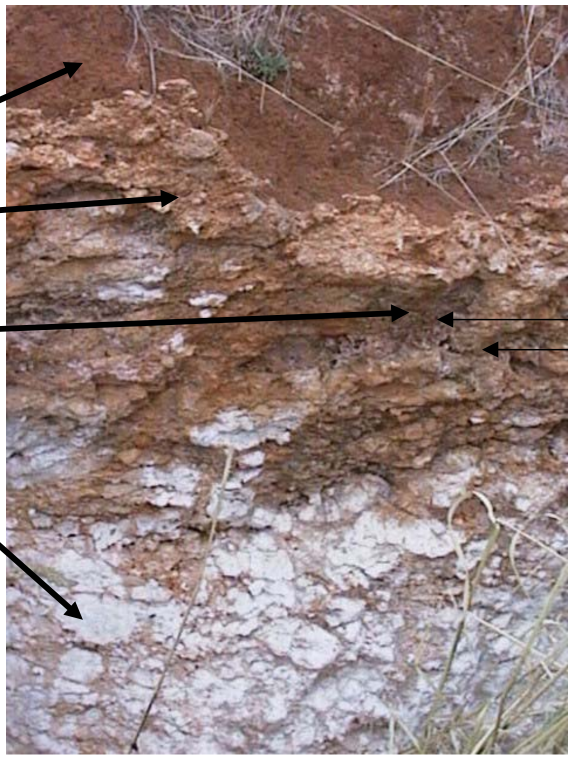

Fig. 5 Terra rossa profile from Coonawarra.