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Variation in soil properties on two partially revegetated saline scalds in south-eastern Australia

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Abstract. During 1999 and 2000, topsoil properties were sampled on a 3 by 3 m grid at 2 saline scalds on the inland slopes of New South Wales (NSW): Bocobra (0.11 ha) and Rugby (0.12 ha). Variability was examined in terms of range, standard deviation and coefficient of variation, maps with interpolated 'contours', and variograms. High variability was evident in all soil properties. $pH_{1:5\ water}$ ranged from 4.8 to 8.0 at Bocobra and 5.9 to 9.0 at Rugby. Spatial 'highs' were evident at both sites but Rugby, which was mostly neutral, had both highs (alkalinity) and lows (acidity). Electrical conductivity ($EC_{1:5\ water}$) ranged from 0.5 to 6.6 dS/m at Bocobra and 0.1 to 2.6 dS/m at Rugby and was expressed spatially as highs across the sites. Concentrations of soluble ions were highly variable with both highs and lows evident. Concentrations of sodium and magnesium at Bocobra were highly correlated with $EC_{1:5\ water}$. Variability in EC and pH were high in comparison with published data from much larger areas of non-saline soils. An indication of temporal variability was obtained by carrying out an electromagnetic induction survey on 2 occasions. Despite changes in spatial patterns over time, EM_h and EM_v values were highly correlated at 1 site but not at the other. Variogram analysis suggested that changes in some variables, e.g. soluble potassium, changed markedly over distances less than 3 m. For most variables, the full range of variability occurred over distances of 8–10 m, though for some, e.g. soluble calcium, a distance of around 19 m was indicated. Variability cannot be ignored when planning revegetation projects or experiments. Partly because of their temporal variability, electromagnetic induction survey results (which were not calibrated with soil profile ECs in this study) may not provide useful guidelines for strategic soil sampling nor for locating experimental plots on scalded saline sites. Consideration should also be given to testing variables other than EC, e.g. pH and calcium, which may also limit plant growth on saline scalds.

Introduction

Spatial variability in soil properties has been recognised for many years — initially by hole diggers and later by soil surveyors. For some, the major issue raised by variability is devising a sampling strategy or analysis tool to obtain a reliable 'average' of some soil property of interest. However, for others such as those involved in precision agriculture (e.g. Viscarra Rossel and McBratney 1998), it is appreciated in its own right and with modern equipment, can be addressed directly.

In soils affected by salinisation, it would be unreasonable to expect that variability would be any less than has been reported for non-saline areas, and perhaps because of the fluctuating nature of salinisation (e.g. Wagner 1987), it may be higher. In the case of a Spanish salt marsh examined by Álvarez-Rogel *et al*. (1997), a relatively uniform electrical conductivity (EC) gradient was present with EC_e ranging from 1.3 dS/m at one end of a 130 m transect to 139 dS/m at the other. Spatial variations in ionic concentrations were also recorded across the marsh but they did not necessarily follow the same pattern as EC. Measurements over a 2-year period at this site also indicated considerable seasonal variation. The authors concluded that seasonal ionic composition was probably as important as EC in explaining the vegetation zonation on the marsh. Temporal variation in EC is not restricted to salt marshes as Hamilton (1972) noted on sites affected by dryland salinity in central-western New South Wales (NSW). He attributed it to seasonal conditions (rainfall, evaporation and depth to watertable) and probable removal of surface salts in run-off water and wind.

Various gradients in other soil properties have also been reported. Analyses of soils along a 200 m transect across a

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saline scald on the northern tablelands of NSW by Kreeb *et al*. (1995) indicated wide variability in $pH_{1:5\ water}$ (about 5.0–10.5) and other soil properties, even over short distances. Bare areas, which were generally highly alkaline, sodic and high in EC, tended to be banded across the site. Various plant communities, each associated with a defined range of pH, EC and soil moisture, were identified.

The success of revegetation techniques, such as stock exclusion, mulching, cultivation and introduction of salt-tolerant plant species, varies between sites (e.g. Hamilton 1972; Semple *et al*. 2003) and even across the 1 site (Semple and Koen 1998). In other areas, such as the southern tablelands of NSW, complete failures have occurred (Wagner 1987). Malcolm (1990) advocated the characterisation of saline sites before attempting revegetation but in central-western NSW at least, this is often minimal (e.g. taking some soil samples for EC and pH testing). Perhaps local practice is due to the observation that a bulked sample from a severely scalded site is likely to indicate high salinity, high sodicity and often high alkalinity (Semple and Koen 1996), leaving revegetators wondering what other soil property needs to be measured, or whether soil testing needs to be done at all. However, the findings of Álvarez-Rogel *et al*. (1997) and Kreeb *et al*. (1995) indicate that chemical properties, particularly ionic compositions, can provide useful insights into existing vegetation assemblages and also, as noted by Williams and Semple (2001), guidelines for revegetation.

Saline sites, particularly those that are severely scalded and/or eroded, can present a considerable challenge to a revegetation practitioner. Experienced practitioners generally know what practices are likely to succeed in their locality. Suspected spatial variability is usually addressed by introducing a 'shotgun mix' of species with varying degrees of salt tolerance with the expectation that some small parts of the site may fail to revegetate. Seeding rate is often increased to compensate for expected plant losses. An added risk is that a revegetation strategy (which is usually the lowest cost option) will fail completely at a site with unfamiliar characteristics.

In an attempt to better understand the effects of salinisation on small scalded discharge sites, 2 contrasting sites in NSW were selected for an intensive survey of topsoil and other properties. The main aims of the investigation were to: (i) describe spatial variability in topsoil properties in the horizontal plane across the scalds; (ii) investigate correlations between soil properties and other site attributes such as vegetative cover; and (iii) obtain some indication of potential temporal variation in apparent EC by carrying out an electromagnetic induction (EMI) survey on 2 occasions.

Methods

Study sites

The sites (Table 1) were located near Bocobra (17 km north-west of Manildra) and Rugby (7.5 km south-south-west of the village). Both were located on lower slope drainage depressions and had apparently uniform scalded surfaces. Altitudes and mean annual rainfalls were similar. The Rugby site was an example of southern tablelands saline scalds, which are often alkaline and relatively low in EC but difficult to revegetate (Wagner 1987), whereas Bocobra was an example of central-western slopes saline scalds, which may be acidic or alkaline and high in EC (Semple and Koen 1996), but are usually less difficult to revegetate. The Rugby site had been extensively disturbed and sown with salt-tolerant plants in a rehabilitation attempt in the late 1980s. Despite the absence of grazing, subsequent plant growth was poor with bare scald predominant. The Bocobra site was located in a naturalised pasture paddock, part of which had been ungrazed since 1996.

Both sites had been used for plant species evaluation trials where plants were sown over 4 seasons during 1996–97. All species performed

Table 1. Site characteristics for saline scalds at Bocobra and Rugby, NSW

Data from Semple *et al*. (2003). ESP, exchangeable sodium percentage; ECC, exchangeable cation concentration

Site characteristic	Bocobra	Rugby
Physical characteristics		
Latitude and longitude	33°05′S; 148°33′E	34°27′S; 148°58′E
Elevation (m a.s.l.)	590	600
Mean annual rainfall (mm)	640	680
Total rainfall (mm) during the period of observation (corresponding mean)	1050 (930) [autumn 1999–winter 2000 inclusive]	600 (485) [spring 1999–autumn 2000]
Soil (0–10 cm) characteristics (n = 4)[A]		
Texture group[B]	Clay loam–light clay	Clay loam–light clay
$EC_{1:5\ water}$ (dS/m)	2.4–3.3	0.2–0.5
Estimated EC_e (dS/m)[B]	21–28	1–5
$pH_{1:5\ water}$	5.2–6.0	7.5–9.4
ECC [cmol(+)/kg (% of sum of cations)][C]		
Na (ESP)	3.0–4.2 (25–38)	2.0–4.4 (24–62)
K	0.1–0.2 (1–2)	0.1 (1)
Ca	2.2–3.3 (2–37)	0.2–0.7 (2–8)
Mg	3.8–5.1 (38–41)	2.1–5.6 (30–67)

[A]Range of results from 4 bulked samples from 4 subsites (March 1996).
[B]Soil texture group according to Slavich and Petterson (1993), who provided multipliers to estimate EC_e from $EC_{1:5\ water}$.
[C]As samples were not analysed for all cations, especially Al which may be significant on acid soils, the percentages may be inflated.

poorly at Rugby and even growth of volunteers (weeds) was poor. Plants performed better at Bocobra despite competition from annual weeds during early establishment (Semple *et al*. 2003).

As part of the site categorisation process for the earlier trials, topsoils (0–10 cm) were sampled on a rough grid basis (about 1 sample /10 m^2) within each of 4 subsites that were sown on 4 separate occasions. Samples from within each subsite were bulked and a subsample analysed for $EC_{1:5\ water}$, $pH_{1:5\ water}$ and exchangeable cations as described by Semple *et al*. (2003). Analyses indicated that both sites were strongly sodic but exchangeable calcium levels at Rugby were particularly low. The Bocobra site was more acid and more saline than the Rugby site (Table 1).

Site layout and monitoring 1999–2000

A rectangular 3 by 3 m grid was laid out across the area encompassed by the former species evaluation trials at both sites using wooden pegs: 48 by 24 m (= 153 grid points) at Bocobra and 36 by 30 m (= 143 grid points) at Rugby. Relative heights of each grid point were measured with a surveyor's level with the lowest point at each site allocated a zero elevation.

To assess spatial (horizontal) variability, topsoil (0–10 cm) samples were taken at each grid point on 1 occasion at each site: May 1999 at Bocobra and April 2000 at Rugby. Soil : water suspensions were prepared and analysed for pH and EC according to methods described by Rayment and Higginson (1992). Suspensions were also analysed for soluble cation concentrations using atomic absorption spectroscopy (Unicam 929 AAS) at the soils laboratory, School of Geography, University of NSW. Soil sampling at Bocobra was supplemented by a visual estimate of vegetative cover in a 0.5 by 0.5 m quadrat centred on each grid point.

Spatial (horizontal and vertical) variability was also assessed by an EMI survey using a Geonics EM38 in both horizontal (EM_h) and vertical (EM_v) dipole modes at each grid point in May 1999 (Bocobra) and September 1999 (Rugby). Conductivity of predominantly near-surface soil is measured in the horizontal mode and of mainly deeper material, about 0.5–1 m, in the vertical mode (McNeil 1986).

An assessment of temporal variability was made by repeating the EMI survey, at the same grid points and with the same alignment of the EM38, in July 2000 (Bocobra) and April 2000 (Rugby). As the timing of soil sampling coincided with 1 of the EMI surveys [the first (May 1999) in the case of Bocobra and the second (April 2000) at Rugby], any correlations between EMI data and topsoil data could be explored.

Data analysis

Data variability was initially explored and summarised by calculating means, standard deviations (s.d.), coefficients of variation (CV%) and by plotting frequency histograms. Matrix plots were used to search for structure within each site's multivariate dataset, a procedure that identified a number of potential outlying data points. Pearson's correlation coefficient was computed to examine the strength of apparent linear relationships. 'Contour' plots, prepared using the CONREC contouring algorithm as implemented in Sigmaplot (2002), displayed spatial maps of site characteristics.

Variograms (Webster and Oliver 2001) were derived to further quantify changes in spatial variability at finer scales of sampling. In order to correctly interpret the variograms, skewed data (primarily soluble cation compositions) were first transformed to natural logarithms. Some data exhibited a linear trend along the principal axis of the sampling grid. So as to not violate the assumption of stationarity of data, and hence affect the form of the variogram, the data were first linearly detrended. This was achieved by fitting a linear regression between the response variable and its spatial coordinates, and adjusting each observation by subtracting the trend component.

Results

Spatial change in topsoil properties

Grid sampling indicated a mean $EC_{1:5\ water}$ of 1.4 dS/m (May 1999) at Bocobra and 0.6 dS/m (April 2000) at Rugby. Coefficients of variation for EC and soluble cations were high at both sites (Table 2). Contour plots of EC indicated areas of uniform EC interrupted by 'highs' (areas of steeply-increasing EC such as are often evident in plots of paddock scale EMI surveys, e.g. Williams 1988) at both sites (Figs 1*a* and 2*a*). The maximum EC gradient was 5.3 dS/m over 3 m at Bocobra and 2.4 dS/m over 3 m at Rugby: the lower salinity site. Some of the highs were associated with 1 or 2 sampling points where salinity was much higher than surrounding areas. Point seepages, which were only evident at the Rugby site, were not associated with areas of high EC nor generally with high concentrations of soluble cations (Fig. 2).

Sampling indicated a mean $pH_{1:5\ water}$ of 5.6 at Bocobra and 7.4 at Rugby but these were deceptive for their lack of detail. At the predominantly acid Bocobra site, an area of neutral pH was evident in the central-north (Fig. 1*b*). At Rugby there was a gradient from moderate-strong alkalinity in the north to slight acidity in the east, west and south but

Table 2. Summary statistics indicating the site variability in topsoil (0–10 cm) characteristics and vegetative cover measured in 3 by 3 m grid surveys on saline scalds at Bocobra (May 1999) and Rugby (April 2000), NSW

Variable	Bocobra (*n* = 153)				Rugby (*n* = 143)			
	Arithmetic mean ± s.d.	Geometric mean	Range	CV%	Arithmetic mean ± s.d.	Geometric mean	Range	CV%
$EC_{1:5\ water}$ (dS/m)	1.4 ± 1.0	—	0.5–6.6	73	0.6 ± 0.5	—	0.1–2.6	94
$pH_{1:5\ water}$	5.6 ± 0.6	—	4.8–8.3	10	7.4 ± 0.6	—	5.6–9.0	8
Soluble cation concentrations [cmol(+)/kg]								
Na	53 ± 49	43	16–267[A]	92	26 ± 20	21	5–108	75
K	0.60 ± 0.31	0.53	0.15–1.54	52	0.19 ± 0.09	0.17	0.06–0.71	50
Ca	2.36 ± 1.41	2.04	0.43–8.78	60	0.63 ± 0.43	0.50	0.1–3.08	68
Mg	10.2 ± 12.2	7.2	1.5–92.2	120	8.4 ± 6.3	6.5	0.8–31.1	75
Elevation/relief (m)	0.5 ± 0.23	—	0–1.0	51	0.9 ± 0.5	—	0–2.1	53
Vegetative cover (%)	91.5 ± 22	—	0–100	24	Not recorded			

[A]The upper limit excludes an outlying value of 381 cmol(+)/kg.

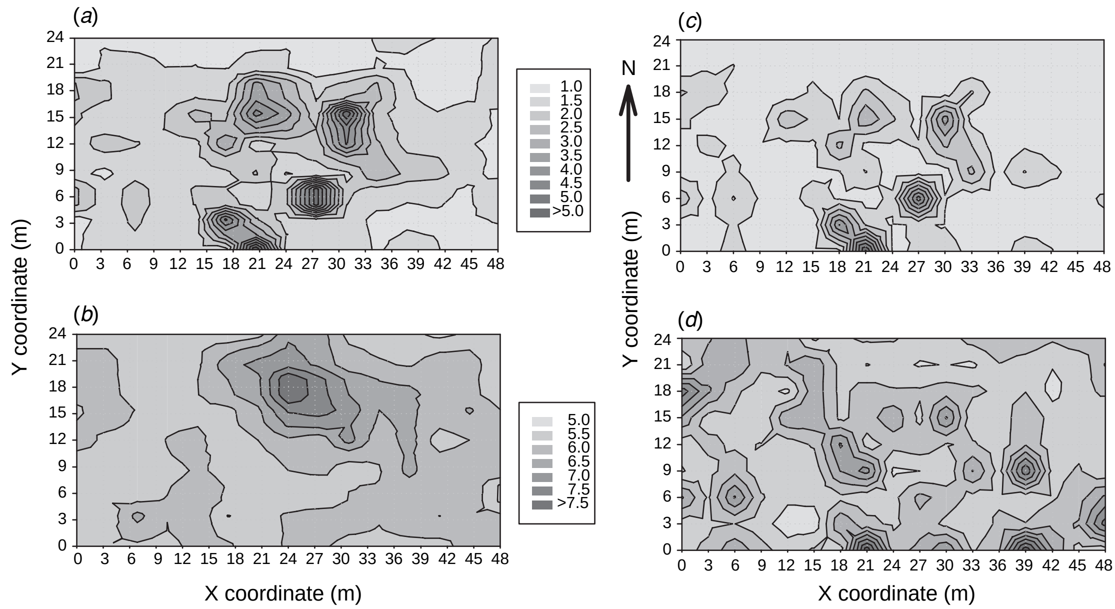


Fig. 1. Spatial variability in topsoil (0–10 cm). (*a*) $EC_{1:5\ water}$ (dS/m), (*b*) $pH_{1:5\ water}$ (*c*) soluble Mg [cmol(+)/kg] and (*d*) soluble Ca [cmol(+)/kg] as recorded in May 1999 on a 3 by 3 m grid of 1152 m^2 saline scald at Bocobra, NSW.

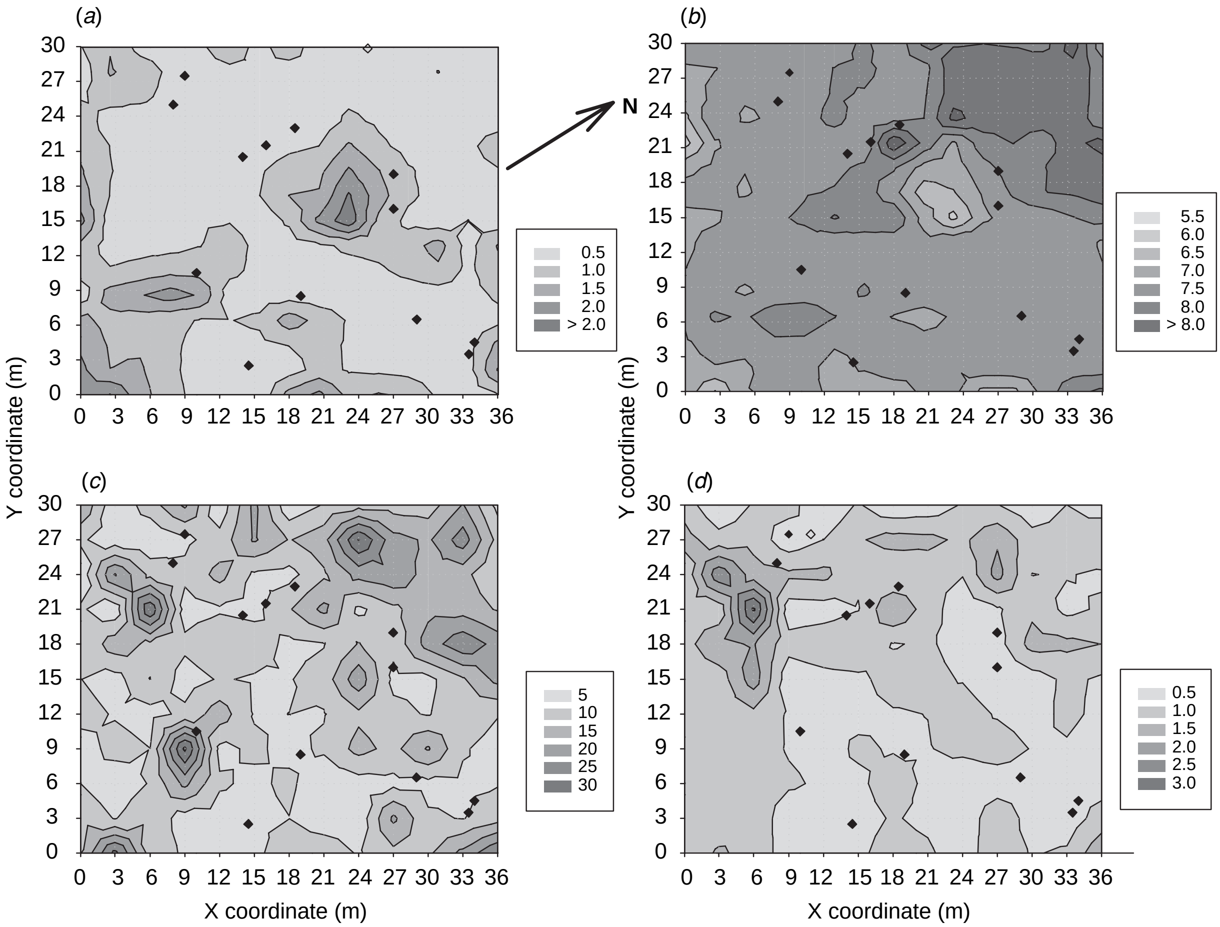


Fig. 2. Spatial variability in topsoil (0–10 cm). (*a*) $EC_{1:5\ water}$ (dS/m), (*b*) $pH_{1:5\ water}$(*c*) soluble Mg [cmol(+)/kg] and (*d*) soluble Ca [cmol(+)/kg] as recorded in April 2000 on a 3 by 3 m grid of 1080 m^2 saline scald at Rugby, NSW. Point seepages present at this site are shown as diamond symbols.

most of the site was neutral (Fig. 2*b*). The maximum $pH_{1:5\ water}$ gradient was 1.9 units over 3 m at Bocobra and 2.4 units over 3 m at Rugby.

Relationships between topsoil and other site attributes

Relationships between each of the measured soil properties (EC, pH, soluble cation concentrations) and between soil properties and other site attributes (relief, EM_v, EM_h and at Bocobra, vegetative cover), measured at the same time are presented in Figs 3 and 4. Strong linear correlations were evident between EC and sodium: the dominant cation at both sites [$r = 0.99$, $P<0.001$, $n = 152$ (excluding outlier) at Bocobra; $r = 0.97$, $P<0.001$, $n = 143$ at Rugby], and with the second most common cation, magnesium, at Bocobra ($r = 0.94$, $P<0.001$, $n = 153$) but not at Rugby. Examination of the contour plot of magnesium concentrations at Rugby (Fig. 2*c*) indicated that it was relatively evenly distributed apart from 'highs' in the north and west that were not evident on the plot of EC.

Correlations between soil properties and other site attributes were low at Rugby (Fig. 4). At Bocobra (Fig. 3), there was a negative correlation between vegetative cover and soluble sodium ($r = -0.83$, $P<0.001$, $n = 152$, excluding outlier), magnesium ($r = -0.71$, $P<0.001$, $n = 153$) and EC ($r = -0.81$, $P<0.001$, $n = 153$). A negative correlation between EC and plant growth is often assumed but has been difficult to demonstrate on saline scalds where EC is usually limiting but where other factors such as pH and concentrations of individual ions also affect plant growth. The EC/vegetation relationship at Bocobra (Inset 2 in Fig. 3) suggested that when $EC_{1:5\ water}$ >4 dS/m (or estimated EC_e >38 dS/m), vegetative cover was always <50%.

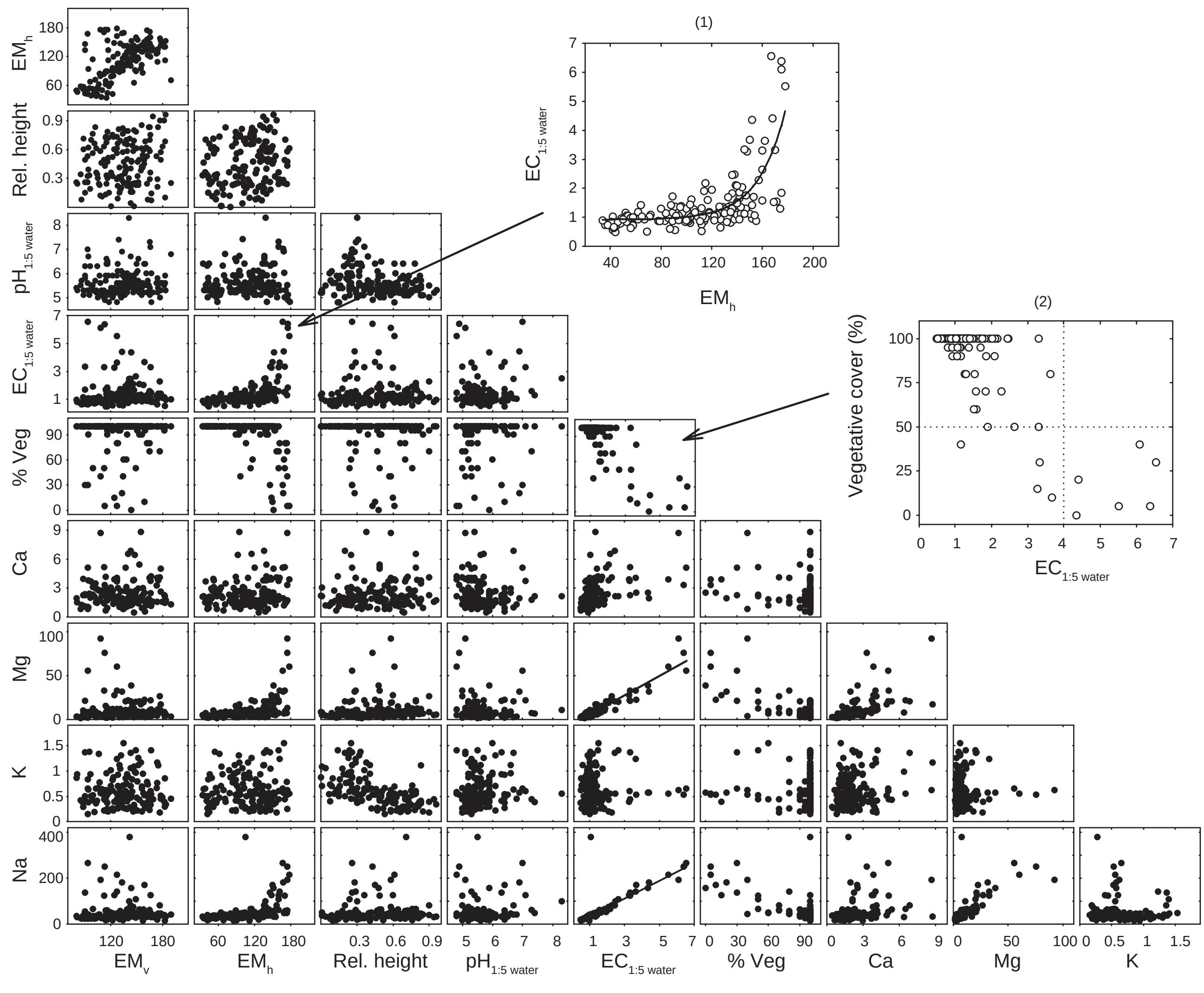


Fig. 3. Matrix plot of soil properties and other site attributes [EM_h (mS/m), EM_v (mS/M), $EC_{1:5\ water}$ (dS/m), $pH_{1:5\ water}$, relative height (m), percentage cover by vegetation (% Veg) and soluble cation concentrations (Ca, Mg, K, Na)] measured in May 1999 on a saline scald at Bocobra, NSW.

Electromagnetic induction survey and changes over time

Linear correlations between EM values and topsoil properties measured at the same time were low at both sites (Figs 3 and 4). There was a weak asymptotic relationship between EM_h and $EC_{1:5\ water}$ at Bocobra but EM_h was a poor predictor of 0–10 cm soil $EC_{1:5\ water}$ especially when EM_h exceeded 120 mS/m (Inset 1 in Fig. 3). This was not unexpected as different depths of soil are measured by the 2 techniques and EM values are affected by other factors such as soil moisture and texture (Williams 1988).

Spatial variation was evident in subsurface conductivity at both sites and on both occasions (Table 3). Highs and lows were evident in shallow (EM_h) and particularly in deeper (EM_v not presented graphically here) measurements at both sites (Figs 5 and 6).

Correlations between EM_v (or EM_h) values taken at the same grid point on 2 occasions were low at Rugby but relatively high at Bocobra (Table 4). Values for EM_h increased over time at both sites but patterns remained relatively constant at Bocobra (Fig. 5) though less so at Rugby (Fig. 6). Patterns of EM_v values were more variable over time than those of EM_h.

Variogram representation of spatial variation

The model required to specify each variogram fell into 1 of 3 forms (Fig. 7). The first form, 'A', was characterised by being poorly defined below the lowest scale of sampling, namely 3 m, and as a result, both a spherical and exponential model fitted the observed range of data well. A number of the variables from Bocobra and the transformed potassium concentrations from Rugby fell into this category. Due to a lack of data at less than 3 m spacing, we are left to infer the consequences of selecting either of the 2 fitted curves. The steepness of the exponential model over the 0–3 m range

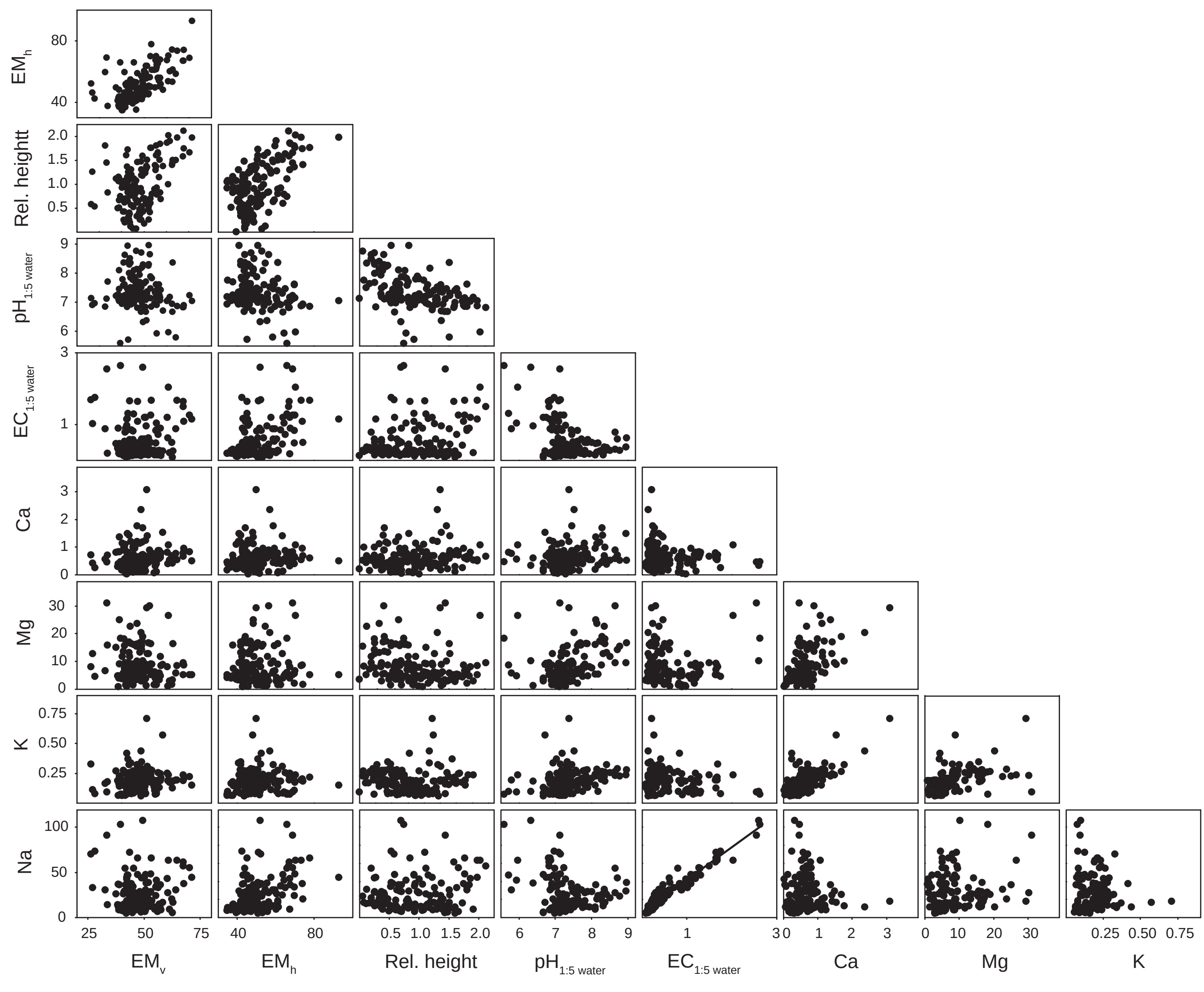


Fig. 4. Matrix plot of soil properties and other site attributes [EM_h (mS/m), EM_v (mS/M), $EC_{1:5\ water}$ (dS/m), $pH_{1:5\ water}$, relative height (m), and soluble cation concentrations (Ca, Mg, K, Na)]measured in April 2000 on a saline scald at Rugby, NSW.

Table 3. Summary of statistics indicating the variability in apparent ECs (mS/m) as measured in 3 by 3 m grid surveys on saline scalds at Bocobra (May 1999 and July 2000) and Rugby (Sept. 1999 and Apr. 2000), NSW

	Bocobra (n = 153)			Rugby (n = 143)		
	Arithmetic mean ± s.d.	Range	CV%	Arithmetic mean ± s.d.	Range	CV%
Apparent EC to depth (EM_v)						
1st sampling	134.2 ± 26.2	80–190	19.5	60.4 ± 17.5	16.0–107.5	29.0
2nd sampling	134.4 ± 28.3	43–223	21.1	48.0 ± 8.2	26.4–71.3	17.0
Apparent shallow EC (EM_h)						
1st sampling	110.5 ± 38.1	34–178	34.5	45.2 ± 13.1	17.6–83.7	29.1
2nd sampling	123.4 ± 27.6	67–220	22.4	51.0 ± 10.3	34.8–92.9	20.2

suggests that most of the variation in these variables occurs within these small distances. The spherical model also cautions about the high degree of variability at small distances. The high intercept on the ordinate axis suggests the presence of a non-zero nugget variance, implying a degree of measurement error plus high spatial variation that occurs over distances less than the shortest sampling interval. Spatial independence is reached after about 13 m for potassium and about 19 m for magnesium concentrations at Bocobra.

Most of the variables analysed fell into the second form, 'B', of variogram model, namely the spherical model (Fig. 7). This form is characterised by a better-defined response curve at the lower sampling distances. Although the nugget variance is still non-zero, it is much smaller than in form 'A'. The steep rise of the fitted curve again implies large changes in variance across these finer scales of distance. Spatial independence is reached at distances between 8 and 14 m for the fitted variables.

The third form of variogram 'C' (Fig. 7), is known as a pure nugget variogram because of its totally flat shape. This form indicates that the minimum sampling interval was definitely greater than the scale of spatial variation as spatially correlated variation failed to be detected. For the logarithmic transform of calcium concentrations from both

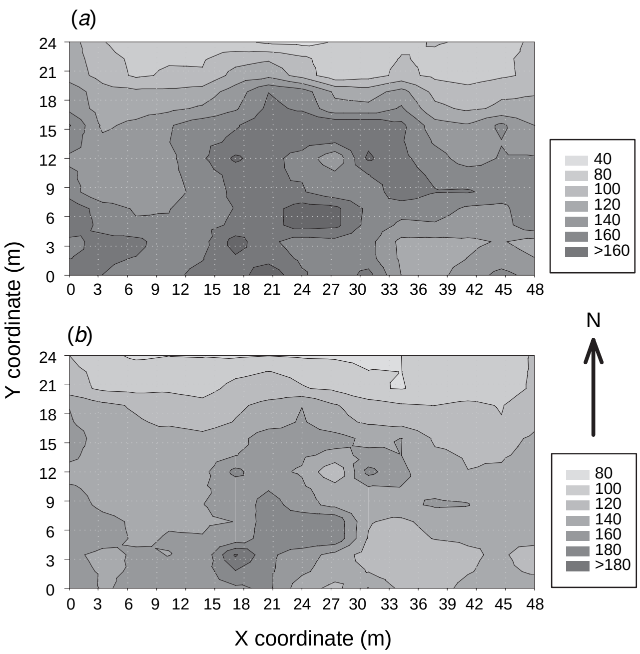


Fig. 5. Spatial and temporal variability in EM_h values (mS/m) recorded on a saline scald at Bocobra in (*a*) May 1999 and (*b*) July 2000.

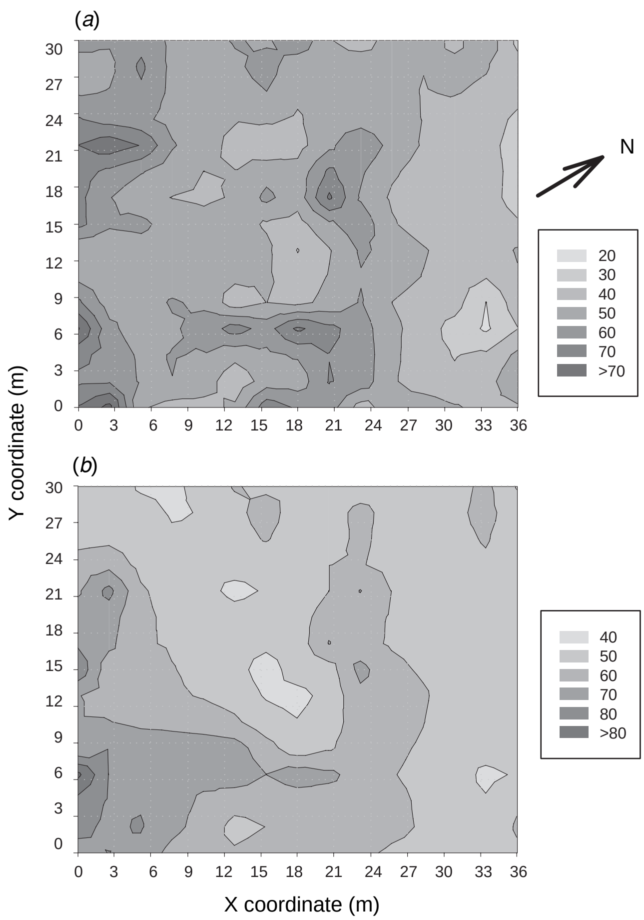


Fig. 6. Spatial and temporal variability in EM_h values (mS/m) recorded on a saline scald at Rugby in (*a*) September 1999 and (*b*) April 2000.

Table 4. Correlation coefficients (*r*) between values of apparent electrical conductivity (EM_v and EM_h in mS/m) when measured on 1 and 2 occasions on saline scalds at Bocobra and Rugby, NSW

	EM_v 1999	EM_h 1999	EM_v 2000
Bocobra (*n* = 153)			
EM_h 1999	0.59		
EM_v 2000	0.80	0.56	
EM_h 2000	0.55	0.90	0.56
Rugby (*n* = 143)			
EM_h 1999	0.38		
EM_v 2000	0.56	0.46	
EM_h 2000	0.45	0.64	0.64

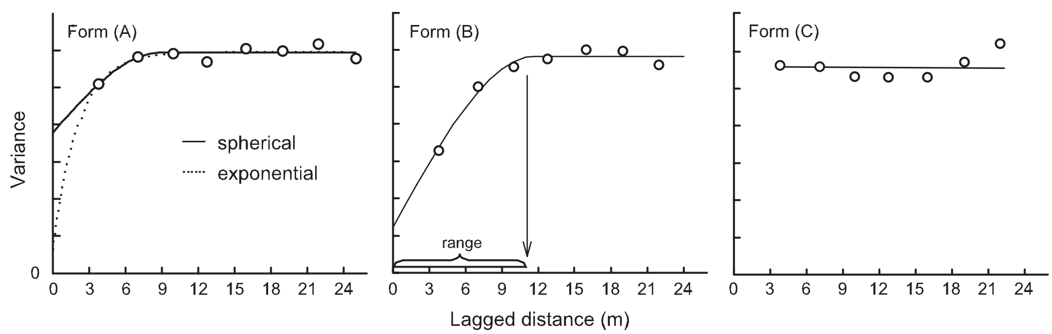
sites, and of magnesium concentrations at Rugby, contiguous positions in space (>3 m apart) yield data that are totally unrelated. Thus, no estimate of range is possible.

Discussion

Spatial change

Measurements at 2 saline scalds of about 0.1 ha (Tables 2 and 3) indicated high spatial variability in all measured topsoil characteristics (soluble cations, $pH_{1:5\ water}$, $EC_{1:5\ water}$) and other attributes (EM_h, EM_v, vegetative cover and relief). Due to high spatial variability, mean values were generally not representative of the real situation at any of the sites. For example, the Bocobra site, though nominally acid, had areas of neutral pH, and Rugby, nominally neutral, had areas of moderate alkalinity as well as areas of slight acidity.

To what extent was this spatial variability different to that which occurs in topsoils of non-saline sites? Unlike the study reported here, most multiple soil sampling is carried out in order to derive a mean value representative of the area sampled. Brown (1993) compiled data from 23 paddock studies where data on mean EC and/or pH, as well as their variability, were recorded. Standard deviations for pH values ranged from 0.03 to 0.90 and coefficients of variation for EC values from 13 to 59%. In a subsequent survey, where 30 samples of 0–10 cm were collected from apparently uniform areas in each of 7 non-saline paddocks and tested for $EC_{1:5\ water}$, coefficients of variation ranged from 14 to 54% (A. J. Brown, pers. comm.). In a 33 by 33 m grid survey over 60 ha at Carcoar NSW, coefficient of variation of $EC_{1:5\ water}$ was 42% and standard deviation for $pH_{1:5\ water}$ was 0.35 (data from W. King and colleagues). In the Bocobra and Rugby surveys of much smaller areas, coefficients of variation for $EC_{1:5\ water}$ ranged from 73 to 94%, and the standard deviation for $pH_{1:5\ water}$ was 0.6 at both sites. These results suggest that pH and particularly EC (which has a



Site	Variable	Range (s.e.)	Variable	Range (s.e.)	Variable
Rugby	$\log_e$(K)	13.8 (0.5)	$\log_e$(EC) [A]	8.0 (4.6)	$\log_e$(Mg) [A]
			$\log_e$(Na) [A]	8.9 (0.9)	$\log_e$(Ca)
			EM_v Apr. 00[A]	11.9 (1.6)	
			EM_h Apr. 00[A]	11.7 (1.3)	
			pH[A]	11.8 (2.7)	
Bocobra	EM_v May 99[A]	12.2 (3.8)	$\log_e$(pH)	11.9 (4.1)	$\log_e$(Ca)
	EM_h May 99[A]	12.4 (2.3)	$\log_e$(EC)	14.7 (4.9)	
	$\log_e$(K) [A]	12.8 (3.8)	$\log_e$(Na)	12.0 (2.3)	
	$\log_e$(Mg) [A]	19.3 (5.8)			

[A]These variables were detrended prior to calculation of variogram.

Fig. 7. Stylised forms of variogram models used to fit to spatially correlated soil variables from Rugby and Bocobra. The range and standard error (s.e.) are estimated from the parameters of each spherical model. Form A is spherical and exponential models with poor definition at low lag distance. Form B is spherical model with better definition at low lag distance. Form C is constant variance over range of lag distances.

higher potential range of values on saline sites) are at least as variable on small dryland saline scalds as they are on non-saline sites of much larger area.

Electromagnetic induction surveys and temporal change

Temporal change in EC would be expected due to seasonal changes (e.g. precipitation of salts, leaching, removal of salts in run-off water and possibly changes in vegetative cover, which according to authors such as Logan (1958) and Barrett-Lennard *et al*. (2003), affects EC by enhancing leaching and/or reducing evaporative concentration of salts at the surface. Negative correlations between vegetative cover and $EC_{1:5\ water}$ (and some soluble cations) at Bocobra add support to their suggestion.

Changes in apparent EC were evident over time. This was not believed to be due to a malfunction of the EM38 due to inadequate soil moisture as seasonal (3-monthly) rainfalls during the period of observation (i.e. autumn 1999 to winter 2000) were about average (Table 1) and (as with most discharge sites) the shallow subsoil was believed to be continuously moist. Whether calibration of the EM values with soil EC profiles would have reduced this variability was not tested. Correlations between values at the 2 times of observation (Table 4) were relatively low at Rugby ($r = 0.56$ for EM_v and $r = 0.64$ for EM_h) but higher at Bocobra ($r = 0.80$ for EM_v and $r = 0.90$ for EM_h). Spatial patterns of EM_h (Figs 5 and 6) and to a greater extent, EM_v, also changed over time. In the absence of subsurface soil data, the reasons for this are conjectural but were presumably due to seasonal changes in rainfall (though run-off may be high on scalds) and watertables and the distribution, possibly along preferred flow-paths, of moisture and salts in the profile.

Documenting site conditions

Reports on revegetation exercises, demonstrations and experiments on saline scalds will have little relevance to other areas unless accompanied by an adequate description of conditions at the site. Barrett-Lennard *et al*. (2003) suggest that the 3 most important factors affecting revegetation are EC, soil texture and season of waterlogging/inundation but the applicability of this WA-derived information to saline scalds on the upper slopes and tablelands of NSW remains to be determined. As these scalds are rarely inundated and topsoils have usually been eroded, other limitations to plant growth are usually present. For example, despite similar topsoil textures, altitudes and mean annual rainfalls, the Rugby site was more difficult to revegetate (for reasons that are still unknown) than Bocobra with its higher EC and acidity.

The common approach of bulking soil samples from across a saline scald and testing a subsample is likely to yield a misleading result. Firstly, the 'average' value obtained may have little relevance to a site, which is likely to be highly variable, and secondly, no indication of that variability will have been obtained. If cost of soil testing is a major consideration, then a few strategically-located samples will yield more information than 1 bulked sample. As vegetative cover was negatively correlated with $EC_{1:5\ water}$ and some soluble cations at Bocobra (Fig. 3), vegetative cover (especially extreme values) may be a useful guide to selecting sampling points. Observations by the authors suggest that dominant plant species also may be a useful guide, for example, common couch [*Cynodon dactylon* (L.) Pers.] may indicate alkalinity. Elevation was not a useful indicator of soil properties in this study (though it was loosely correlated with apparent EC at Rugby; Fig. 4) but it may indicate local differences in seasonal waterlogging or inundation: an important saline site descriptor in its own right.

Further, temporal variability in EC suggests that its measurement, whether by EMI or by $EC_{1:5\ water}$, should be accompanied by a statement of the time at which it was made and that measurements at different sites, which are to be compared, should be carried out at times when moisture contents are comparable.

Design and layout of revegetation experiments on saline scalds

Although the surfaces of untreated saline scalds may appear to be relatively uniform, gradients in topsoil characteristics will generally not be evident until intensive soil sampling has been carried out. At least 2 options for improved experimental design present themselves. The ideal would be to perform an intensive grid survey of the area for the relevant soil properties, and to make use of this information in selecting the experimental site in unbiasedly allocating treatments to plots and in the subsequent statistical data analysis. Alternatively, one could use a row–column design to accommodate high spatial variability in perpendicular directions, and before treatment application, take soil samples from each plot for laboratory analysis and later use them as covariates. For either option, and especially when the causal soil variables are unknown, an accurate statistical analysis can be performed by including local terms for the smooth natural spatial variation in both principal directions using autoregressive terms (Gilmour *et al*. 1997) or cubic smoothing splines (Verbyla *et al*. 1999).

Conventional randomised block or completely randomised designs using large plots are inappropriate where variability is high and/or gradients are not known in advance. Even where gradients are known, they are likely to be multidirectional and concentrated over relatively short distances which will not be compatible with conventional small plot dimensions of about 5–10 m. Depending on which soil characteristic is considered to be most influential on the experiment's response variable(s), the current variogram analysis indicates that the ideal individual plot size would need to be a minimum size of 19 by 19 m so as to completely embody all the spatial variation of the site. The resources required to conduct replicated trials of this physical magnitude would be impossible for the majority of research teams. Since the field work for this study was completed, we have opted for small (0.5 by 0.5 m) plots, high replication and row–column designs arranged in incomplete blocks. Attempts to minimise soil tests by sampling just the central line of the longest dimension at 2 such trial sites provided inadequate data for covariate analysis (Semple *et al*. 2004) and has been replaced by sampling soils in each plot (which, incidentally, has confirmed high spatial variability at sites other than Rugby and Bocobra) and more recently, by repeated pH and EC testing to monitor temporal variation. Whether these procedures will provide useful covariates for adjusting plant performance values remains to be seen and is dependant on what soil tests are chosen.

Revegetating saline scalds

The selection of appropriate soil tests for identifying limiting factors for plant growth would be of most interest to those attempting revegetation. This study has shown that topsoil $EC_{1:5\ water}$ is not a particularly useful test on saline scalds. It appears that once scalding becomes evident, EC (whether relatively low as on southern tablelands sites like Rugby, or high as on central-western slopes sites such as Bocobra) is not a good predictor of vegetative cover between sites, though it may be useful at a particular site (e.g. Inset 2 in Fig. 3). This, together with high variability, suggests that expending resources on accurately describing EC (apart from the purpose of site description) on scalded sites may not be warranted. The same probably applies to soluble salt concentrations, though data on ions other than sodium may be of interest. Observations at other sites suggest that the availability of topsoil moisture, year-round or seasonally, may have higher predictive value.

The use of 'shotgun' mixtures of plant species — particularly if they include species appropriate for the range of ECs and pHs present — is still recommended on saline scalds. A more practical approach to variability may be to attempt to reduce it by artificially imposing uniformity. Examples include cultivation (McBratney 1992) or straw mulching, which may, though the evidence is not conclusive, enhance seed retention and infiltration and in the case of mulching, reduce evaporative concentration of salts.

The results also suggest that some caution is needed when interpreting the conclusions, published or otherwise, of previous revegetation exercises and trials. Supposed associations between the success/failure of particular species or treatments and reported site conditions may be misleading due to soil sampling being at an inappropriate time or inadequately located.

Conclusions

Grid topsoil sampling at 2 small saline scalds with contrasting EC values indicated high spatial variability in $EC_{1:5\ water}$, apparent EC (EM_h and EM_v), $pH_{1:5\ water}$ and soluble cation concentrations. Variograms suggested that values of some attributes changed markedly over distances <3 m and that the full range of variablity for most attributes could be expected to be captured in plots with dimensions of about 12–19 m. The levels of variability, as described by standard deviations or coefficients of variation, were consistent with what would be expected in a non-saline area of paddock size rather than in a small area of about 0.1 ha. Repeat EMI surveys at the same locations on the scalds also indicated considerable temporal variation in EC values and patterns.

Variability cannot be ignored when planning revegetation projects or experiments. In the former case, variability can be assessed by strategic sampling but in experimentation, intensive soil sampling, probably at intervals of <3 m, is indicated. EMI survey results (albeit uncalibrated with soil profile ECs in this study), partly because of their temporal variability, may not provide useful guidelines for strategic soil sampling nor for locating experimental plots on saline scalds. Consideration should also be given to testing variables such as pH and calcium, as factors other than EC are likely to be limiting in scalded situations.

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