Low induction number EM surveys for assessing land management attributes in upland environments.

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Abstract

Electromagnetic induction (EM) techniques that measure apparent bulk soil profile electrical conductivity have been extensively used for geophysical investigations and are increasingly being used for environmental objectives. These include soil physical and chemical attributes such as soil salinity, moisture, and the depth to, type, and thickness of clay-rich horizons, particularly of relevance for agronomy and dryland salinity investigations. EM measurements of apparent electrical conductivity (ECa) enable large areas to be surveyed quickly and non-invasively. This research investigates the applicability of low induction number ground based instruments (Geonics EM38 & EM31) for providing information for improving land management. Biotic (floral and faunal) and a suite of abiotic metrics were collected along transects in ten grassy woodland sites on the Southern Tablelands of NSW (STNSW). Landscape Function Analysis, which focuses on soil surface and hydrological processes, was also used. The EM surveys were conducted during autumn and spring, to investigate temporal variations, particularly moisture regimes. Results indicate that the EM38 ECa yielded strong correlations ($p<0.001$) with many of the biotic and most abiotic metrics, including those associated with ecological processes (e.g. pH, compaction) and soil and vegetation degradation associated with soil ‘health’ and productivity such as soil organic matter. A newly developed inversion technique was used to assess moisture levels. Correlations with the deeper measuring EM31 were weaker, with all surface attributes showing an inverse relationship with depth and no strong correlations with biotic metrics with the deeper (vertical) EM31 dipole. Results confirm that the EM38 can provide valuable abiotic and biotic information associated with a sustainable ‘healthy’ ecosystem. It should be further investigated for assessing healthy agronomic systems. In addition the EM31 can also be useful, particularly when used in conjunction with the EM38 and with the shallower dipole.

Key Words

geophysical surveys, uplands, soil degradation, dryland salinity,

Introduction

Electromagnetic induction (EM) techniques that measure bulk soil profile apparent electrical conductivity (ECa) have been extensively used for geophysical investigations and are being increasingly used for environmentally and agronomy focused objectives (e.g. Corwin and Lesch 2003, 2005). These include soil physical and chemical attributes such as soil salinity, moisture, and the type, depth to, and thickness of clay-rich horizons, particularly of relevance for agricultural productivity and salinity investigations. McBride *et al.* (1990) identified associations between ECa and forest productivity, however very few studies have been performed to date which investigate ECa and associated biological attributes (Johnson et al. 2001). The possible advantages of using EM for environmental and ecological applications, including sustainable agronomy activities, are considerable, as the EM instruments have previously proven to be both rigorous and efficient for related investigations. Large areas can be surveyed extremely quickly, efficiently and non-invasively, by carrying the lightweight instruments on foot, or attaching to vehicles such as quad bikes. This paper investigates the applicability of ground-based EM instruments, the Geonics EM38 and EM31, which measure to approximately 0.75m and 1.5m and; 3m and 6m depths, in two dipole configurations, horizontal (H) and vertical (V) respectively (McNeill 1980, 1992) for assessing land management attributes.

Methods

Ten sites on the STNSW were intensively surveyed during 2004-2006. All sites were located in endangered yellow box (*Eucalyptus melliodora*) and red gum (*E. blakelyi*) grassy woodland stock reserves in a relatively uncleared condition with reduced grazing regime and weed incursion. Biotic and abiotic metrics were collected from stations along 50m length transects and included the Landscape Function Analysis methodology which focuses on soil surface and hydrological processes (Tongway and Hindley 2005), such as surface vegetation attributes and bulk microbial respiration (CO_2 production), in addition to soil organic matter, surface soil macro-invertebrate, and reptile surveys. The EM surveys were conducted during autumn and spring 2005 (different moisture regimes) to investigate temporal variations. Correlation coefficients and regression analyses were carried out to investigate associations between the indicators and EM readings.

Results

The EM38 yields strong correlations ($p<0.001$) with most of the abiotic and many of the biotic metrics, especially the vegetation attributes (Tables 1 & 2). However, correlations with faunal attributes were generally absent. The regression analyses also confirmed these results. Strong negative correlations ($p<0.001$) were consistent between the EM38 (ECa) in both dipoles (depths) and the presence of soil organic matter, measured with the application of H_2O_2, surface rainsplash protection, perennial vegetation, litter amount, type of vegetative cover (sparse or dense grass, trees or bare soil), bulk soil microbial respiration (CO_2 production) and the soil evaporation potential (as measured from a number of indicators). The correlations with the deeper-sensing EM31 were consistently weaker than the EM38 (Tables 1 & 2), with all abiotic and biotic metrics showing an inverse relationship with depth. The deeper readings from the EM31 (i.e. vertical dipole at 6m depth) yielded no strong correlations with any biotic metrics, indicating the deeper parameters are not associated with the surface conditions. Similar correlations were attained with the ECa and surface soil electrical conductivity ($EC_{(1:5)}$) measurements (Table 1). Moreover, abiotic metrics likely associated with ecological processes, such as pH, surface compaction and soil slakeness also yielded strong correlations ($p<0.001$) with the ECa readings, particularly the EM38. The correlations with the biotic indicators in particular, are likely associated with soil moisture levels, depth and thickness (and type) of the clay-rich B horizon, and soil salinity levels. These attributes also exhibit spatial heterogeneity, as shown in Figure 1 and discussed by Bann and Field (2006). The inversion analyses also provided useful information, with a new technique developed for monitoring soil moisture (Smiarowski *et al.* 2011), which may also be of value for management applications. The few associations that were attained with fauna are difficult to explain, with weak negative correlations ($p<0.05$) between the EM38 (both dipoles) in season 1, when soil moisture levels were dryer (autumn) and the presence of ants (no correlations in season 2), and positive weak correlations ($p<0.05$) between the EM38 in vertical dipole season 2, and all the EM31 dipoles except horizontal in season 2, with the presence of reptiles.

Table 1. EM (ECa) correlations with the abiotic and biotic indicators, showing an inverse relationship with measuring depth (indicated by arrow). Both modes from each instrument (H and V) and both seasons (1 = autumn 2005; 2 = spring 2005 after considerable rainfall) are shown. Abiotic indicators shown are; EC (surface 5cm), scald (bare, scalded surface - yes/no), pH (surface 5cm), and slake (soil surface slake). The biotic indicators shown are; SOM (soil organic matter measured with application of H_2O_2); Rainsplash protection percentage cover (soil surface); Perennial vegetation % cover; Litter (amount); Patch (bare soil, sparse/dense grassland and trees); Evaporation Index (combination of a number of surface attributes associated with soil surface evaporation); CO_2 production (measured as bulk soil microbial respiration with respirometers), and the presence of ants and reptiles (lizards and geckos). No other faunal indicators showed correlations.

EM/dipole/season	EC	scald	pH	slake	surface	SOM	Rain P	P veg	litter	patch	CO2	evap	ants	reptiles
EM38 H1	0.45	0.58	0.57	0.6		-0.57	-0.52	-0.49	-0.51	-0.43	-0.49	-0.53	-0.22	0.15
EM38 H2	0.39	0.39	0.56	0.52		-0.49	-0.49	-0.47	-0.49	-0.44	-0.43	-0.51	-0.19	0.16
EM38 V1	0.38	0.38	0.51	0.51		-0.51	-0.45	-0.42	-0.47	-0.39	-0.47	-0.47	-0.2	0.16
EM38 V2	0.3	0.3	0.49	0.52		-0.4	-0.4	-0.38	-0.44	-0.37	-0.37	-0.43	-0.16	0.19
EM31 H1	0.27	0.28	0.56	0.35		-0.33	-0.33	-0.31	-0.37	-0.33	-0.41	-0.37	-0.17	0.2
EM31 H2	0.24	0.24	0.44	0.3		-0.28	-0.29	-0.28	-0.37	-0.31	-0.32	-0.34	-0.13	0.21
EM31 V1	0.11	0.11	0.38	0.1		-0.1	-0.15	-0.13	-0.23	-0.21	-0.29	-0.2	-0.08	0.2
EM31 V2	-0.01	-0.01	0.15	-0.06		0.05	0.03	0.02	-0.1	-0.08	-0.1	-0.04	-0.02	0.19

$p < 0.001 = 0.32$

$p < 0.05 = 0.19$

n=264

Table 2. Correlation coefficients (p < 0.001 and 0.05) of EM (ECa) when analysed against all variants (indicators), across all ten sites. Depth increases down the table.
V = Vertical dipole; H = horizontal dipole; S1 and S2 = seasons 1 and 2 (autumn and spring); H_2O_2 = reaction when placed on soil surface; Surface = soil surface compaction; Scald = bare, scalded surface; infiltration (time for rain water to infiltrate soil surface); RP = rainsplash protection % cover; PV = % cover perennial vegetation; Patch = vegetation type (trees, sparse or dense grass, or bare); Evap = Evaporation Index; CO_2 = bulk soil respiration; Pine W = Pine log discs with worms beneath; Euc W = red gum (euc) log disc with worms beneath; Total Taxa no. = pitfall and log disc total taxa numbers; Geology = 2 types, Ordovician metasediments and Silurian volcanics and metasediments, Lachlan Fold Belt

Variant	Positive p<0.001	Positive p<0.05	Negative p<0.001	Negative p<0.05
EM38H S1	pH, Surface, Scald, EC	Geology	H_2O_2, Slake, RP, PV, Litter, Patch, Evap, CO_2	Ants
EM38H S2	pH, Surface, Scald, EC	Geology	H_2O_2, Slake, RP, PV, Litter, Patch, Evap, CO_2	zero
EM38V S1	pH, Surface, Scald, EC	Geology	H_2O_2, Slake, RP, PV, Litter, Patch, Evap, CO_2	Ants
EM38V S2	pH, Surface, Scald	Geology, Reptiles, EC	H_2O_2, Slake, RP, PV, Litter, Patch, Evap, CO_2	zero
EM31H S1	pH, Surface, Geology, Scald	Reptiles, EC	H_2O_2, Slake, RP, Litter, Patch, Evap, CO_2	PV
EM31H S2	pH, Surface	Geology, Scald, EC	Litter, Evap, CO_2	H_2O_2, Slake, RP, PV, Patch
EM31V S1	pH, Surface, Geology	Infiltration, Reptiles	zero	Litter, Patch, Evap, CO_2
EM31V S2	Infiltration	Surface, Reptiles	zero	zero

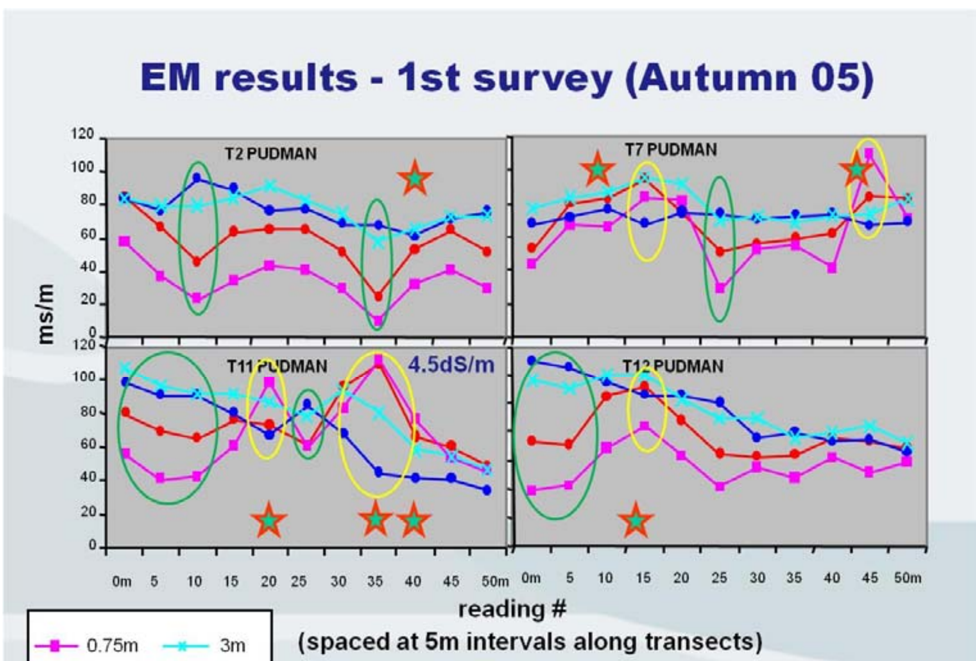

Figure 1. The EM results (ECa) from the first survey performed (autumn 2005) along four transects at one site (Pudman TSR) showing heterogeneity along the 50m transect; the effect of trees on the ECa shown with green circles (shallow EM38 readings are reduced, deeper EM31 readings are not); the effect of degraded, bare scalded areas on the ECa shown with yellow circles (shallow EM38 readings are increased, deeper EM31 readings are not) and elevated surface $EC_{(1:5)}$ on the ECa (shown with red/green stars – EM38 readings often increased; EM31 no effect). In many cases the deeper EM31 readings do not appear to correlate (i.e. are not associated) with the surface attributes and sometimes with the EM38. (Note that the depths indicated for each dipole is dependent upon a number of factors, so is approximate)

Discussion

The results show that on the STNSW, the EM38 provides valuable information regarding both abiotic attributes associated with soil and vegetation degradation, which elevated salinity levels are but one of many synergistic symptoms, and ecological attributes, particularly associated with the presence and condition of surface vegetation and the soil health and consequent productivity. This is also associated with soil moisture levels and clay, which are both major factors that influence the EM readings (ECa). The correlations with the ECa and pH and SOM appear to be related to the degree of soil and vegetation degradation, with pH levels usually increasing where elevated soil evaporation can occur (hence evaporite deposition), such as at bare areas, and reduced SOM levels associated with the lack of vegetation and litter incorporation (and soil microbial activity). The shallow ECa readings are usually reduced beneath trees, whereas the deeper ECa readings of the EM31 are often elevated, possibly due to better drainage at the surface beneath trees, effectively flushing any evaporites that may accumulate, if indeed they do accumulate with the reduced surface evaporation rates. In many cases, the A1 horizon, and hence the SOM content, is very thin and compacted, and sometimes, completely removed, such as at bare and scalded areas, which markedly increases the ECa. A thin A horizon effectively reduces the depth to the clay rich B horizon, which thereby increases the shallow penetrating ECa, especially the shallow (horizontal) dipoles which are heavily influenced from surface conductivity. The ECa is therefore a function of a number of factors associated with both a sustainable ecosystem and a productive environment, predominantly, soil moisture, depth to and thickness of the B horizon (or clay rich region), SOM content, salinity and conductive minerals.

Conclusion

The EM38 is particularly useful for identifying parameters associated with soil and vegetation degradation and therefore agricultural productivity. By surveying at strategic times of the year, both spatial and temporal information can be gathered. The methodology has potential for rapid monitoring and evaluating management practices such as site remediation and soil amelioration activities. This could include addition of SOM, improvement to soil moisture levels and retention and soil biology, revegetation and the addition of gypsum (calcium). The EM31 may be useful when used strategically with the EM38 (in the shallower reading, 3m depth horizontal dipole), but the deeper measuring vertical dipole showed few correlations, especially with the surface biotic attributes. It is therefore recommended that the EM38 in particular, be further investigated for biotic associations for environmental and land-management based investigations in other regions, particularly with improved data presentation software and inversion techniques (Smiarowski *et al.* 2011).

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