RICE CRC

FINAL RESEARCH REPORT

ISBN 1 876903 44 0

P1102FR09-05

Title of Project :	Better prediction of groundwater recharge from rice growing
Project Reference number :	1102
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BETTER PREDICTION OF GROUNDWATER RECHARGE FROM RICE GROWING

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SUMMARY

A range of restrictions are associated with rice growing – land suitability, target rice water use, buffer areas and hydraulic loading limits. The Land and Water Management Planning process undertaken in southern New South Wales Irrigation Areas and Districts clearly identified the need to improve the rice land suitability criteria. Improvements to rice soil suitability criteria (including soil sodicity) are required due to the continuing restrictions to irrigation water availability, along with the need to limit recharge to regional groundwater systems. These criteria will assist irrigators maximize rice water use efficiency by allowing selection of the most suitable soils for rice growing.

The Problem

Although the EM31 instrument, GPS and computer mapping technology have enabled significant improvements in the assessment of rice land to reduce groundwater accessions, modifications to the soil assessment process are needed. Cumulative infiltration during rice growing is known to vary significantly over four broad soil categories: self mulching clay soils, non self mulching clay soils, near levee soils and transitional red brown earths, there are also large differences in the level of infiltration within these soil categories (Van der Lelij and Talsma, 1978). Localised sites, which have high infiltration rates and thus allow high levels of groundwater recharge, may exist within rice fields and their delineation and exclusion or modification is an important aspect of rice land management in the southern Australian rice industry.

Many of the soils in southern NSW are sodic. In sodic soils both swelling and dispersion of the soil occur. Swelling and dispersion reduce soil infiltration, permeability and ultimately deep drainage/ groundwater recharge.

The Objective

The overall project aim was to improve rice land soil suitability identification and assessment approaches. The primary objective of this work was to investigate ways of refining the electromagnetic (EM) technology approach to include soil chemical characteristics specifically soil sodicity or exchangeable sodium percentage, in the rice land assessment process. Additional objectives were to: identify if the EM31 horizontal mode or EM38 provide better definition of the suitable rice land than the currently used EM31 vertical mode; and identify if land with ECa < 50 mS/m (EM31v) can be classified as unsuitable for rice without further determination of soil properties. The final objective was to promote adoption of the findings to date, particularly among irrigation company staff, DLWC regulatory staff and EM service providers to industry.

Methods

A number of rice fields within the rice growing areas of the Murray and Murrumbidgee Valleys were surveyed using the electromagnetic induction instrument EM31 in the vertical dipole. These fields were sampled across the range of EM readings within each field with soil properties being assessed (ECe, Saturation percentage, clay percentage, soluble cations, SARe and ESPe). We explored different methodologies to estimate soil sodicity (ESPe) in the field and in the laboratory for samples covering the range of EM31v values found in each field.

Results

The highlights of the results were:

1. Variations in EM31v values across fields reflected variation in soil sodicity values across those fields where variation was present.

2. Although a commercial field salinity/sodicity kit could reliably estimate laboratory measurements of electrical conductivity and sodium content of saturated soil pastes, the kit could not reliably estimate the saturation extract sodium adsorption ratio compared to laboratory measurements.

3. None of the simple “field“ tests could reliably estimate the degree of soil sodicity and therefore laboratory assessments of soil sodicity (ESP) must be undertaken to assist in defining rice suitable lands.

4. In established rice fields, the response of the EM31 and EM38 instruments, although not identical, were highly related both between instruments and instrument dipole orientations. This means that similar spatial variation of EM values would be mapped and hence a suitable soil sampling location strategy could be obtained using either of the instruments.

5. EM31v values of less than 30 mS/m reflect soils of high infiltration capacity and areas characterized by such values could be excluded from rice growing without further investigation of soil properties.

6. A high level of interest by irrigation companies in project progress and adoption of project findings

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BETTER PREDICTION OF GROUNDWATER RECHARGE FROM RICE GROWING

1. Background

Rice growing has been undertaken on up to 130 000 ha annually in southern NSW, using about 2000 gigalitres of irrigation water, this being about 60-70 % of irrigation water diverted annually in New South Wales from the Murray and Murrumbidgee Rivers. Significant recharge to the groundwater system can occur under rice growing, with resultant raised groundwater levels and increased risks of both soil and stream salinisation. The rate of groundwater recharge from rice growing varies widely depending on soil physical and chemical properties. Excessive infiltration from all irrigated activities has been identified to account for 40-50% of groundwater accessions in some irrigation areas (Gutteridge, Haskins and Davey, 1985).

Rice growers are under considerable pressure to increase the water use productivity (t/ML) and to reduce the water use (ML/ha) of rice-based systems to remain profitable and to meet community expectations regarding the use of irrigation water. One way to increase rice water use productivity and reduce rice water use is to reduce annual deep drainage and / or recharge below rice fields. The target for deep drainage is currently 200 mm however sites significantly in excess of this target occur. Dwyer Leslie Pty Ltd (1992) recommended the adoption of a rice industry target recharge figure of 1 Ml/ha (100mm/ha).

Humphreys *et al.* (1994) reviewed on-farm rice growing restrictions to minimise groundwater recharge. These include soil-based criteria, paddock rice water use limits, exclusion of land from rice growing and limits on the intensity of rice growing. Rice culture is confined to soils with at least 2-3 m of continuous medium to heavy clay (i.e. >45% clay) in the top 3.5 m, one soil profile per 4 ha (i.e. a 200 m grid) is generally assessed. Irrigation water use must not exceed a target set at the end of each rice season based on actual net evaporative demand. (Rice water use target = ETo – rainfall + 400mm) (ETo – reference crop evapo-transpiration). In addition, the total area of rice that can be grown each year is restricted, and rice area and water use are closely monitored by the water delivery authorities. “Rice environmental policy” is defined and implemented by the water delivery authorities as part of their overall Land and Water Management Plans.

There is considerable variation in percolation rates across soil types and within fields (van der Lely and Talsma 1978; Beecher *et al.* 2002) and small highly permeable areas can make a large impact on total percolation losses (Humphreys *et al.* 1998).

There has been rapid adoption of electromagnetic (EM31) survey technology for rapid, accurate and relatively inexpensive identification of soil variability and assessment of rice land suitability from soil texture, for rice fields, irrigation channels, drains and water storages (Beecher *et al.* 2002). To date more than one-third of the rice growing region has been surveyed using EM technology.

There is considerable evidence that the existing rice soil suitability criteria (based on thickness of a medium clay textured material) do not necessarily define land with high or low levels of groundwater recharge. For example Loveday et. al. (1978) proposed that water entry into the soil is controlled by a ‘throttle’ which develops “probably” in the upper B horizon where clay is at a maximum, electrolytes are at a minimum and (where) there may be appreciable quantities of exchangeable sodium and magnesium. Many soils of this description may be currently excluded from rice growing. Whilst Van der Lelij and Talsma(1978) reported that in “the texturally uniform self mulching soils flow restriction occurred at much greater depth (than the immediate sub surface)…Deep seepage (drainage) in such soils was **not** negligible”. These soils are frequently accepted as suitable for rice growing based upon the thickness of clay criteria. In addition, the Salinity and Contaminant Hydrology Group (1997) suggest that cracking clay soils have variable deep drainage rates depending on the subsoil sodicity. More sodic soils have lower deep drainage rates whilst low ESP soils have higher deep drainage rates, even with very high clay content, because the soils develop good structure.

McIntyre and Loveday (1979) found that clay type (eg. kaolinite, illite, smectite) appears to have little influence on the relationship between hydraulic conductivity and ESP. Clay swelling and dispersion were identified as the major mechanisms responsible for changes in soil hydraulic properties by Quirk (1986). Oster (1994) noted that reducing the salinity of the soil solution increased the swelling of clay soils and that sodic clays swell more than calcium clays. Oster (1994) further commented that soils respond differently to the same combination of salinity and SAR because of differences in clay content, mineralogy, iron and aluminium oxide content and organic matter content. He concluded that increasing SAR and decreasing salinity can cause the soil to swell, resulting in significant reductions (10-25%) in saturated soil hydraulic conductivity. Soil sodicity is thus important in determining soil permeability.

Although sodicity has been included in the Murrumbidgee Valley assessment criteria since 1995, no quantitative or qualitative measurement of soil sodicity is undertaken when classifying potential rice soils and it has only recently been part of the current Murray Valley soil criteria process (Norwood 2003).

Table 1: Rice soil suitability criteria for the Murray region

Rice growing category	Depth of continuous medium or heavy clay in top 3.6 m of soil
Suitable for rice under continuous rotation	>3.0m
Marginal for rice growing (1 crop every 4 yrs)	2-3m (minimum is 2m in the top 2.5m of soil)

Source: Murray Irrigation Limited Rice Growing Policy for 1998-99

Table 2: Rice soil suitability criteria for the Murrumbidgee region

Rice growing category	Depth of continuous medium or heavy clay in top 3.5 m of soil
Suitable for rice under continuous rotation	>2.0m where a sodic heavy clay B horizon is present from 0.1 to 0.6m OR >3.0m if there is no low permeability B horizon present

Source: Dept. of Land and Water Conservation recommendations for 1998-99

The application of an improved rice land classification criterion could reduce groundwater recharge from rice growing. Using soil texture (clay content) profiles as a criterion for rice land suitability has been useful in eliminating sites of potentially high groundwater recharge due to the occurrence of sand at shallow depth. However, texture profiles alone are poor indicators of recharge beneath flooded rice fields where soil chemistry and structure are significant factors controlling recharge, e.g. in self mulching soils or sodic transitional red brown earths (Beecher *et al*. 2002). An inclusive three-stage classification system, involving electromagnetic surveying (EM31v) and assessment of soil sodicity (ESP) at two depths, has been developed to identify soils with low recharge rates.

The classification process suggested by Beecher et al (2002) is:

1. Include the soil if the EM31v measurement is equal to or greater than 150 mS/m.
2. If EM31v < 150, include the soil if the ESP of the top 60 cm of the soil is greater than 6, or the ESP of the depth interval between 60 and 150 cm is greater than 12,
3. All other soils are excluded from rice growing.

Use of such a system, would improve the efficiency of detecting high groundwater recharge sites within rice fields and other water bodies (channels, drains, on-farm storages). Appropriately using / managing these high groundwater recharge areas will reduce overall groundwater recharge and help moderate increases in groundwater levels of irrigation areas and subsequent soil salinity.

2. Objectives

The project was established to address several aspects of the rice land soil suitability assessment issue. The objective of this work was to investigate ways of refining electromagnetic (EM) technology to include soil chemical characteristics, specifically soil sodicity or exchangeable sodium percentage in the rice land assessment process. To this end, we explored different methodologies to estimate soil sodicity (ESP/ESPe) in the field and in the laboratory. Additional objectives were to: identify if the EM31 horizontal mode or EM38 provide better definition of the rice suitable land than the currently used EM31 vertical mode; and identify if land with ECa < 50 mS/m (EM31v) can be classified as unsuitable for rice without further determination of soil properties. A final aim was to increase awareness and promote adoption of the findings, particularly among irrigation company staff, DLWC regulatory staff and EM service providers to industry.

3. Introduction

Previous work (Hume *et al.* 1999 and Beecher *et. al.* 1994) identified that the rice land suitability assessment process could be improved by the use of electromagnetic induction instruments to map variability in soils in rice fields and target sampling sites on the basis of the EM mapping. Hume *et al.* (1999) further identified that assessment of soil sodicity could be used to better refine the soil assessment process.

Ground based electromagnetic induction (EMI) instruments can provide rapid measurement of the apparent electrical conductivity (ECa) of a soil profile. There are essentially two models of non-contact EMI sensors that are commonly used in agriculture, the EM38 and EM31 (Geonics Limited). The EM38 is designed for relatively shallow applications, specifically within the root zones of many crops, while the EM31 measures the soil conductivity to a depth of several metres. The EM31 is currently used in conjunction with targeted soil profile sampling for surveying irrigated fields in south-eastern Australia for the assessment of soil suitability for rice growing based on soil texture. The relationship between ECa measured by the EM31 and EM38 was investigated in a semi-arid region of Texas by Scanlon *et al.* (1999). They took measurements at the ground surface in both vertical and horizontal instrument dipoles, finding the instruments to be highly correlated ($r = 0.96$ to 0.98) and suggested that the EM31 and EM38 could be interchangeable. Triantafilis *et al.* (2001) obtained a large number of ECa readings in an irrigated cotton field in the lower Gwydir Valley in northern New South Wales using EM38v located 25 cm above the soil surface and EM31v, 1 m above the soil surface. Their results identified the EM38v readings to be lower than the EM31v readings and were correlated with r^2 of 0.58.

Rice production in rotation with winter and summer crops and annual subterranean clover pastures is the major land use of the irrigated lands in the Riverina region of southern New South Wales, Australia. This area includes the Murrumbidgee and Coleambally Irrigation Areas, Murray Irrigation Districts and riparian irrigators along regulated streams in the Murrumbidgee, Murray and Lachlan Valleys. Rice fields are ponded with water between 120 to 180 days, so the potential for excessive deep drainage / groundwater recharge is higher than for intermittently irrigated crops or pastures. It has been estimated that rice growing consumes in the order of 2000 gigalitres of water annually. Lehane (1983) estimated that up to 25% of applied rice water bypasses the crop root zone. This excessive infiltration has been identified to account for 40 – 50 % of groundwater accessions in some irrigation areas (Anon. 1985). Groundwater recharge from rice growing varies between 0 and 10 ML / ha / year. Rising regional groundwater levels contribute to waterlogging of the rootzone and soil salinisation.

To minimise the impact of recharge on rising regional groundwater levels, soils are assessed for their suitability for rice growing. Rice soil suitability is currently assessed by hand texturing of soils and suitable soils must have more than 2 m of continuous medium/heavy clay (Van der Lelij 1995). Rice industry regulators (irrigation companies and NSW Department of Land and Water Conservation) have recently incorporated the use of electromagnetic surveys (Geonics EM31) in the rice land suitability assessment process. The sites identified by EM31 survey are then bored to 3.5 m depth and assessed for rice suitability using the existing soil textural-based criteria. Van der Lelij (1988) incorporated soil sodicity into the rice soil suitability assessment criteria. However, he did not propose any quantitative measure of sodicity. Sodic soil conditions can contribute to reduced recharge in rice fields, although there are agronomic constraints in establishing a rice crop in soils with high surface soil sodicity (Humphreys and Barrs, 1998).

Beecher *et al.* (2001) used a Geonics EM31 instrument in the Murrumbidgee and Murray Valley to undertake rice soil suitability investigations of 29 rice fields. The Geonics EM31 instrument, which measures the bulk electrical conductivity (ECa) of soil up to 6 m depth (from the soil surface), was used to assist in the identification of soil suitability assessment sites. They reported that the current soil texture classification for rice growing is not fully valid. High ground water recharge levels can occur under self mulching clay soils that meet the soil textural criteria and low recharge can occur under lighter textured soils with higher soil sodicity levels. They suggested that the use of EM31v (ECa measured by the Geonics EM31 in the vertical mode) to target soil assessment sites combined with soil sodicity assessment could improve the rice suitability assessment criteria and reduce groundwater recharge. They further suggested the use of mean ESP of 6 and 12 for the 0-60 and 60-150 cm depth intervals to predict low permeability soils that would be suitable for rice growing.

EM31v surveying of rice fields has had a large impact on the positioning of soil sampling sites for further investigation, changing the procedure from a random grid approach to one that is targeted based on variations in soil physico-chemical properties across the field as assessed by the EM reading. But changing of the assessment criteria for rice soil suitability, from one that looks at soil texture from a depth of 3.6 m or more, to a criteria based on soil sodicity to a depth of 1.5 m leads us to question whether EM31v is the most suitable for this application.

This work has shown that soil sodicity strongly influences recharge (deep drainage/ recharge) from ponded rice. They recommended that more studies be undertaken to investigate the spatial variability of soil sodicity within rice fields. There was also a desire to explore the use of rapid in-field tests for sodicity assessment in rice fields.

4. Methodology

Simple methods to determine or infer sodicity in the field were investigated. These methods were seen as needing to be: grower friendly, cost effective, time saving with rapid results providing decisions of rice land suitability similar to the field texturing assessment approach. The methods to assess soil sodicity investigated included a range of ESP/sodicity indicators including the Emerson aggregate test (Emerson and Loveday and Pyle, 1973), SASKIT turbidity test (Regasamy and Bourne 1997), estimation of soil SAR in 1:5 (soil/solutions) from Na (Horiba Cardy meter) and EC (portable EC meter) and the USSL/Hach field Salinity/sodicity field kit in addition to saturated soil solution extract sodium adsorption ratio analysis.

4.1 Rice fields and site selection

Commercial rice fields in the Murrumbidgee Irrigation Areas (Yanco and Mirrool), Coleambally Irrigation Area and in the Berriquin, Deniboota and Wakool Irrigation districts of the Murray Valley were surveyed using the Geonics EM31. All fields had a rice growing history of at least 10 rice crops. They represented four general soil groups: red brown earths (RBE), transitional red-brown earths (TRBE), non self-mulching clays (NSMC) and self-mulching clay soils (SMC) (in terms of Stace *et al.* (1968), red brown earths and grey, brown and red clays). The soil types included Birganbigal sandy loam (RBE), Mundiwa clay loam, Tuppal clay loam(TRBE), Gogelderie clay (SMC), (Van Dijk, 1961) and an un-named NSMC from near Murrami. In the Murray Valley the soils included Marah loam (TRBE), Bunnaloo loam (RBE), Riverina clay (NSMC) (Johnston, 1953) and Moulamein clay (SMC) (Smith *et al.*, 1943).

4.2 EM31 surveying

The Geonics EM31 instrument (McNeill 1980), mounted on the front carrier of a 4WD motorcycle, was used to survey the fields. The instrument was supported by a non-inductive PVC structure and was ‘setup’ following the manufacturer’s instructions to ‘null’ the motorcycle from the instruments view. Measurements of the soil ECa (apparent electrical conductivity) were taken with the instrument coils in the vertical dipole orientation (EM31v) and 1 m above the soil surface. EM31v readings were taken at 1 second intervals as the motorbike traversed the field and the measurement positions were located geographically using a differential global positioning system (dGPS). The distribution of EM31v values was contour mapped based on dGPS data using the mapping program SURFER (Golden Software, 1999). The mapping program interpolated a regular 10 m grid of EM31v values from irregular, though densely located data points, using the interpolation procedure, kriging. Mapped EM31v values over the fields ranged from 25 to 200 mS/m in the Murrumbidgee Valley and from 96 to 338 mS/m in the Murray Valley. Four or five EM31v classes were defined, for each rice field based on the frequency distribution of EM31v values in the field. The mapped values of EM31v were used to randomly locate 5 sampling sites at approximately the mean EM31 value within each EM31v class (Fig. 1). Soil sampling sites were chosen either on the basis of drill points, as per the adopted survey approach, or based on the mid point of quartile ranges of the EM data for each field.

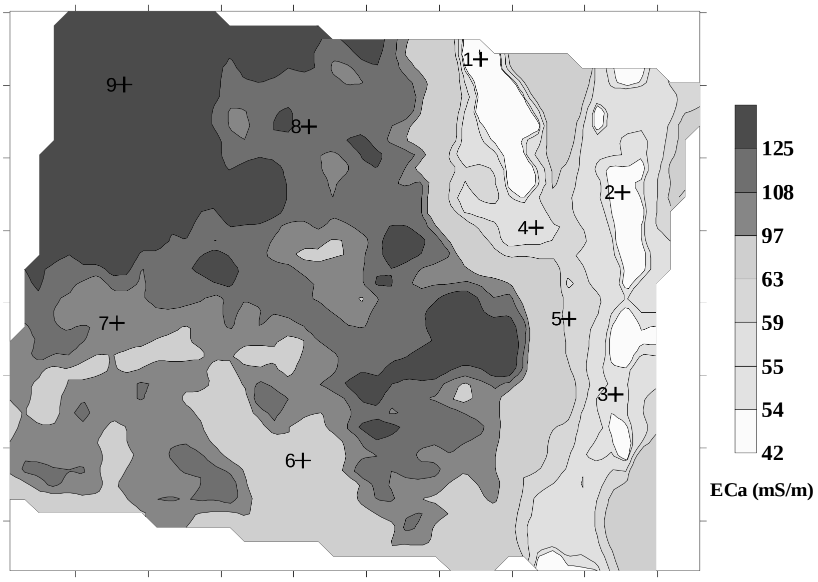


Figure 1. *Apparent electrical conductivity (ECa) map of a rice field showing the location of rice land suitability sampling points for depth of clay assessment.*

4.3 Soil sampling and sample preparation

At each sampling site, soil samples were obtained by augering and were taken in 15 cm increments to 30 cm, and then 30 cm increments to 150 cm. The soil samples were air-dried and crushed using a jaw crusher (Van Gelder Crushers Pty Ltd Sydney) several times to pass a 2mm sieve and then stored in plastic bottles.

Un-crushed sub-samples of soils from each sampling site were retained in order to undertake Emerson dispersion tests and SASKIT Jar tests

4.4 Emerson dispersion test

Soil dispersion related to high soil ESP levels in soil is commonly assessed in the field using the Emerson dispersion test. Loveday and Pyle (1973) refined Emerson’s test by subdividing the classes and taking the rate and degree of dispersion into account developing a dispersion index. Their index was highly correlated with ESP. They were able to use the modified test to predict broad classes of soil hydraulic conductivity. The soil samples that they examined also included soils from the Riverina region.

Samples were processed as per the methodology of Loveday and Pyle (1973).

4.5 SASKIT turbidity jar tests

Rengasamy and Bourne (1997) investigated the use of a jar test to assess the likely most important problem in a soil (acidity, salinity or sodicity) based on the turbidity, acidity and salinity of the 1:5 soil water suspension and the soil texture. They developed a ranking that identified the likely most important problem of the soil. The system adopted allows most soils (surface and subsoils) to be ranked into non sodic, sodic and highly sodic categories.

4.6 Ion specific meters

The availability and relative low cost of specific ion sensitive electrodes such as the Horiba Cardy meter allow the accurate measurement of sodium of solutions in the field. This meter employs a selective sodium ion electrode that is unaffected by pH and the presence of other ions, enabling the accurate measurement of sodium ion concentrations.

An assessment was made of the ability of the Cardy meter with associated EC measurements to measure the SAR of the 1:5 soil extract. Nelson *et.al* (2002) utilised the Horiba Sodium Cardy meter to measure sodium concentrations in 1: 5 soil water extracts in the north Queensland sugar industry. They found a significant correlation between the sodium concentration measured in the 1:5 soil water extract and the ESP as measured by the Tucker method (Loveday 1974).

4.7 Hach Salinity and Sodicity field kit

Beale *et al.* (1998) reported the development of a field based soil sodicity meter at the USDA Salinity Research Laboratory, Riverside, California. Beale *et al.* (1998) recommended that the in-field sodicity meter be evaluated as (for) an objective measurement of soil properties important in the assessment of rice soil suitability. This meter (kit) was developed by Rhoades *et al.* (1997) and sold as the Hach Field Test Kit.

Literature about the Hach kit claims “Farmers and land managers can determine in the field whether their soils contain too much salt or sodium. The presence of excessive levels of sodium in soils and irrigation waters causes deleterious effects on their use for crop production. This hazard is referred to as sodicity and is a serious problem in some parts of the US and abroad. The reclamation and management of such soils and waters requires appropriate, practical methods for diagnosing sodicity. Conventional methodology takes about seven separate analytical operations to determine the sodium-adsorption-ratio (SAR) which is the traditional index of soil and water sodicity hazard. Much faster and simpler methods were developed and successfully tested on a wide range of salt-affected soils and extract solutions. The methods avoid the need for laboratory analyses of calcium and magnesium concentrations and, in the case of soils, to separate extracts from the saturated soil-pastes. The SAR is sufficiently accurately estimated in the methods using simple electrode measurements made directly in the pastes.”

4.8 Soil chemical analysis

4.8.1 1:5 Soil:Water Extracts

The electrical conductivity (ECe) of the 1:5 soil:water extract (dS/m) was measured using a Hanna HI 9033 conductivity meter. Soil samples were analysed for $pH_{1:5}$ in the 1:5 soil:water suspensions (Loveday 1974).

4.8.2 Saturation extracts

Air dried, ground soil samples passed through a 2-mm sieve were used to prepare saturated soil pastes. The saturated soil paste was prepared by hand mixing (Rhoades and Miyamoto 1990). Prepared pastes were kept overnight. Before extraction of the soil solution, soil pastes were re-checked for saturation.

The saturated soil paste was then split into three parts for the following measurements:

1. Standard Saturated paste laboratory measurements: The saturated pastes were centrifuged (RCF 8000 g for 15 min) and a sample of the saturated soil paste extract obtained (Slavich and Petterson 1993). The electrical conductivity (ECe) of the saturation extract (dS/m) was measured using a Hanna HI 9033 conductivity meter. An atomic absorption spectrophotometer (Perkin Elmer model 2380, USA) was used to measure Na^+, Mg^{2+} and Ca^{2+} concentrations (mg/L) of the saturation extract. These data were used to calculate the sodium adsorption ratio (SARe) values using the relationship $Na/\{(Ca+Mg)/2\}^{1/2}$ where the cation concentrations are in meq/L. The SARe values were then used to calculate the exchangeable sodium percentage (ESPe) of the saturated soil paste using the relationship of US Salinity Laboratory Staff (1954).

The ESPe data for the soil depth intervals analysed were used to calculate average depth weighted ESPe data for the 0-60 cm and 60-150 cm intervals for each site sampled.

2. Saturation Percentage: This was determined from oven drying (U.S Salinity Laboratory Staff 1954).

3. Hatch kit measurements: Soil paste pH, electrical conductance, temperature, Na^+ electro potential (mV) and weight of the paste in the conductivity cup (50 cm^3) were measured. The estimation of Na^+ concentration (Nae), pH (pHe), sodicity (SARe), electrical conductivity (ECe), estimated Ca^{2+}+Mg^{2+} concentration (Ca+Mg)e in the extract and saturation percentage (SP) in the paste were calculated using the SoilSYS software.

Horiba Cardy meter

Soil saturation extracts were obtained from the saturated soil pastes. The electrical conductivity (ECe) of the saturation extract (dS/m) was measured using a Hanna HI 9033 conductivity meter. Sodium ion concentration was measured using the Horiba Cardy meter. Estimates of the soil SARe were made using the relationship of McIntyre (1980) between EC and sum of cations, (assuming K is minimal, ie 0).

$SARe = Na/((TCC-Na))/2)*0.5$

4.9 Comparison of EM31 and EM38 instruments within rice fields

Data were collected from 358 sites across 13 irrigated fields with a history of rice growing. Their characteristics are listed in Table 3. The fields used for the EM31/EM38 comparisons were in various stages of their rice rotation crop sequences when measurements were obtained, but all had a near full soil moisture profile.

Table 3. Characteristics of rice fields EM surveyed.

Field No.	Area	Soil type	Field Size (ha)	EM Sites	EM31v Range
1	MIA	Red brown earth	22	20	27 – 111
2	MIA	Non self mulching clay	18	29	133 – 214
3	MIA	Non self mulching clay	20	40	87 – 210
4	MIA	Non self mulching clay	20	46	76 – 167
5	MIA	Red brown earth	21	20	45 – 135
6	MIA	Red brown earth	6	24	79 – 204
7	MIA	Self mulching clay	22	29	30 – 107
8	MIA	Red brown earth	10	27	20 – 113
9	MIA	Red brown earth	16	27	53 – 157
10	WMV	Red brown earth	16	26	49 – 146
11	WMV	Red brown earth	10	15	71 – 173
12	WMV	Transitional Red brown earth	26	26	31 – 113
13	WMV	Red brown earth	48	28	14 – 214

MIA- Murrumbidgee Irrigation Areas, WMV- Western Murray Valley

4.9.1 Site Selection and Location

For each field, the existing EM31V survey was used to guide site selection for EM31/EM38 comparisons. The ECa map was displayed using the software mapping program ‘Surfer’ (Golden Software), and the recorded EM31 values layered over the contour map at their actual position. Sites with ECa values including the lowest and highest and covering the range in each field were selected and the dGPS location coordinates for each site recorded. Each site selected had a number of similarly valued ECa sites around it. The position coordinates for each site were transferred to a dGPS with sub-metre accuracy, which was used to navigate to each site.

4.9.2 EM31/38 readings

The Geonics EM31 instrument (McNeil, 1980) was mounted on the front carrier of a 4WD motor bike approximately 1 m above ground level and at right angles to the direction of travel. The instrument was supported by a non-inductive PVC structure and was 'setup' following the manufacturers' instructions to 'null' the motorbike from the instrument view. The EM31 was set to the 0-1000 mS/m scale, which has proved the most appropriate and manually rotated 90° between the vertical and horizontal dipoles when necessary. The Geonics EM38 instrument was carried by hand to take the field measurement of soil ECa. The instrument was setup following the manufacturers' instructions and all metal objects were removed from the user due to the instrument's high sensitivity to metal objects.

After navigating to each site, the EM31 vertical and horizontal dipole ECa readings were recorded. A wooden peg was then used to mark the site and the motor bike driven at least 15 m away. The EM38 was then placed on the soil surface at the site and ECa readings recorded for both the vertical and horizontal dipoles.

4.10 Statistical analysis

Summary statistics were used to observe the ranges and means of parameters in the each depth interval. Analysis of variance and linear regression analysis of the data were conducted using Genstat 5 (IACR Rothamsted 1998). Analysis of variance was used to estimate the least significant differences (L.S.D) of means at the 5% level to compare the differences in sodicity across EM31v classes at the 0-60 cm and 60-150 cm depth intervals and individual depth intervals for all soil types. Significant differences of slopes and intercepts of linear relationships for soil types were compared using simple linear regression. The correlation coefficients of parameter averages within the (0-60 cm) and (60-150 cm) intervals were calculated.

In the statistical comparison of the EM31 and EM38 surveys, there are two aspects to the adopted sampling scheme that should be noted:

1. The existing EM31v survey consisted of sampling along transect across the entire field.
2. Sampling sites for the four sets of measurements were chosen to cover a range of values within a field from the existing survey.

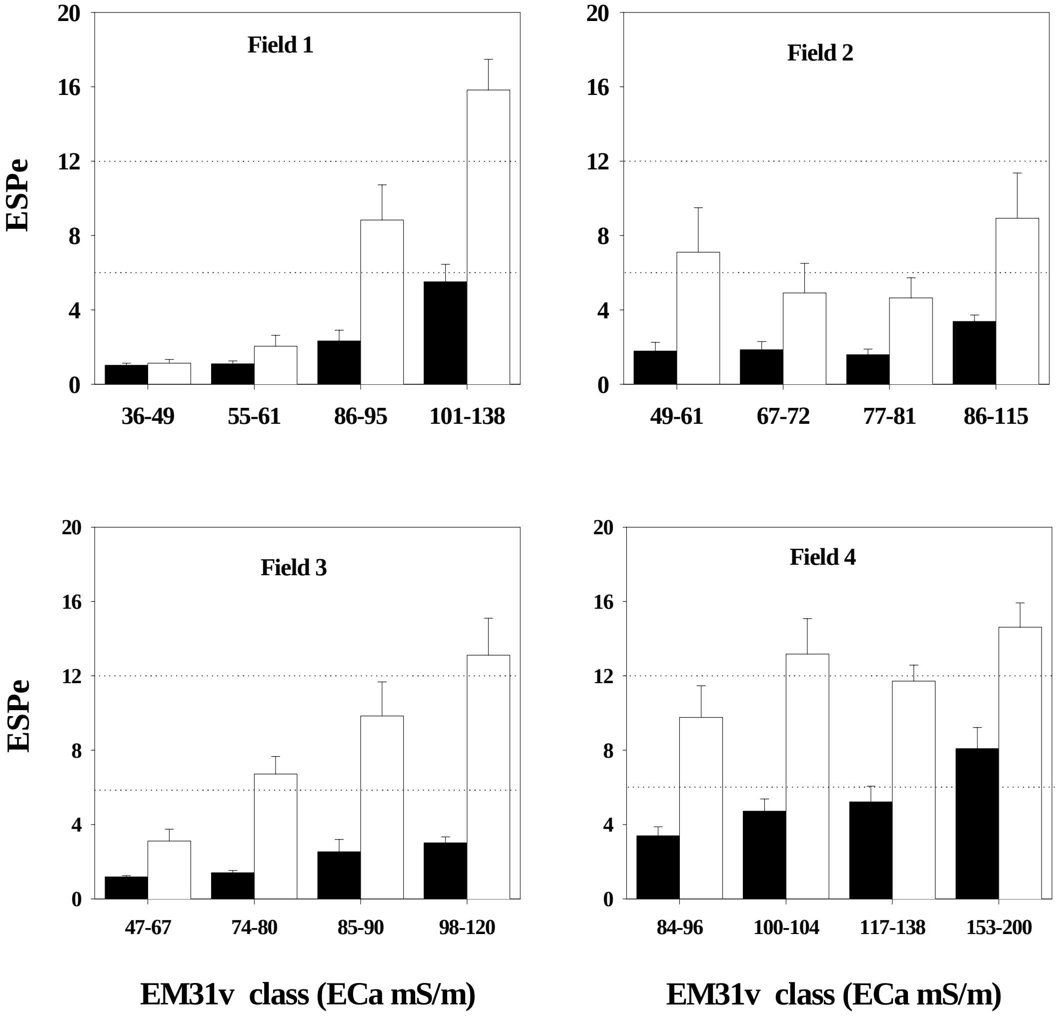
The sampling sites for the four sets of measurements are therefore neither on a regularised grid nor have been randomly selected. The statistical analysis of the relationship between the four sets of measurements (EM31v/h, EM38v/h) is achieved with the use of a factor analytic (FA) model which respects the notion that the ECa measurements are essentially functions of some unobserved factors. The FA1 and FA2 models were fitted using the statistical software package ASReml (Gilmour et. al. 2002).

5. Detailed Results

5.1 Variation in ESPe across rice fields from MIA, Coleambally and the Murray Valley

The ESPe of the 0-60 cm and 60-150 cm depth intervals across the range of EM31 values for fields surveyed using the EM31 are shown in figures 2 and 3 (below).
The fields covered a range of soil type and groundwater conditions - Field 1 red brown earth, Field 2 Transitional red brown earth, Field 3 self mulching clay and field 4 non self mulching clay.

Figure 2. *ESPe values for soils sampled across EM31v rages of 4 fields in the Murrumbidgee Valley*



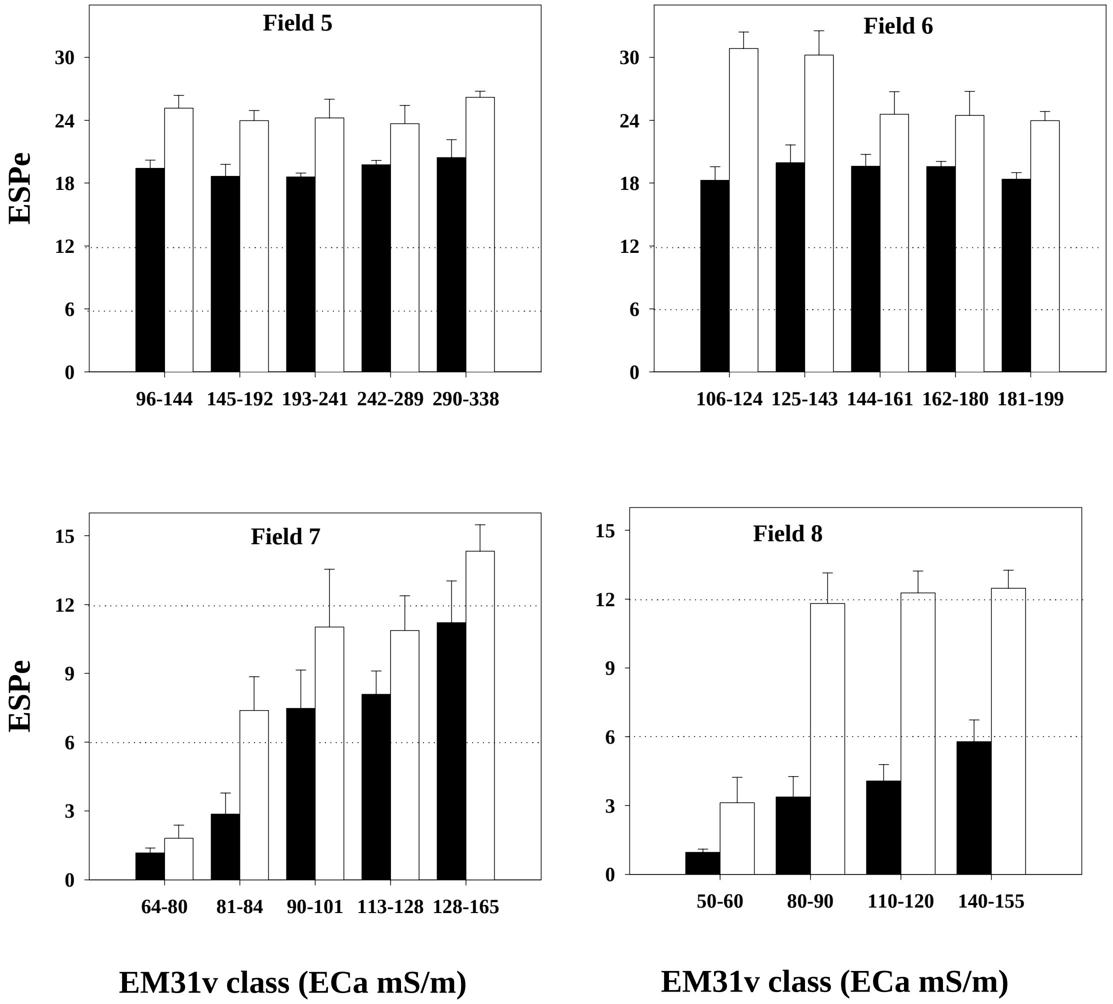


Figure 3. *ESPe values for soils sampled across EM31v rages of 4 fields in the Murray Valley*

Variation in ESPe values showed generally a progressive increase across the EM range (Fields 1, 3, 7, 8). Whilst in other fields (5, 6) where high EM values occurred the ESPe values were found to be consistently high - as expected in being saline/sodic soils.

5.2 Dispersion Index Tests

The dispersion test indexes were unable to distinguish between soils identified as being non saline non sodic, non saline sodic, saline sodic or saline based on soil analyses. Figure 4 below indicates the lack of discrimination.

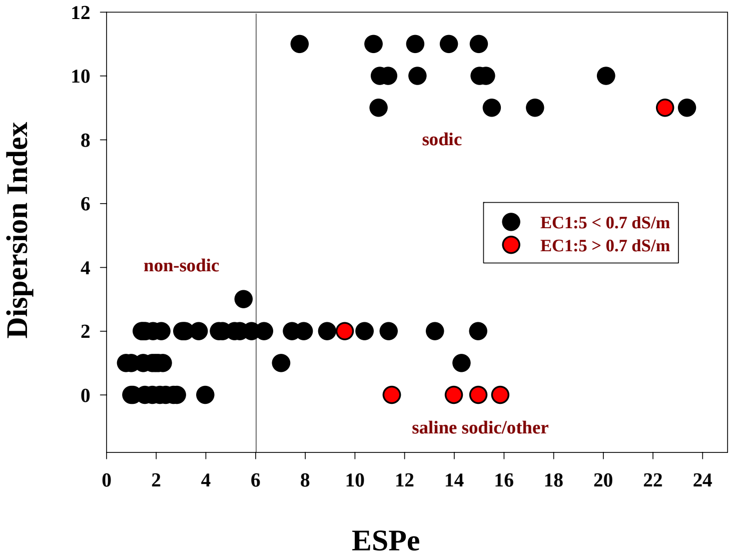


Figure 4. *Variation of dispersion index (Loveday and Pyle 1973) values for a group of soils with varied salinity and ESPe.*

Murphy (1995) concludes that the Emerson aggregate test is a quick, cheap, and useful test to assist in the identification of sodic soils but further work is required to evaluate the effects of salinity level, clay content, pH, and organic matter on the relationship between Emerson aggregate classes and subclasses and ESP.

5.3 SASKIT Turbidity Jar test

The SASKIT system was unable to appropriately categorise the soils based on ESPe measurements.

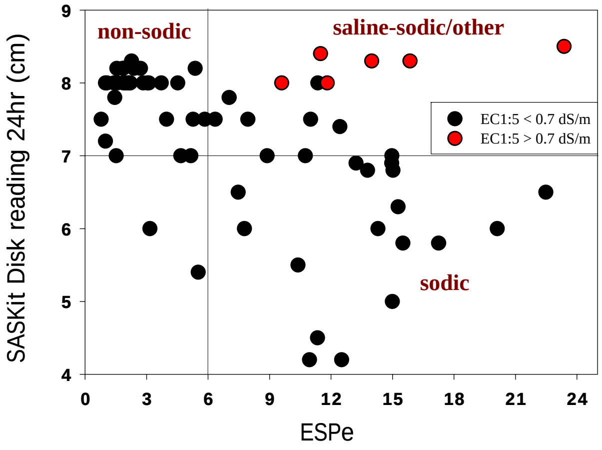


Figure 5. *Relationship between SASKIT disc readings and ESPe measurements*

5.4 Horiba Cardy Ion Specific meters

The reliability of the Horiba Cardy sodium meter was found to be quite reliable in estimating the sodium concentration of soil solution extracts although the relationship between sodium measurements by ASS and the Cardy meter deviated from a 1: 1 relationship (Figure 6).

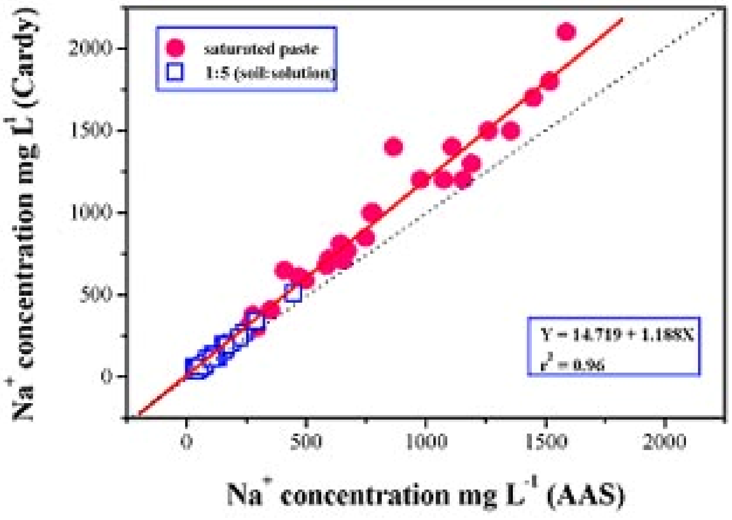
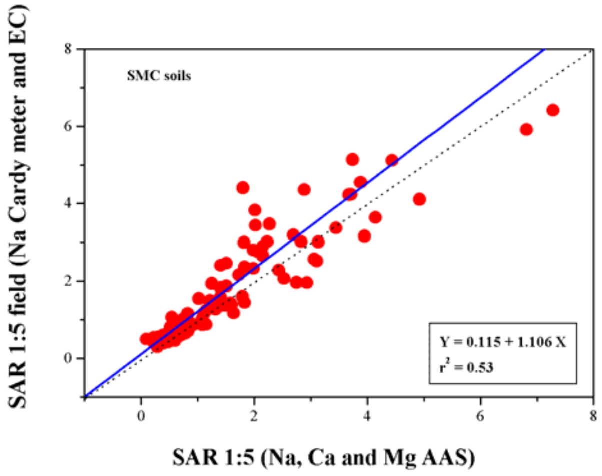


***Figure 6.** Relationship between soil solution sodium concentration measured by cardy meter and by atomic absorption spectrophotometer*

Estimation of the SAR of 1:5 soil: water solutions using the Cardy meter along with EC of the solution readings compared to the SAR 1:5 measured using ASS measurement of the sodium, calcium and magnesium concentrations was not satisfactory Figure 7.

***Figure 7.** Relationship between SAR of soil solution measured by atomic absorption spectrophotometer and by ion specific electrode and electrical conductivity meter*



5.5 Hach Salinity/ Sodicity Field Kit

Overall strong relationships were found between the Hach field kit estimates and conventional laboratory measured values using standard methodology for the electrical conductivity of soil saturation extracts (ECe) (Fig. 8), saturation extract sodium concentration (Nae) (Fig. 9) and soil saturation percentage (SP) (Fig.10).

Figure 8. *Relationship between ECe (dS/m) estimated from standard methodology and the Hach Salinity/Sodicity field kit (regression relationship is for all soils).*

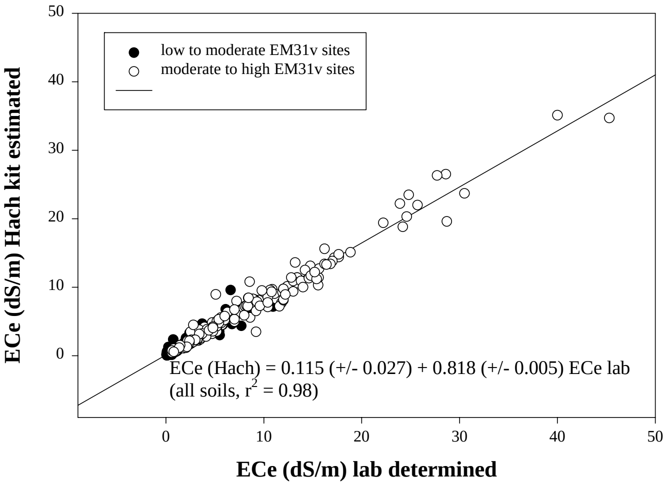
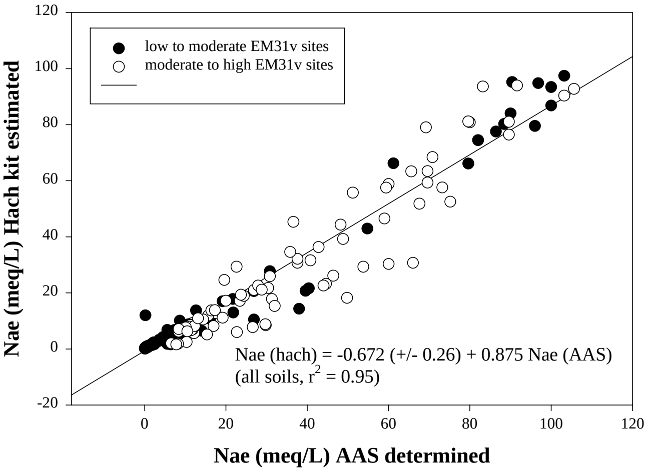


Figure 9. *Relationship between estimated Nae (meq/L) from standard AAS methodology and from the Hach Salinity/Sodicity field kit (regression relationship is for all soils).*



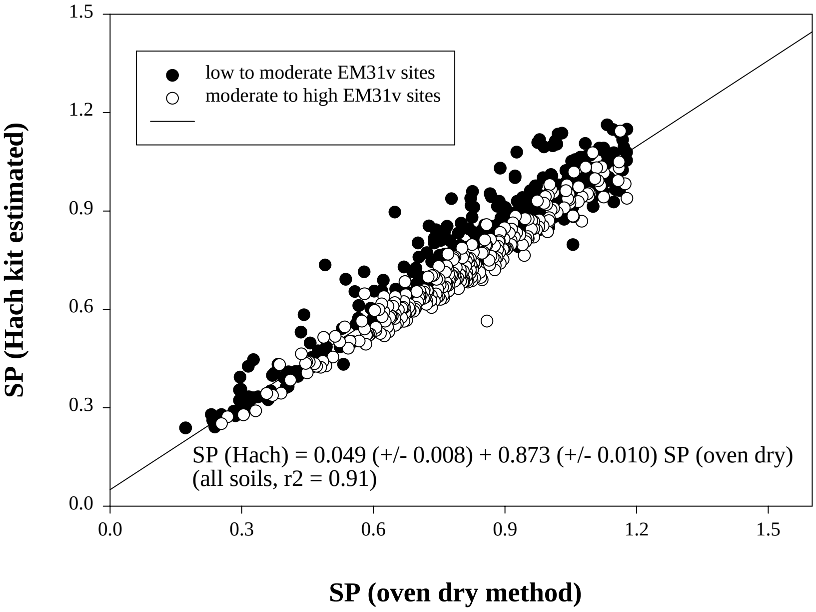


Figure 10. *Relationship between saturation percentage determined by oven drying and by Hach Salinity / Sodicity field kit.*

Although there was a strong relationship between the saturation percentage determined by oven drying and the Hach Field kit, the Hach field kit methodology consistently underestimated the saturation percentage measured by the oven drying method.

However a such close relationship was not apparent in the estimation soil sodicity (SARe) estimation when using this Hach field kit compared to conventional laboratory (ASS) analysis.

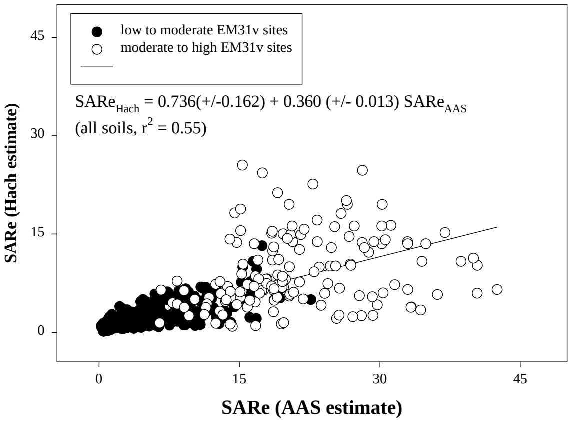


Figure 11. *Relationship between SARe estimated from two methods (regression relationship is for all soils).*

Following discussions with Scott Lesch (USDA Salinity Laboratory, Riverside) regarding use of the Hach salinity and sodicity field kit further evaluation of the Hach kit was undertaken. We explored the kit measurements using the approach described by Rhoades *et al.* (1997) to compare the Hach salinity and sodicity field kit and the standard laboratory methods for the same measurements. Scott Lesch provided all the software equations in the SoilSYS software to calculate all the parameters included in the kit calculations. This exercise identified an error in the software calibration of the commercial product.

However we were unable to resolve poor relationships between SAR measurements made by the field kit and standard soil saturation extract measurement methods.

5.6 Elimination of low EM31v valued sites prior to ESP measurement.

We were able to review our data and Murray Irrigation's EM31/ESP data as an expanded data set to review if land with ECa values of less than 50 mS/m could be excluded from rice growing without further assessment of soil properties. There were sites with EM31 values between 30 and 50 which had acceptable ESP values. Additionally the soil moisture content at the time of survey does influence the EM31 values measured. A difference in EM31 values in the order of 15-20 mS/m between "dry" and "wet" field has been observed (e.g. when fields have been surveyed before and after an irrigation – although the patterns of EM31v value distribution across the field remains consistent). So a conservative approach has been applied in assessing a lower value (30mS/m) at which sites might be eliminated as not suitable for rice growing on the basis of EM31 readings alone thus not requiring ESP assessment.

5.7 Comparison of EM31 and EM38 instruments within rice fields

Data were collected from 358 sites across 13 irrigated fields with a history of rice growing using EM31 and EM38 instruments in both vertical and horizontal dipole modes. Within individual fields, the EM31 in vertical dipole mode (EM31v) was most highly correlated with EM31 horizontal dipole readings ($r^2 = 0.93 – 0.99$) followed by EM38 in vertical dipole (EM38v)($r^2 = 0.88 – 0.96$) and EM38 in horizontal dipole ($r^2 = 0.74 – 0.95$) (Table 4, Figure 12).

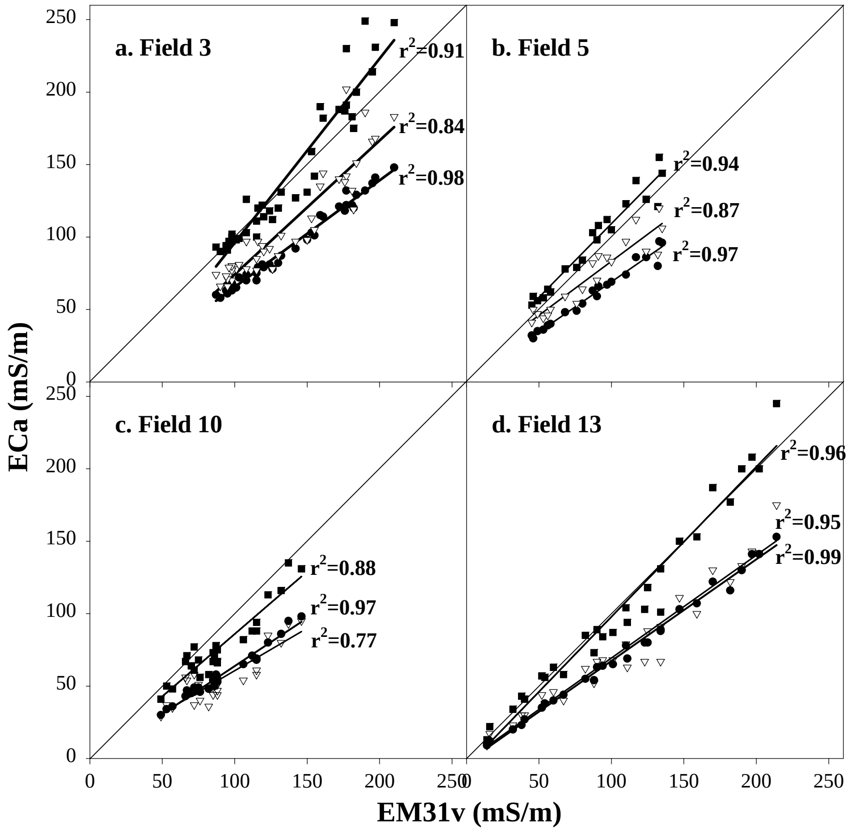
These results indicate that the EM31 could be used in either the vertical or horizontal dipoles and it would make little difference to the outcome. There would be no benefit in using the EM31 in the horizontal mode, as there is no cost saving in equipment and the range of EM values would be reduced by 29%. The EM31v value of 150 mS/m used in the recommended criteria (Beecher 2002) would also have to be modified if the instrument were used in the horizontal dipole.

Results also show that it would be possible to use the EM38 in the vertical mode to survey for rice soil suitability, but again the 150 mS/m EM31v value in the suggested criteria would need to be changed if the EM38v were used. Although strong relationships exist on a within field basis no acceptable general relationship was identified. The EM38 is considerably cheaper to purchase than the EM31 and its compact size is also beneficial. The disadvantages of the EM38 include that it has to be towed on a sled or trailer which has considerable wear problems and makes it unsuitable for surveying rough fields. Another problem relates to its reduced depth of penetration and the requirement for moisture in the soil profile for accurate results. Scanlon et al. (1999) identified that in areas of below threshold water contents, EM induction is insensitive to variations in chloride content that could indicate zones of high infiltration in the past.

Table 4. Linear regression relationships showing the r^2 and equation between the EM31v and EM31H, EM38v and EM38H for each of the fields in this study.

Field	EM31H	EM38v	EM38H
1	0.93, y=0.58x+0.8	0.90, y=1.05x+7.0	0.86, y=0.77x+9.2
2	0.99, y=0.76x-12.5	0.94, y=1.41x-62.2	0.89, y=1.04x-49.6
3	0.98, y=0.74x-8.1	0.91, y=1.27x-30.9	0.84, y= 0.84x-18.0
4	0.98, y=0.68x-5.3	0.93, y=0.86x+2.5	0.83, y=0.50x+17.9
5	0.97, y=0.69x-0.1	0.94, y=1.02x+7.5	0.87, y=0.75x+8.6
6	0.99, y=0.78x-10.9	0.93, y=1.39x-39.7	0.83, y=1.04x-17.4
7	0.98, y=0.59x+0.8	0.92, y=0.64x+12.8	0.76, y=0.34x+19.9
8	0.97, y=0.66x-3.0	0.89, y=0.94x+3.3	0.86, y= 0.81x-0.1
9	0.99, y= 0.67x-0.9	0.95, y=0.88x+11.7	0.90, y=0.64x+12.9
10	0.97, y=0.66x-2.3	0.88, y=0.85x-0.1	0.77, y=0.59x+2.1
11	0.98, y=0.77x-13.0	0.91, y=1.50x-61.3	0.84, y=1.10x-46.9
12	0.97, y=0.44x+12.1	0.89, y=0.77x+7.2	0.74, y=0.65x+0.2
13	0.99, y= 0.70x-2.6	0.96, y=1.04x-5.5	0.95, y=0.71x-1.5

Figure 12. *EM31v values plotted against EM31H (✍), EM38v (✉) and EM38H (🗐) for a) field 3, b) field 5, c) field 10 and d) field 13.*



6. Discussion

6.1 Soil sampling targeted on the basis of EM31 readings can be used to stratify variation in soil texture and ESP profiles across rice fields.

The rice land suitability classification process suggested following initial studies was as shown in Figure 13.

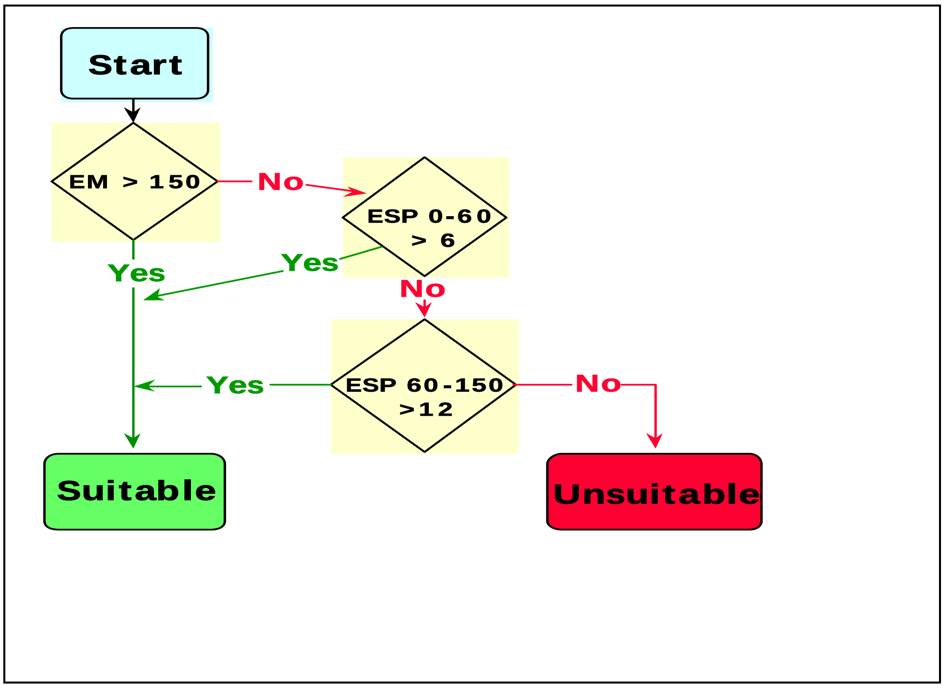


Figure 13. *Initial soil suitability decision tree based on EM 31 reading and assessment of soil sodicity*

Modifications to the flow diagram were made following investigations in this study (and include reference to Murray Irrigation investigations). These have been made to the rice soil suitability decision tree, as shown in Figure 14 (below). Analysis of sample number showed that although 3 soil samples provided an accurate estimate of the 0-60 cm ESPe within an EM band, in the depth interval 60-150 cm 7 samples gave a less accurate estimate of the mean value (+/- 1 ESP unit). Following consideration of accuracy and cost issues, the threshold value for the 60-150 cm interval was changed to an ESP of 16 if 3 sample sites were used and remained at ESp of 12 if 7 samples were used (Figure 14). As well as indicated above sites with an EM31 value of 30 or less are considered unsuitable for rice growing

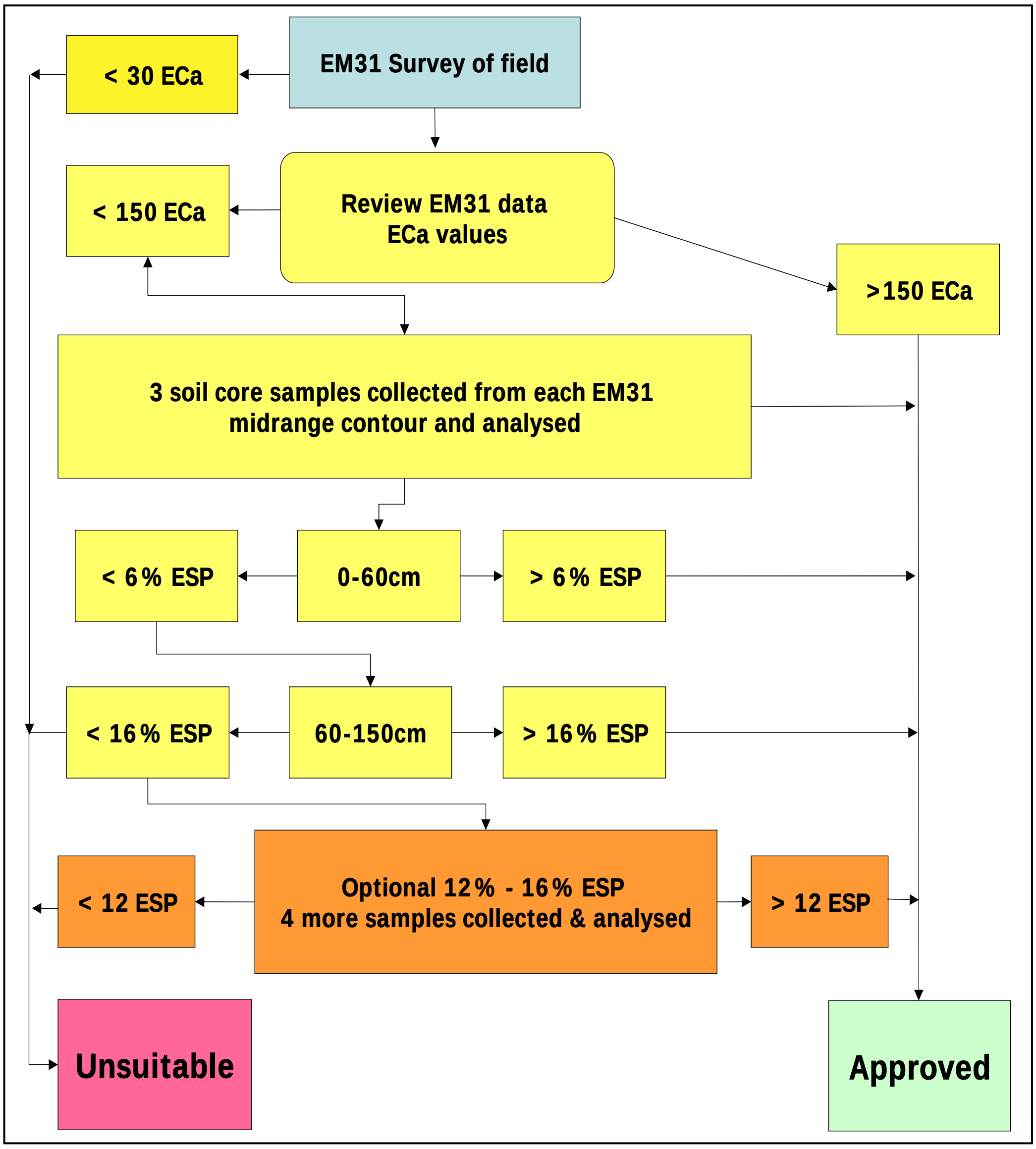


Figure 14*. Decision process for rice suitable soils adopted by Murray Irrigation Limited and accepted by REPAG*

6.2 Rapid, infield sodicity assessments

Field test approaches to the assessment of soil sodicity were found to be unsuitable and unreliable, so use of laboratory ESPe measurements has been adopted in the rice land suitability assessment process.

There has been increased awareness and interest in adoption of EM technology and soil sodicity for rice land assessment by the irrigation companies, DLWC and EM31 service providers. Large areas in the Murray Valley and CIA have been surveyed using EM31 technology. Around mid-2004 EM31 surveys had been completed on 376 of 475 farm units under the jurisdiction of CICL, and over 80,000 ha had been surveyed in the Murray Districts. Policy committees of some irrigation companies were involved in on-going discussion on adoption of the EM/ESP approach to rice land suitability assessment.

6.3 Comparison of EM31 and EM38 instruments within rice fields

The relationship between the EM31 and EM38 measured values in rice fields on the Riverine Plain of south-eastern Australia is very strong. We believe that both the EM31 and the EM38 in the vertical dipole mode would be suitable to survey rice fields for rice soil suitability assessment. The EM38 has the advantage that it is cheaper to purchase than the EM31, but it has the disadvantage of having to be towed in a sled or trailer close to the soil surface. This would cause wear and high maintenance and would not be suitable for cultivated fields.

6.4 Extension and Adoption

Extension meetings were organised with Murray, Murrumbidgee and Coleambally Irrigation Companies, Department of Land and Water Conservation (DLWC) staff from Leeton, Deniliquin and Albury and EM31 service providers. There is a high level of interest in adopting the EM/ESP approach with discussion moving from contact with technical staff to contact with policy staff. There has been an excellent response in terms of increased interaction and increased awareness from irrigation company and DLWC staff. This interaction is ongoing.

7. Implications and Recommendations

Adoption of these rice soil criteria changes has the potential to considerably modify the existing soil texture rice soil suitability land classification assessments. Soils currently approved for rice growing may be considered unsuitable (for example highly self mulching clays, dominated by calcium on the exchange sites) and other soils (for example some transitional red brown earths) currently classed as unsuitable, may be considered as having a sufficiently low level of groundwater recharge as to be considered suitable for rice growing. Improved identification of soils/ lands suitable for rice growing will also contribute to improved rice field water use application efficiency (i.e. a reduced water requirement ML/ha). The irrigation industry and the irrigated environment of southern NSW in general, will benefit by a reduction in groundwater recharge. This, in turn, will reduce land and stream salinisation and allow for the increased sustainability of irrigation farming and the more efficient use of land and water resources.

The adoption of changes to the rice policy will allow a better definition of the location of land which contributes significantly to ground water accessions. These changes will reduce the area of land ‘retired’ from rice growing, and better define land requiring remedial soil treatments. Implementation of the methods developed by this work will allow more appropriate and environmentally sustainable use of soil and water resources.

Accurate identification of land suitable for rice growing will provide savings for individual landholders by: (i) optimising farm development / re-development - where costly development of unsuitable land for rice growing will be avoided; (ii) reducing water use where rice water use is excessive (i.e. saving water); (iii) increasing the flexibility of farm management by increasing the availability of water. This would occur especially under the water availability conditions that currently apply to irrigators in southern NSW – MDBC Cap, NSW water reforms, expansion of rice growing into non traditional rice growing areas and increased access of irrigation water in non traditional rice growing areas and the impact of the ongoing drought conditions.

An economic evaluation of the impact of implementation of the EM31 component of these rice soil suitability studies has been conducted by (the) Centre for International Economics (2003). This analysis showed a very high benefit / cost ratio indicating the importance and economic benefit accruing from adoption of the approach.

However, some growers may be affected negatively by re-classification of some currently suitable land.

Research findings are being rapidly adopted within Land and Water Management Plans. These plans already endorse the need to improve the way soil is assessed for rice growing.

There is a high level of interest in adopting the EM/ESP approach, with discussion moving from contact with technical staff to contact with policy staff of regulatory authorities. Policy staff are beginning to look at implications of changing the rice land assessment process in terms of land valuations, grower acceptance, and effects on farmer sustainability (in $ terms), if self mulching clay soils with low ESP were removed from rice growing. There has been an excellent response in terms of increased interaction and increased awareness from irrigation company and DLWC staff. This interaction is on-going.

8. Project intellectual property and commercially significant developments

It is not anticipated that any restriction on the release of the information generated during this project is appropriate.

The project developed a considerable body of intellectual property with regard to variability in soil properties, identification and selection of rice suitable land.

The results of this project (and its precursors) have been widely discussed at CRC Symposia, technical conferences, policy meetings and presented in annual project progress reports and industry journals and presentations. In fact, there has been a significant level of parallel studies undertaken by irrigation companies in rice growing areas on the approaches developed by this project. Consequently it is unlikely that any significant developments exist that have not already been put into the public arena that could be commercialized.

A project focus has been on extension, promotion and encouragement of adoption of project outputs so as to achieve a high level of adoption. This has meant on-going accrual of benefits to the irrigation areas and districts in terms of reduced groundwater accessions and improved water productivity from rice growing.

9. Recommendations

9.1 Further development

Further development to identify if the type of relationships between soluble sodium and ESP by the Tucker method found by Nelson *et.al.* (2002) for the soils of sugar production areas of northern Queensland are applicable in the soils used for rice growing in southern NSW.

9.2 Commercial exploitation

The incorporation of sodicity assessment into the rice land approval process has been agreed to by REPAG Rice Environmental Policy Advisory Group and is being actively adopted and implemented by Murray Irrigation Limited and Coleambally Irrigation Co-operative Ltd.

9.3 Dissemination

There has been considerable effort directed at dissemination and adoption of the outcomes of this project and precursor projects. Direct interaction with rice land regulatory staff of Murray Irrigation, Coleambally Irrigation and Murrumbidgee Irrigation has occurred. Presentations and discussions have taken place with DIPNR staff in both Murray and Murrumbidgee regions. In addition presentation and discussions have been undertaken with commercial electromagnetic survey service providers and rice land soil drilling contractors.

The results of this project (and its precursors) have been widely discussed at Rice CRC Symposia, technical conferences, policy meetings and presented in annual project progress reports and industry journals and presentations. The work undertaken in this project and precursors was presented at “Electromagnetic Techniques in Agricultural Resource Management”, ASSSI Riverina Branch, Yanco Agricultural Institute, Yanco 3-5 July, 2001. The conference was highly successful, attracting more than 90 delegates, including delegates from all Australian States, USA, Canada, New Zealand and Ireland including researchers, policy makers, service providers, regulators and irrigation industry consultants.

Use of the electromagnetic induction instrument (Geonics EM31) and progress in Land and Water Management plans has directly resulted in adoption of practices that improve the ability to identify land suitability for rice growing. There are significant potential flow-on benefits to irrigation farm design and layout, irrigation farm management, location of channels, drains and on-farm irrigation water recirculation storages. The adoption of these research and extension initiatives will lead to improvements in on-farm rice water use productivity resulting from reductions in groundwater accessions.

On-ground adoption of EM31 surveying has been significant - e.g., the “Coleambally Irrigation Environmental Report 2003” states that: “EM-31 surveying is being undertaken on a large scale in CICL’s area of operation. EM-31 data, combined with soil drilling and crop water use information, is used to identify areas that use excessive amounts of water to grow crops due to insufficient quantities of clay in the soil profile. This information is used to assist in effective planning of farm designs.”

Data presenting the status of EM-31 field surveying, interpretation and information packages in CICL’s regions show that the landholders in all regions have embraced EM-31 technology. The data show that by July 2003 approximately 80,000ha had been surveyed since the project commenced. It is expected that 110,000 ha will have been field surveyed in the Coleambally, Kerarbury Channel and Outfall District LWMP areas by July 2005.

Shaw and McLeod (2001) reported that “Over 80,000ha of rice land has been surveyed using EM31 Technology in the Murray Irrigation Area of operations since 1996/97. A high level of confidence has been developed in the use of the technology. Factors that influence the EM31 values is (are) well understood and now being taken in to account with survey and drilling strategies.”

9.3.1 Soil Sodicity

The incorporation of soil sodicity into the rice land approval process is being investigated by Murray Irrigation Ltd. Murray Irrigation Ltd tested soil samples for sodicity during rice soil suitability testing of 50 rice fields during the 2001-02 rice growing season to further evaluate the possibility of including sodicity in the identification of suitable soils for rice growing. Northwood (2003) indicates that Murray Irrigation Limited adopted soil sodicity as a rice soil suitability criteria for the 2003-04 rice growing season.

Coleambally Irrigation Co-operative Limited explored use of soil sodicity as a rice soil suitability criteria on a limited number of holdings during the 2001-02 rice season and is currently pursuing adoption of this criteria..

The Rice Circle (Rice CRC Newsletter – 2004 edition) reported that REPAG (Rice Environmental Policy Advisory Group had adopted the "recommendations as acceptable criteria for the selection of rice ground".

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11. Acknowledgements

The author would like to thank Dr Neel Jinadasa and Mr Brian Dunn for their significant contributions to the conduct of this project in the laboratory and in the field. The contributions of Mr Iain Hume and Mr David Mitchell through RIRDC projects DAN 95A and Dan 145 A is gratefully acknowledged. The many rice growers who allowed access to their fields for these studies to be undertaken are acknowledged.

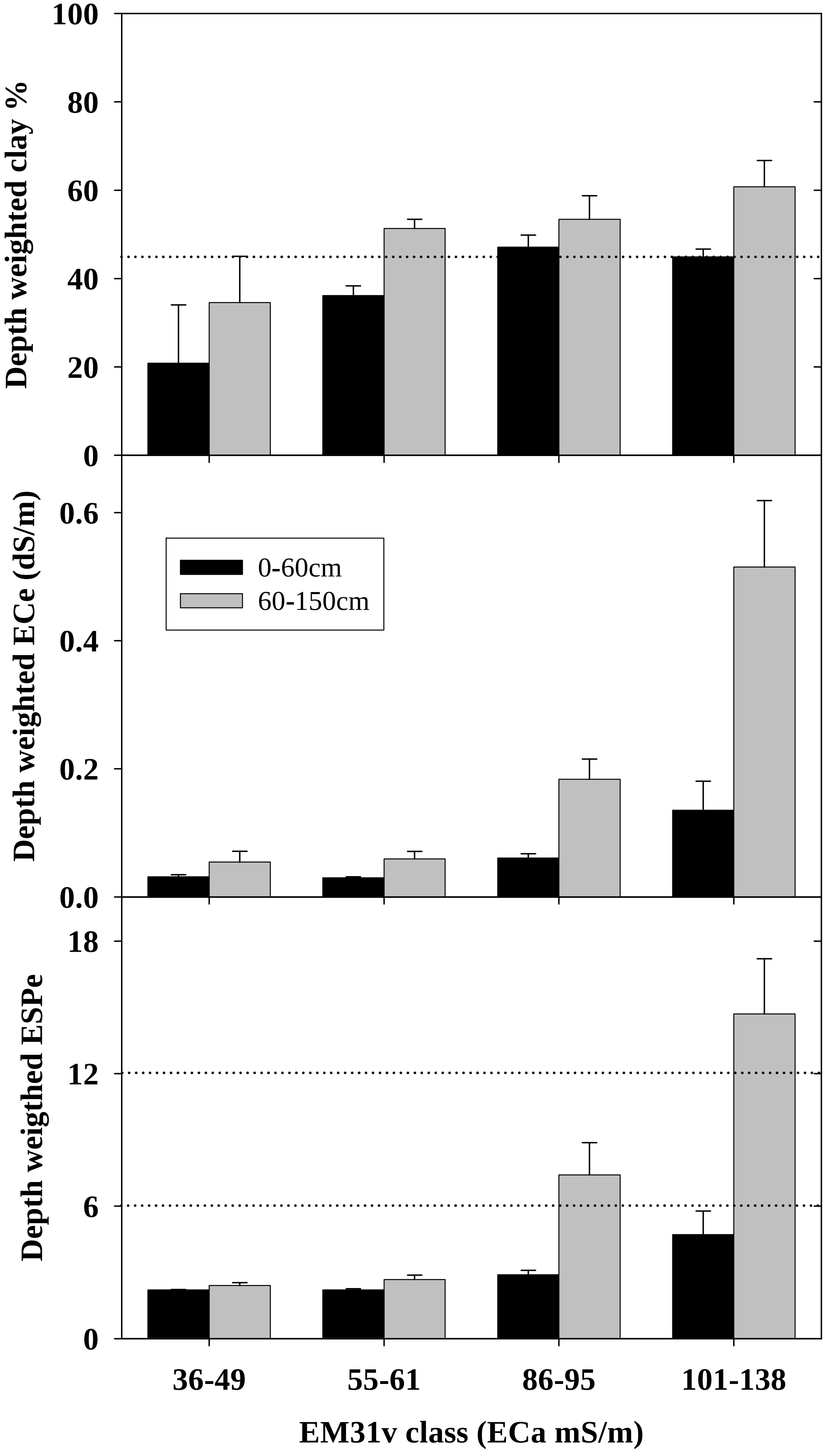
Appendices

List of figures

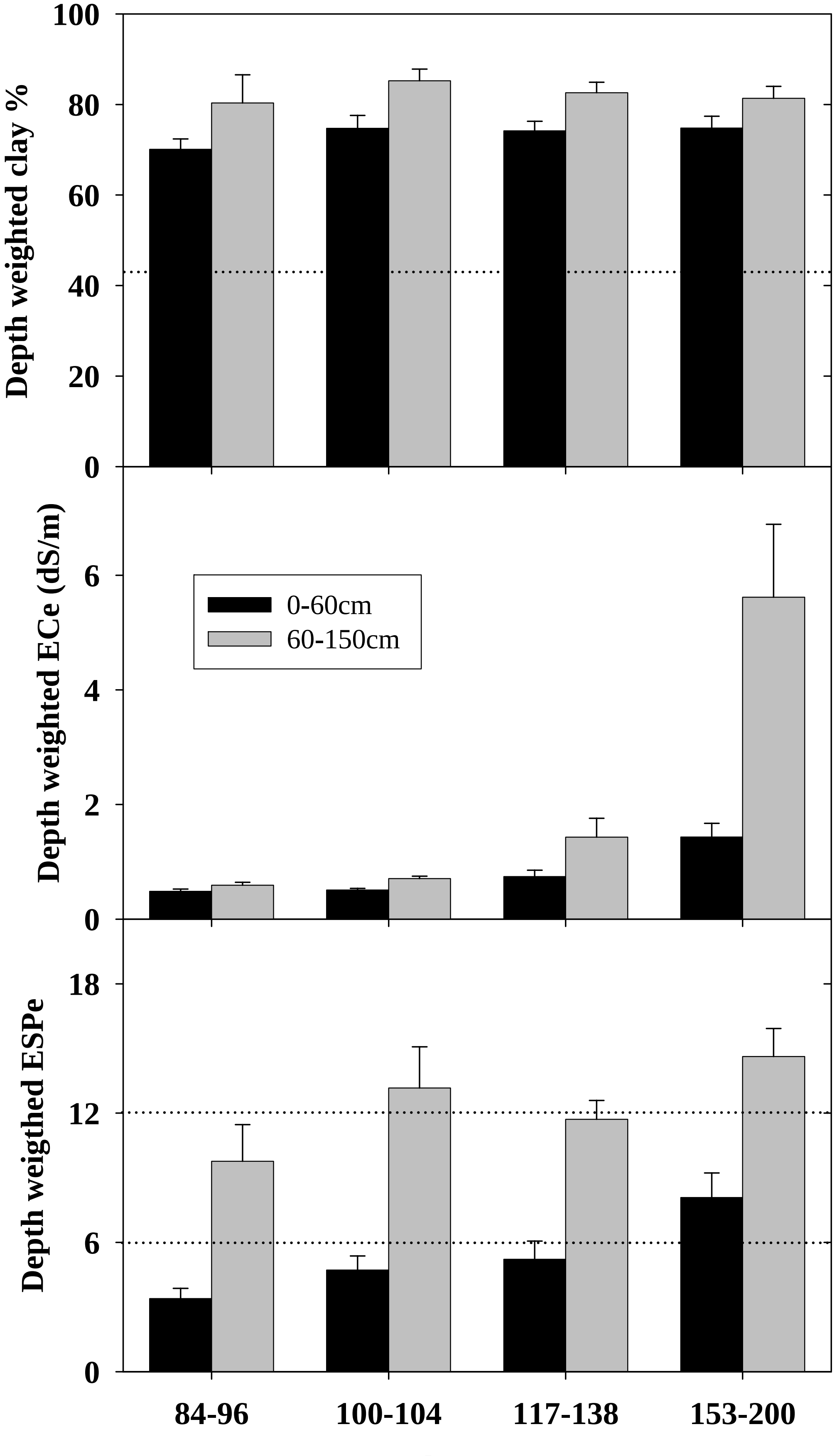
Replicated

Unreplicated

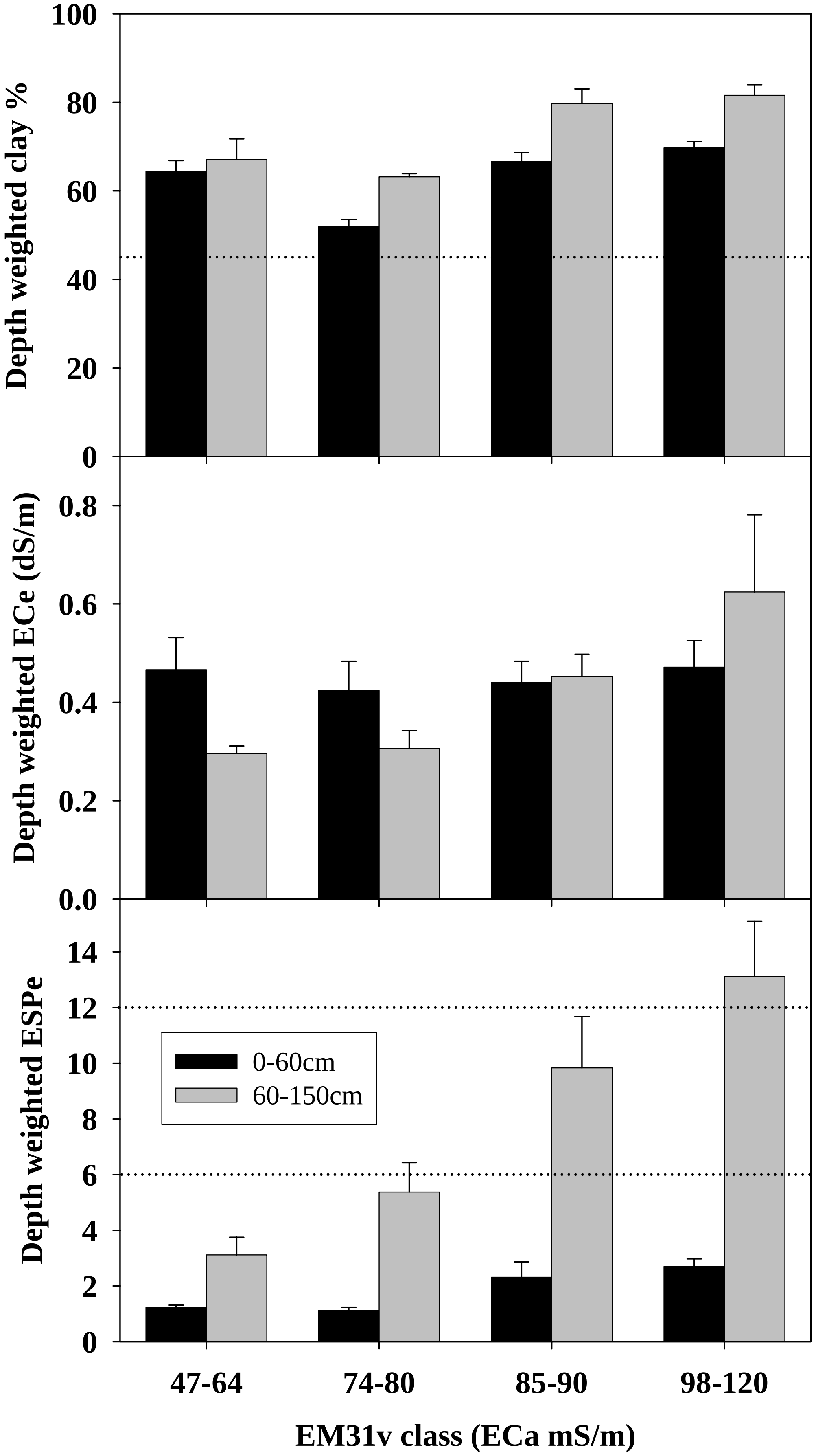
Field 1 – Red brown earth, Murrumbidgee IA



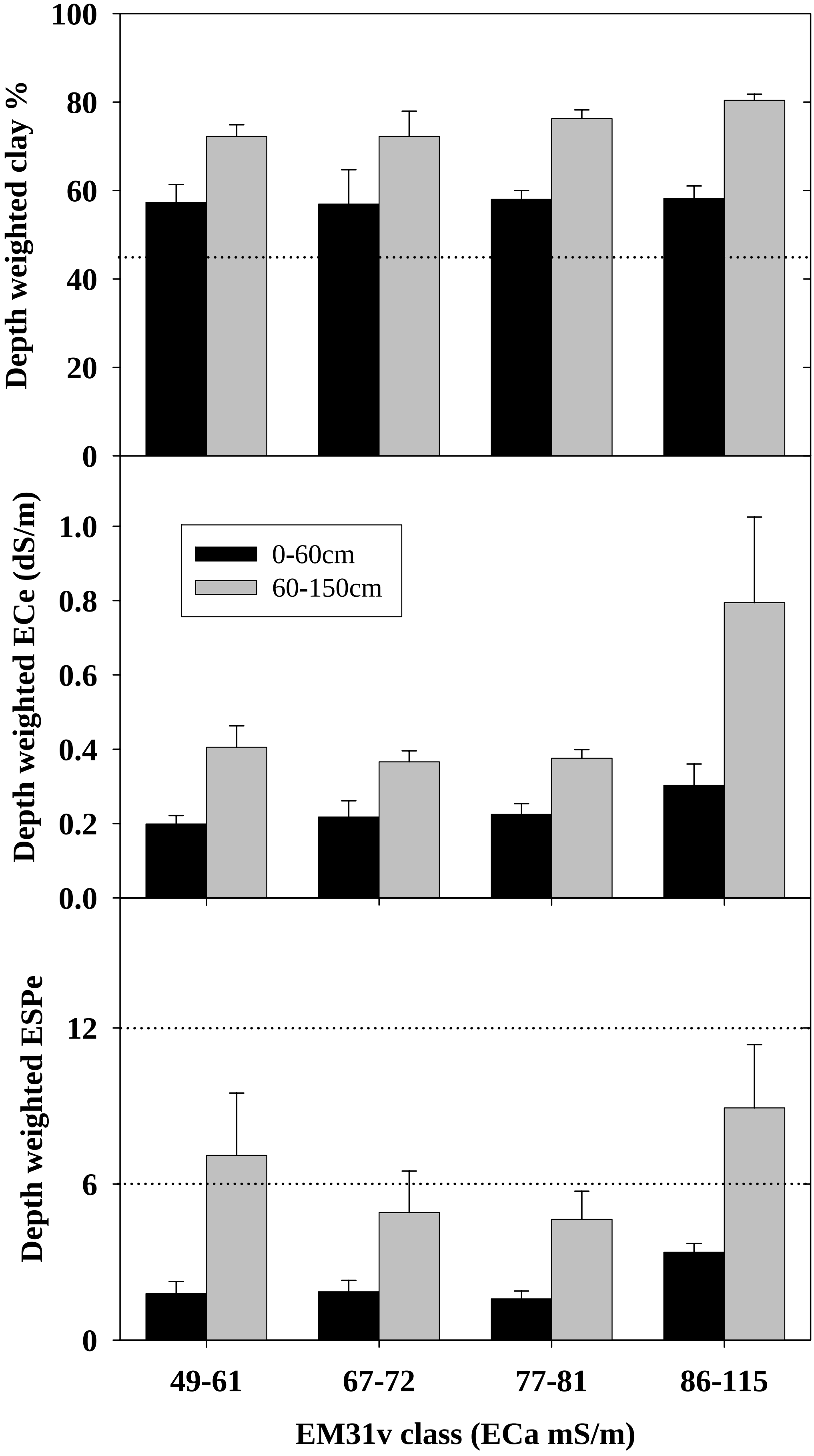
Field 2 – Non self-mulching clay, Murrumbidgee IA



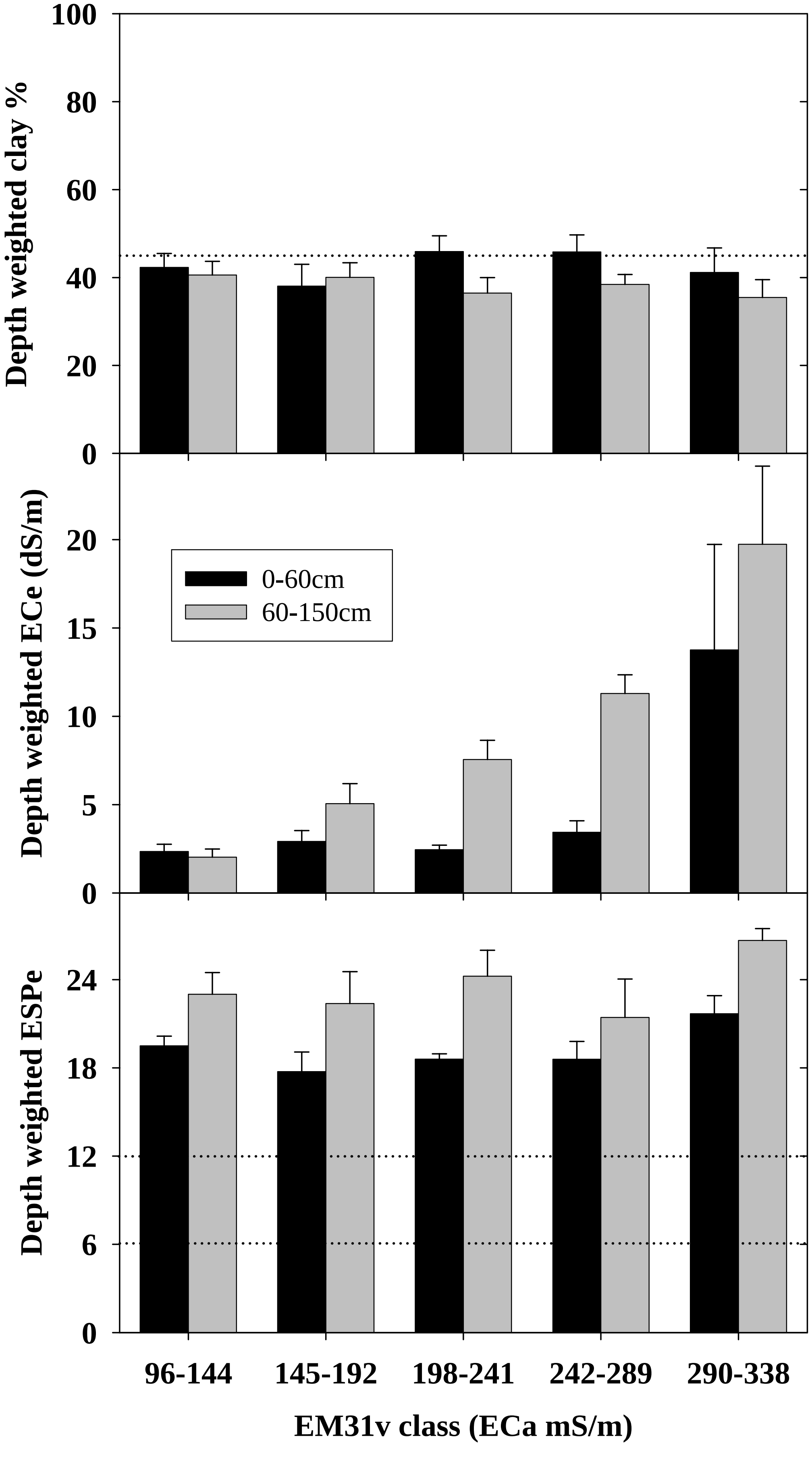
Field 3 – Self-mulching clay, Murrumbidgee IA



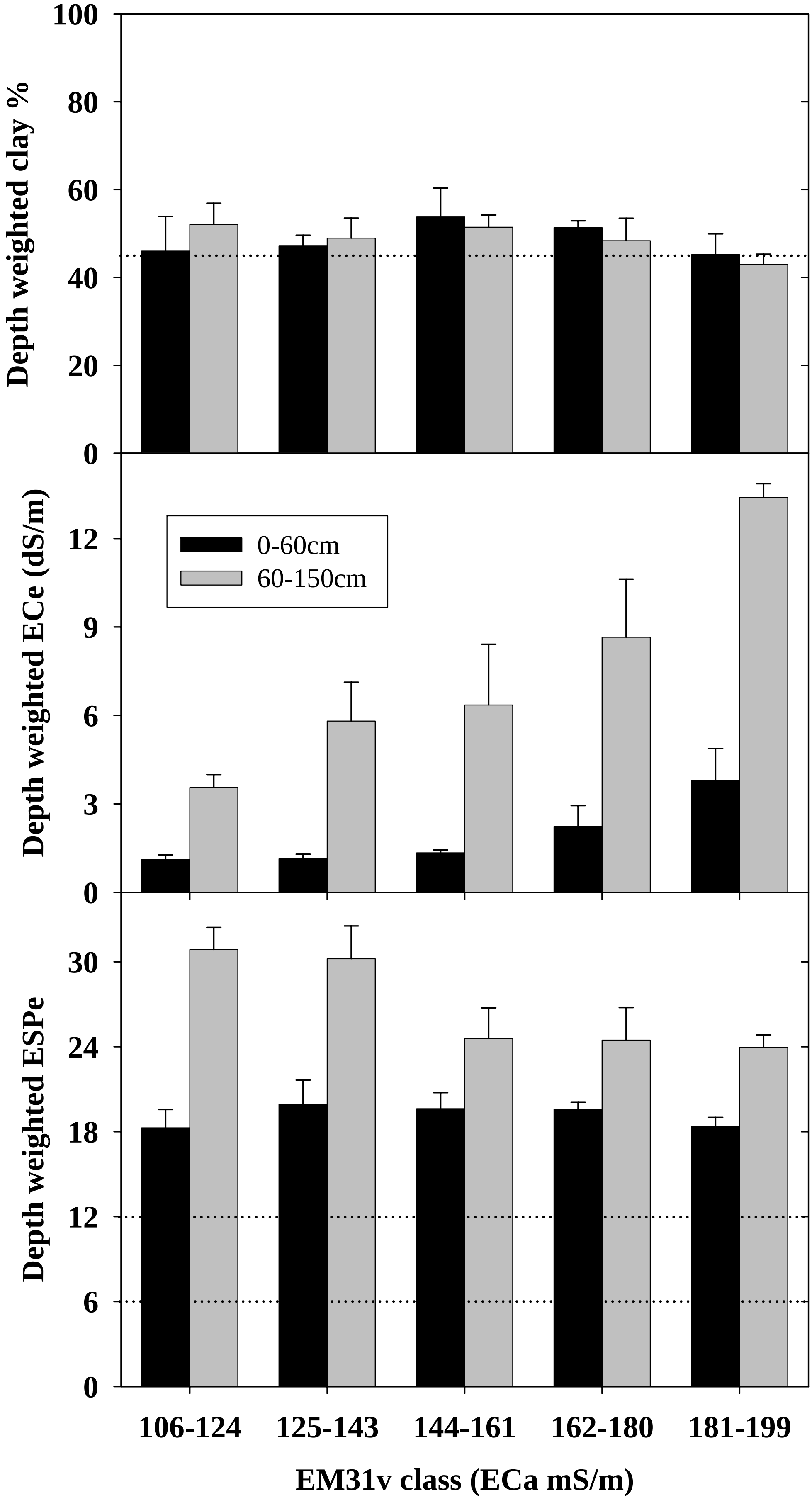
Field 4 – Transitional red brown earth / self-mulching clay, Murrumbidgee IA



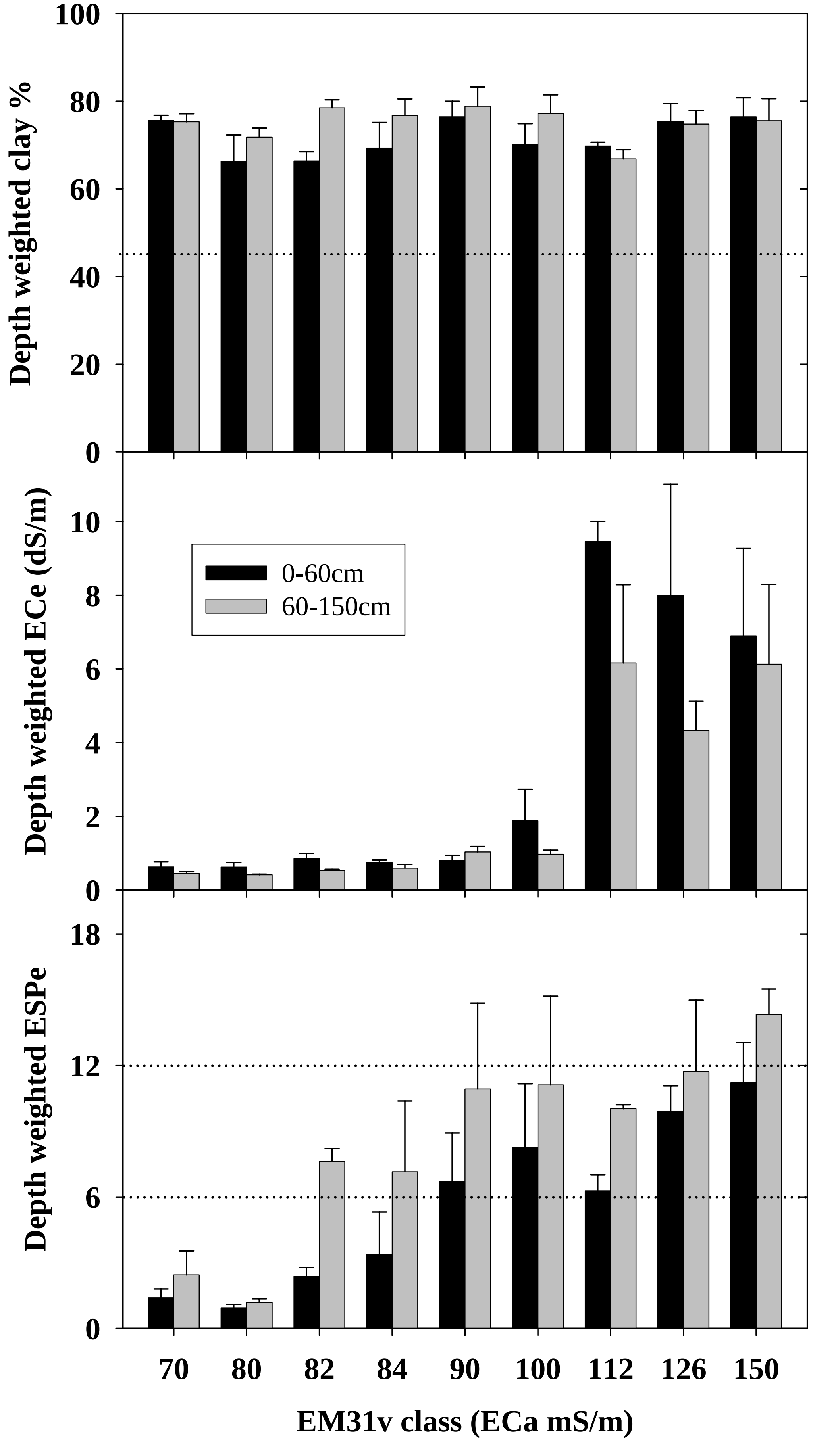
Field 5 – Non self-mulching clay, Wakool ID



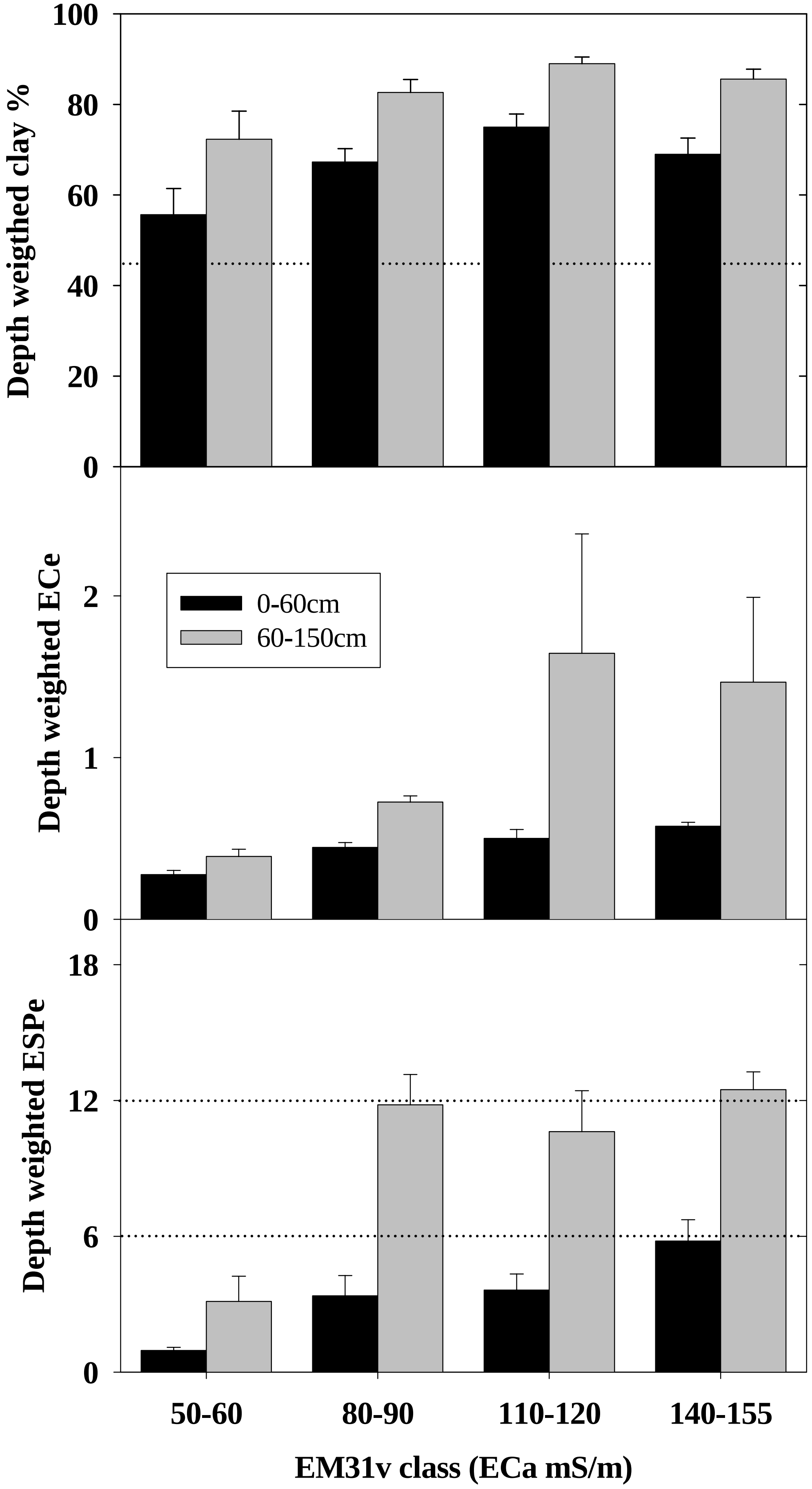
Field 6 – Transitional red brown earth / red brown earth, Deniboota ID



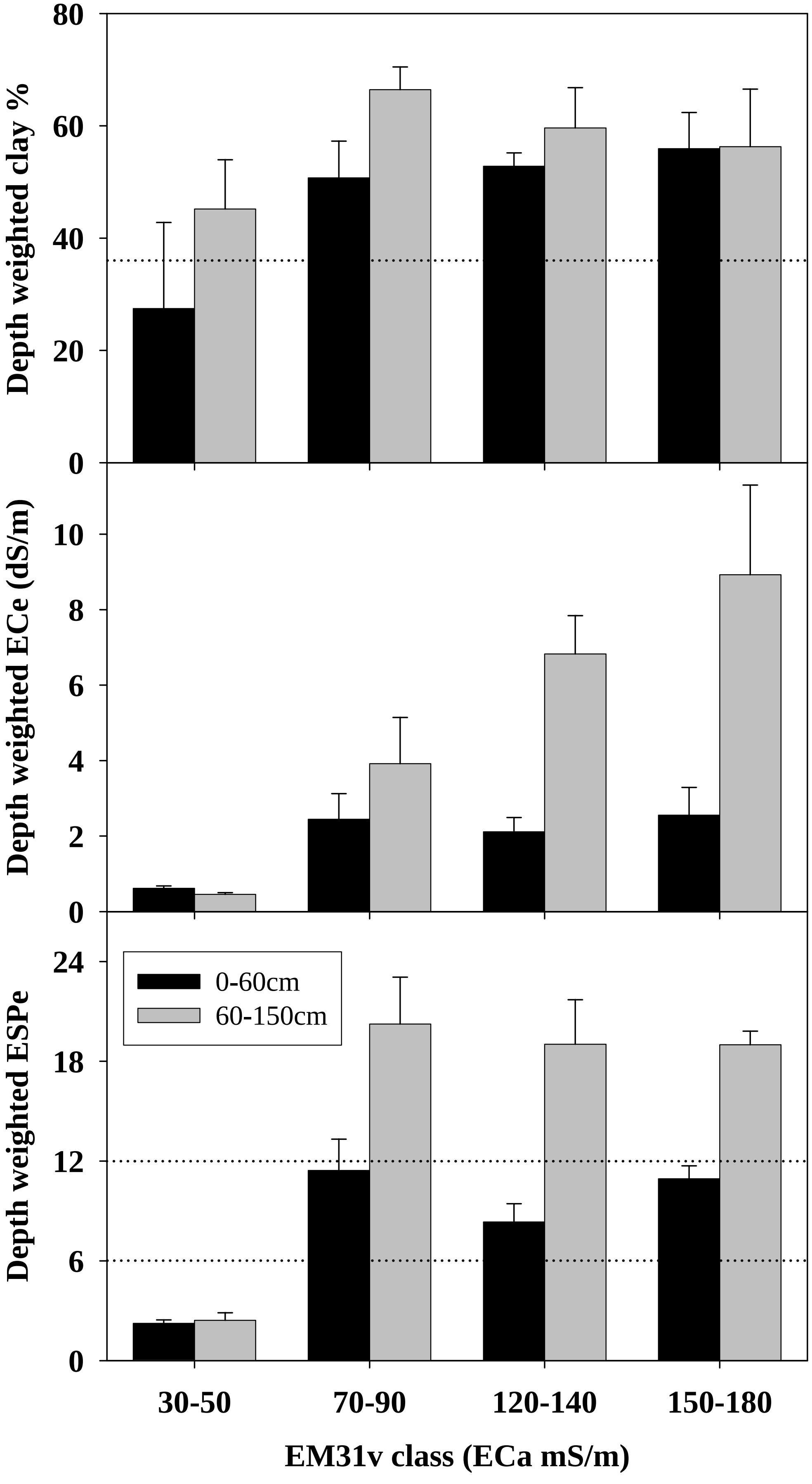
Field 7 – Red brown earth, Berriquin ID



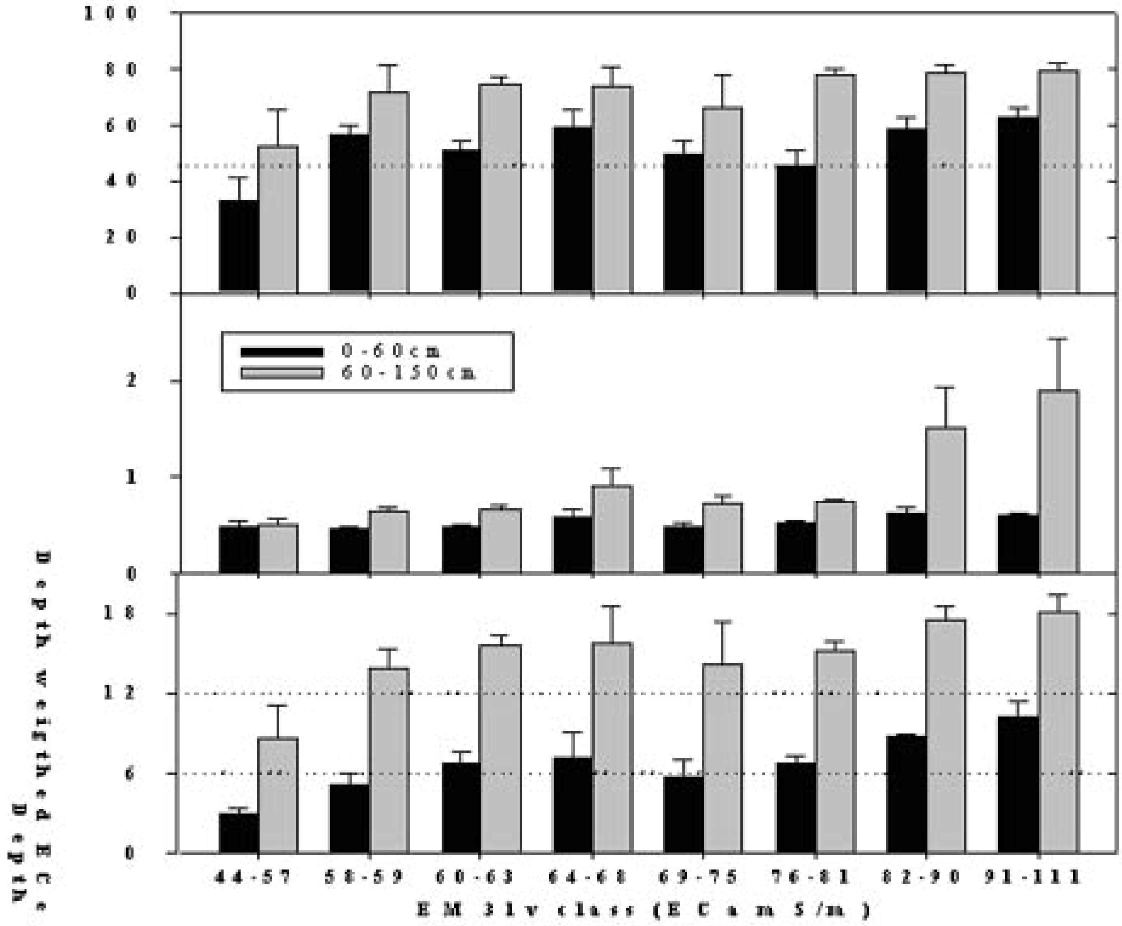
Field 8 – Self-mulching clay, Berriquin ID



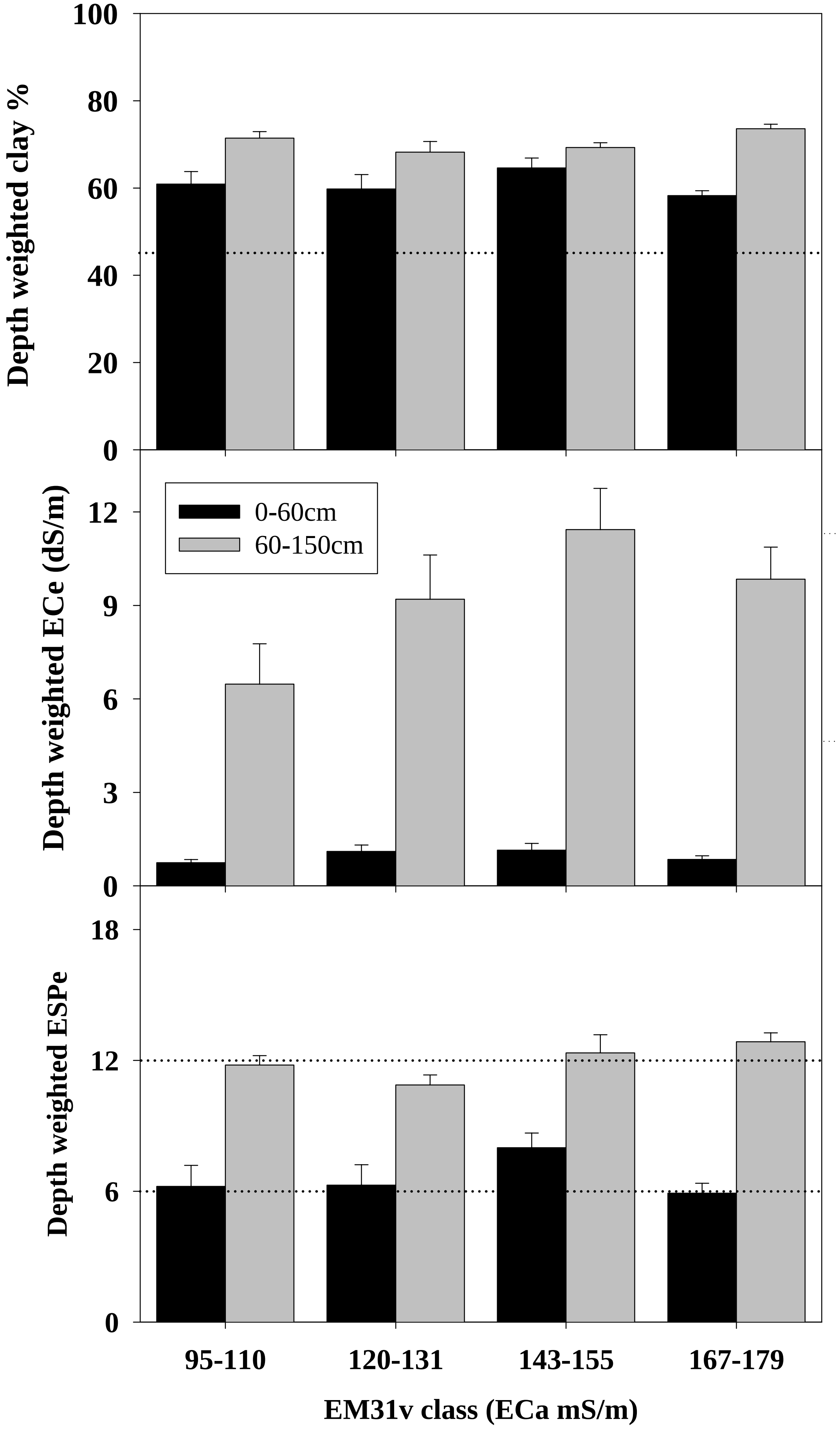
Field 9 – Red brown earth, Coleambally IA



Field 10 – Red brown earth, Berriquin ID



Field 11 – Transitional red brown earth / self-mulching clay, Coleambally IA



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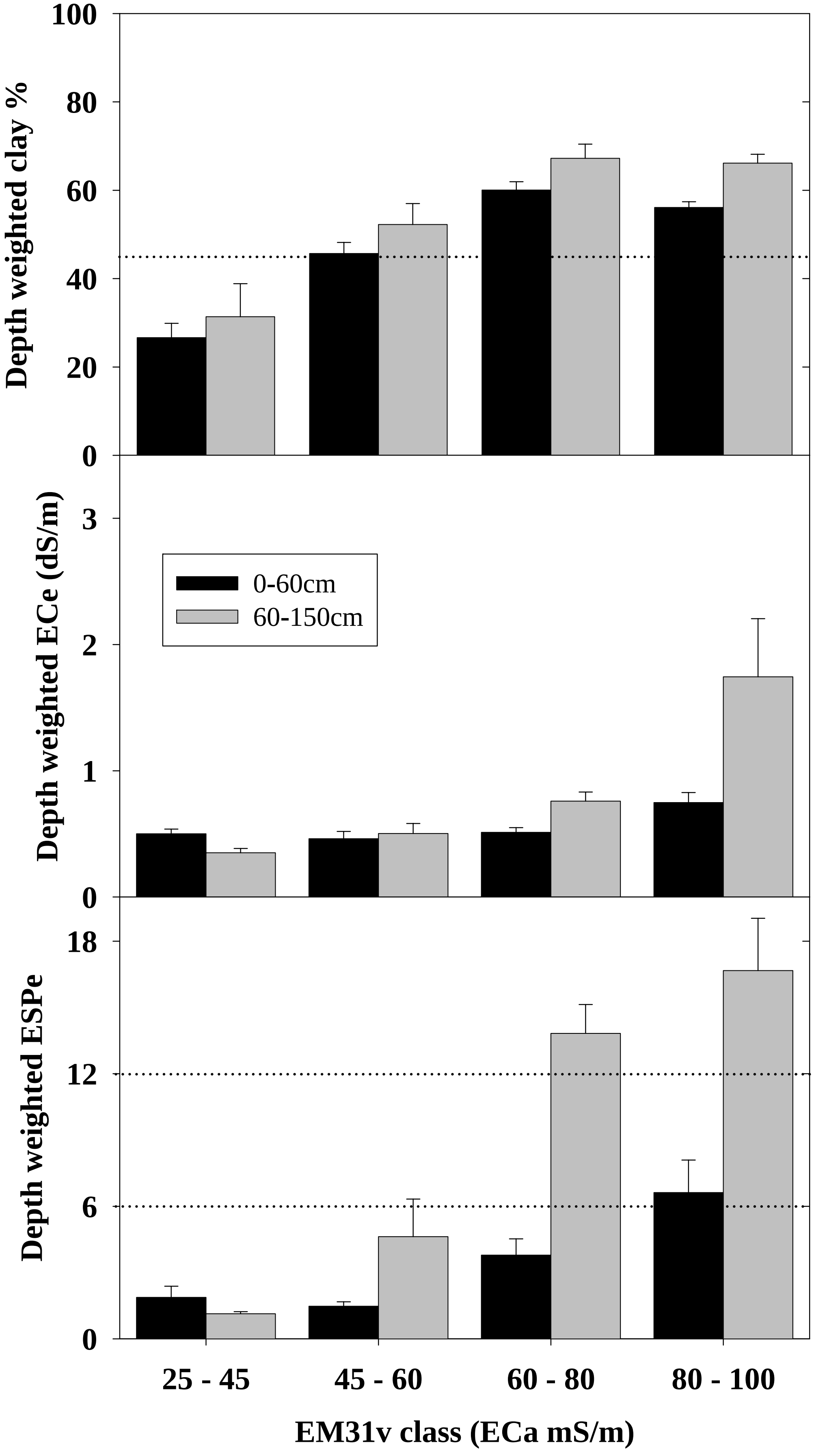
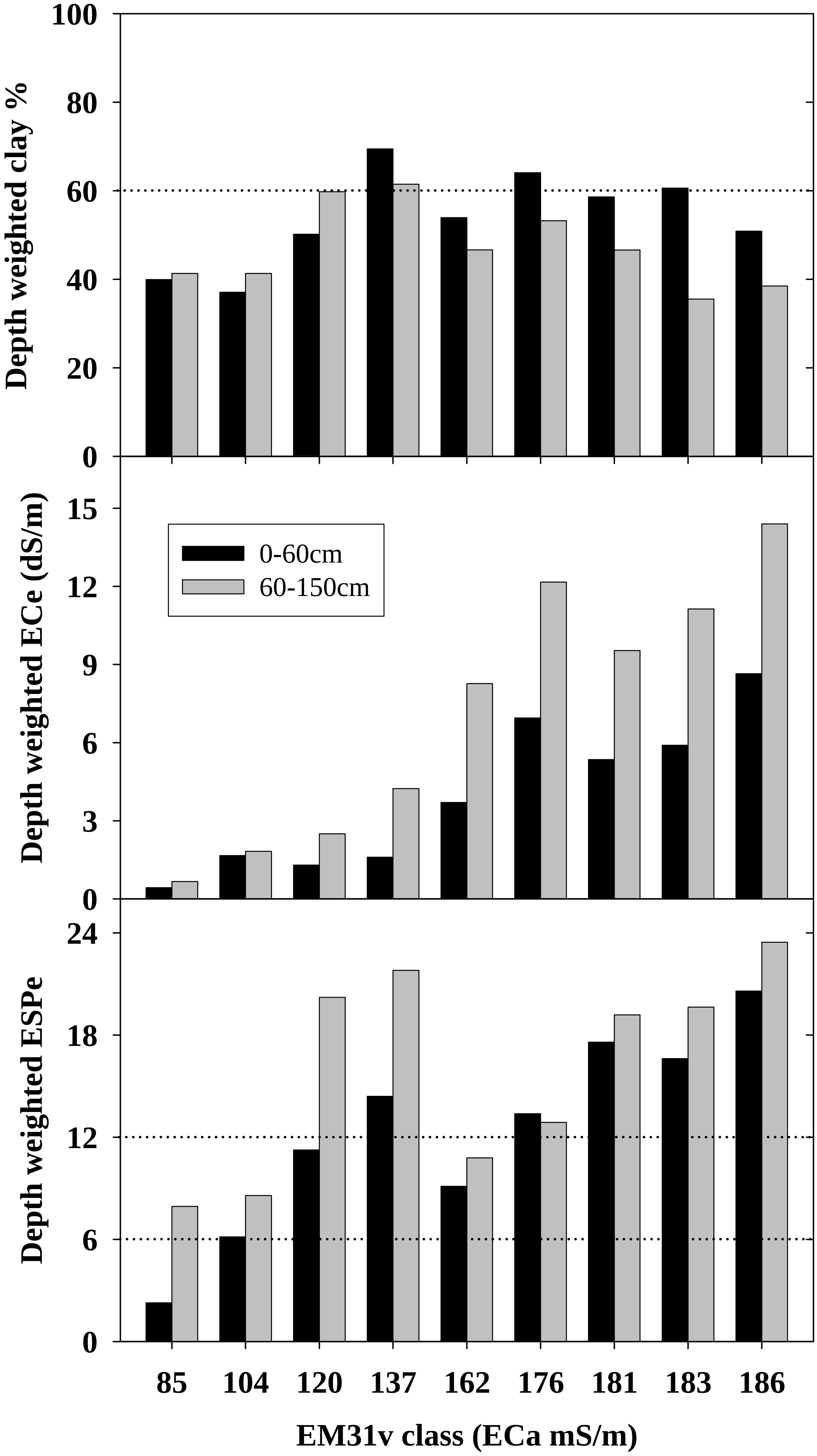
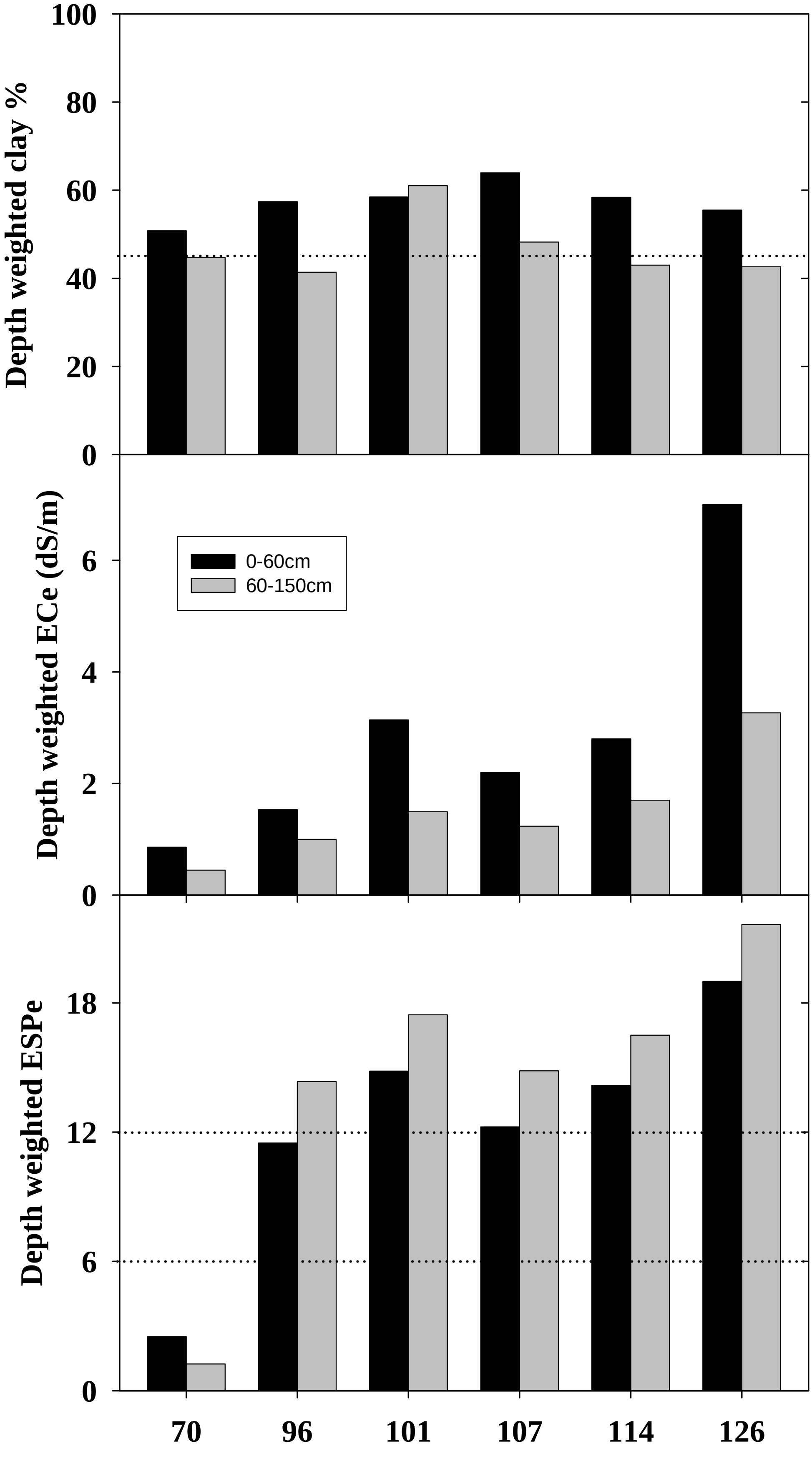


Unreplicated samples in association with CICL staff

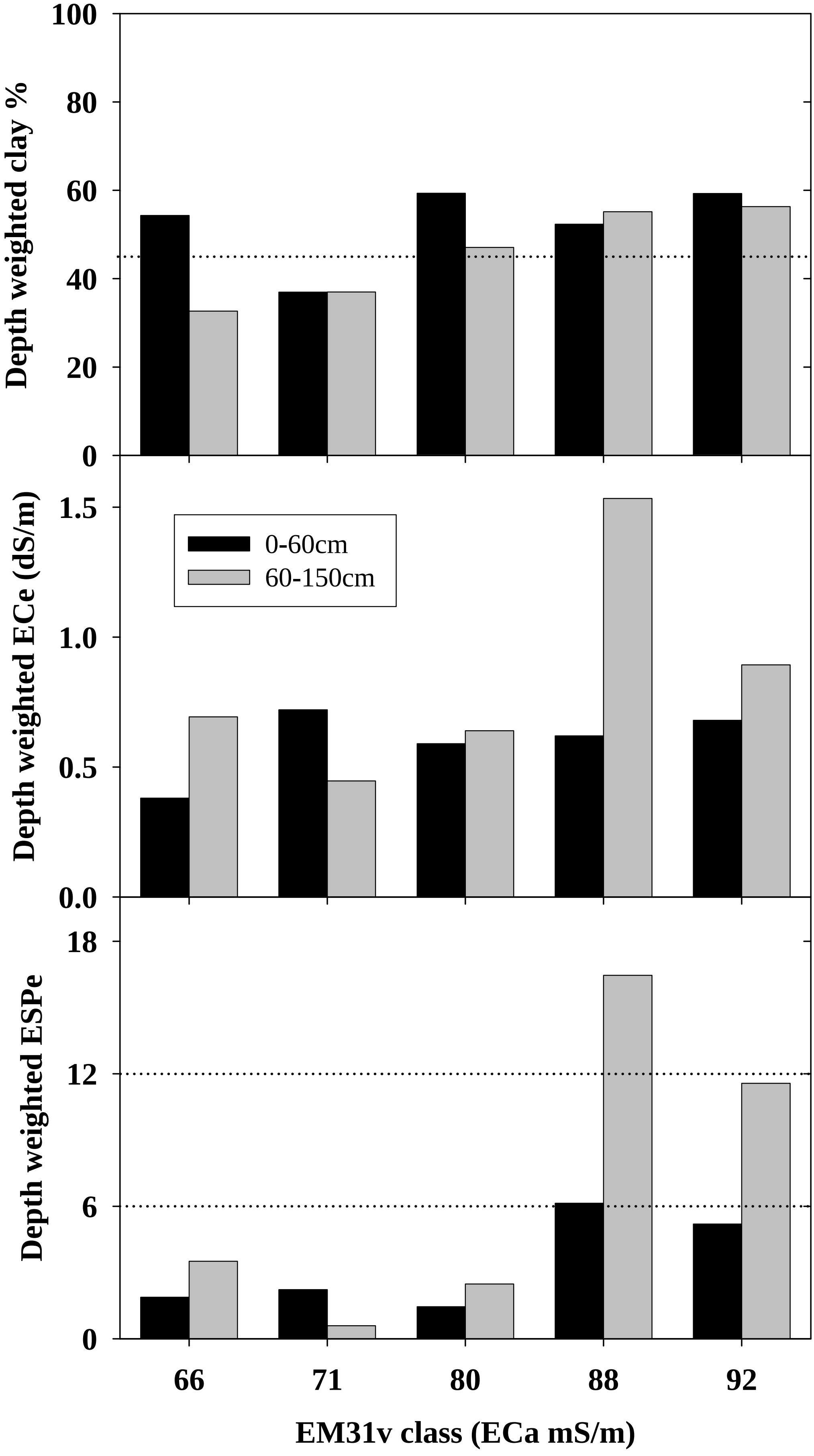
CIA – Field 13



CIA – Field 14


Depth weighted clay %
100
80
60
40
20
0
Depth weighted ECe (dS/m)
6
4
2
0
0-60cm
60-150cm
Depth weighted ESPe
18
12
6
0
70
96
101
107
114
126
EM31v class (ECa mS/m)

CIA – Field 15


Depth weighted clay %
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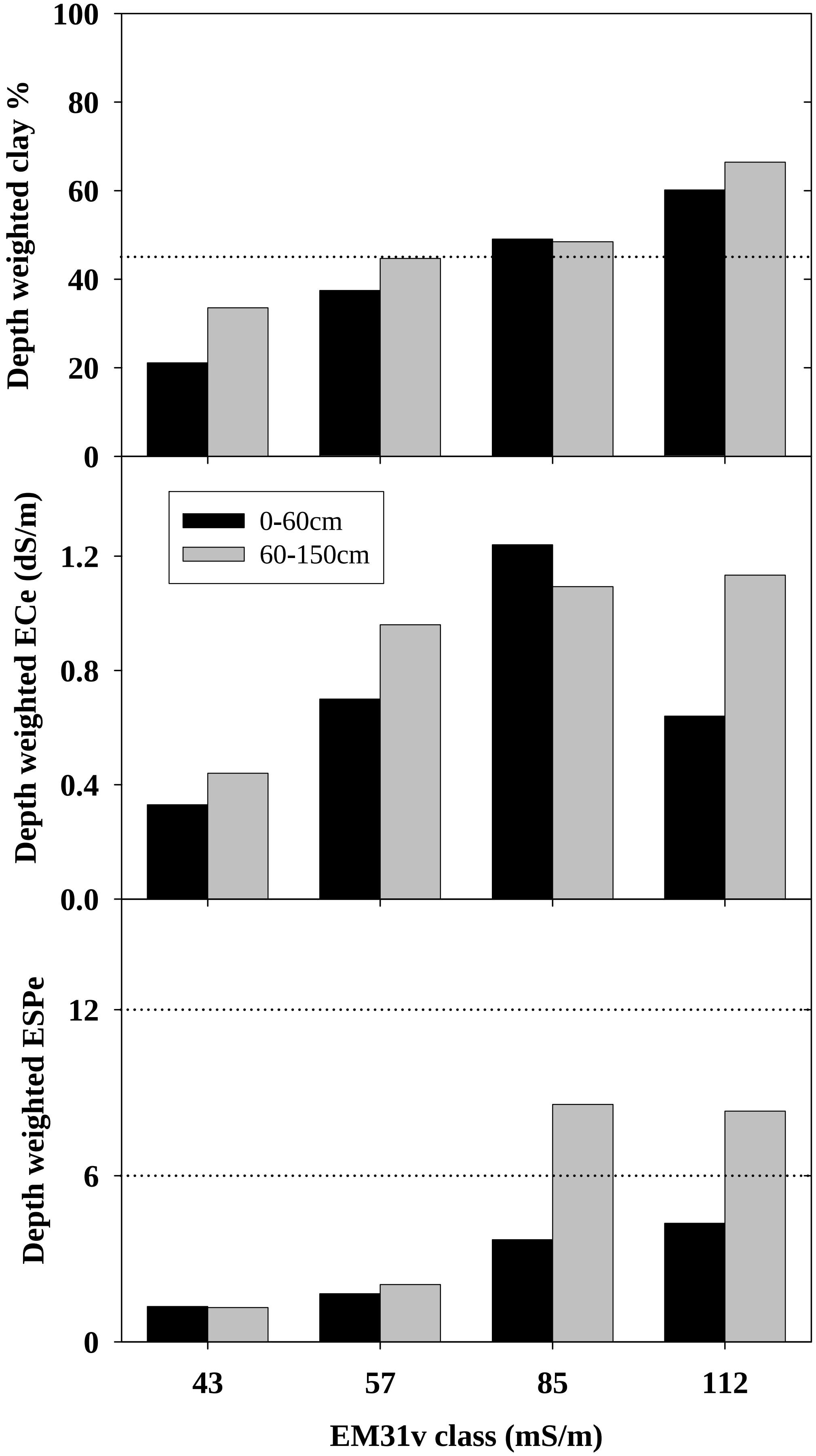
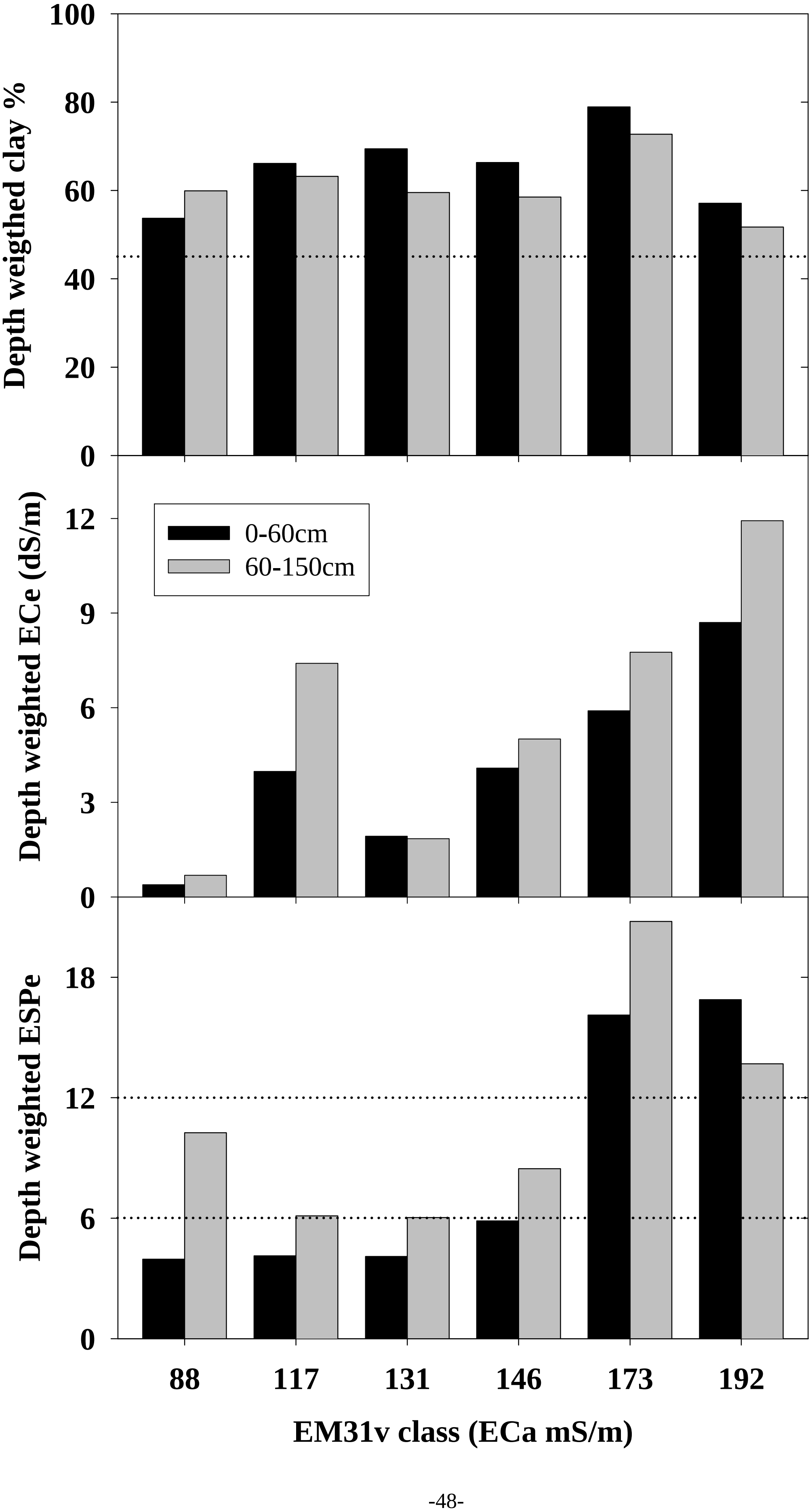
80
60
40
20
0
Depth weighted ECe (dS/m)
1.5
1.0
0.5
0.0
0-60cm
60-150cm
Depth weighted ESPe
18
12
6
0
66
71
80
88
92
EM31v class (ECa mS/m)

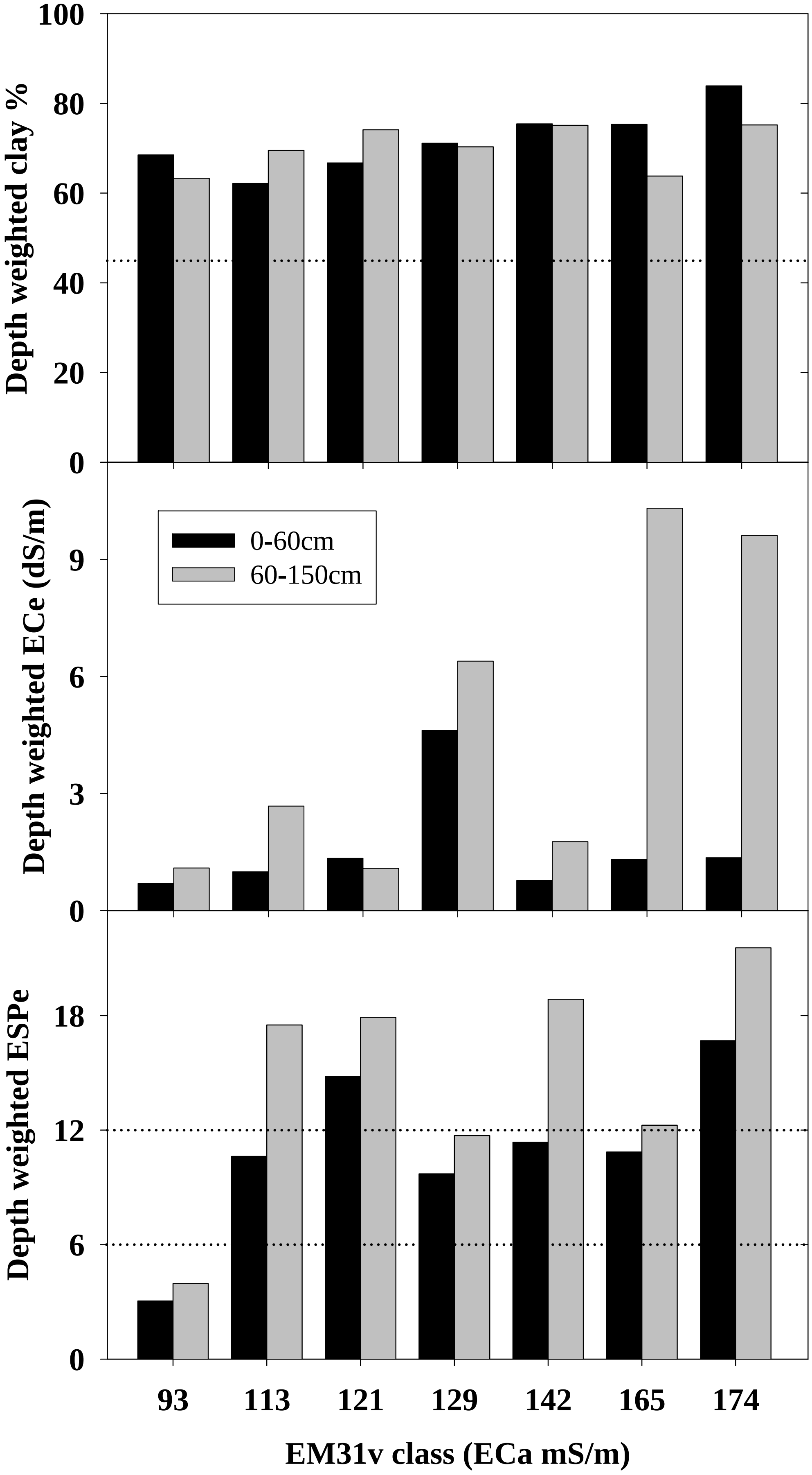
CIA – Field 16


Depth weighted clay %
100
80
60
40
20
0
Depth weighted ECe (dS/m)
1.2
0.8
0.4
0.0
0-60cm
60-150cm
Depth weighted ESPe
12
6
0
43
57
85
112
EM31v class (mS/m)

CIA – Field 17



Depth weigthed clay %
100
80
60
40
20
0
Depth weighted ECe (dS/m)
12
9
6
3
0
0-60cm
60-150cm
Depth weighted ESPe
18
12
6
0
88
117
131
146
173
192
EM31v class (ECa mS/m)


Depth weighted clay %
100
80
60
40
20
0
Depth weighted ECe (dS/m)
9
6
3
0
0-60cm
60-150cm
Depth weighted ESPe
18
12
6
0
93
113
121
129
142
165
174
EM31v class (ECa mS/m)