Testing McBratney *et al*.'s (2005) Model About Relations Between Electrical Conductivity Data and Soil Properties: Is it of Practical Use In Soil Survey?

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Introduction

- Using electrical conductivity data (EC_a) in soil survey and particularly for Precision Farming has become popular because it is related to several soil properties that could affect crop yield

- Theoretically sound reasons exist to explain these relationships but they vary spatially making interpretation of EC_a patterns difficult even within fields

- Some have advocated using EC_a data to show relationships with soil properties for which there is no theoretical basis

Introduction

- Most EC_a research has involved establishing relationships with soil properties or uses EC_a as a covariate for co-kriging or regression kriging - this may not be the best use of it (McBratney *et al*., 2005).

- Theoretically sound relationships developed between high frequency devices like time-domain reflectometers can be used to inform interpretation of the lower frequency EC_a data (McBratney *et al*., 2005).

McBratney *et al*.'s (2005) Model

- McBratney *et al*. (2005) presented a three part model:

  If (1) is false investigate (2), if (1) and (2) false, (3) will be true:

  - (1) If the soil is hyper-electrolytic (EC_a:clay ratio is larger than ~5) EC_a is measuring soil salinity
  - (2) If the profile thickness is thinner than the effective depth of measurement and the EC_a of the underlying material is much smaller than the soil, EC_a is measuring the soil depth
  - (3) If there is no compaction and the electrolyte concentration is in balance with the soil charge, EC_a measurements show variation in clay and moisture content

Research Purpose

Test the validity of McBratney *et al*.'s (2005) model at several field sites on different parent materials that are likely to satisfy the conditions of the model and determine if it is of practical use to soil survey

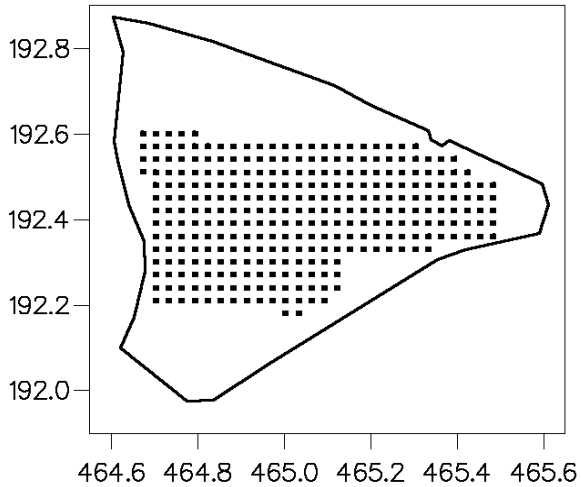
Site Description

- Soil samples were obtained at five arable field sites in southern England and one in Utah

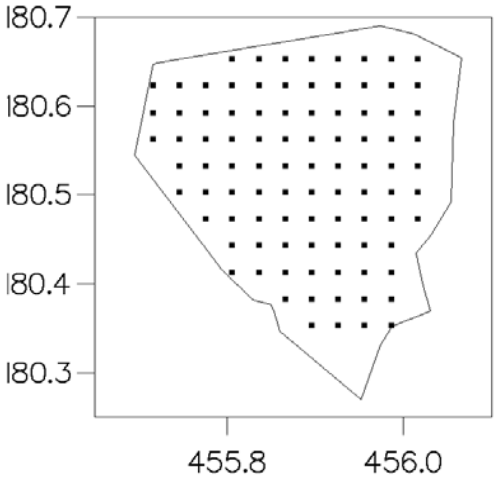
- The soil parent materials at the sites were:
  - Shuttleworth: Lower Greensand – 11.77 ha
  - Wallingford: flint and quartzite pebble gravel – 43.54 ha
  - Yattendon: Chalk – three fields Y214 – 10.35 ha, Y215 – 15.27 ha and Y217 – 35.17 ha
  - Utah (work in progress)

Soil Sampling Schemes

- Top-soil (0-15 cm) sampled on 20-m (Shuttleworth) and 30-m grids (Wallingford and Yattendon)
- 6 cores from 1 m^2 were bulked



Wallingford



Yattendon – Y214

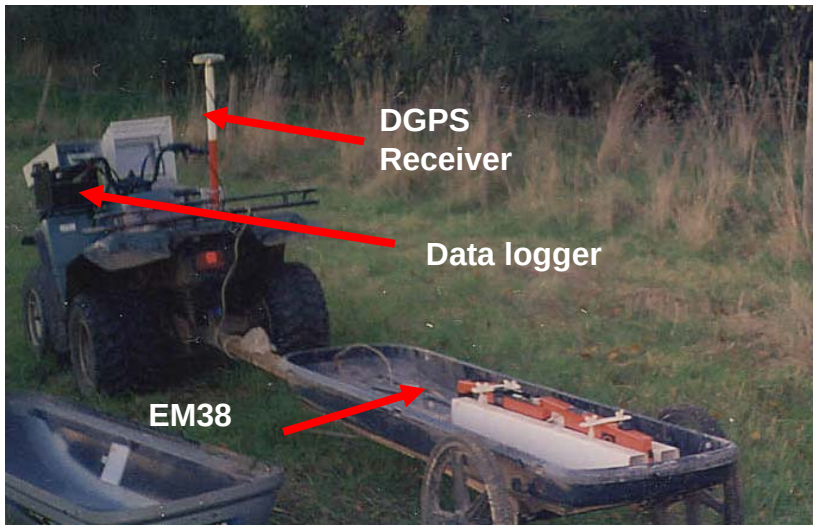
Field and Lab Methods

Soil property	Method
Compaction	Soil structure observations (Hodgson, 1974)
Depth (cm)	Auger and tape measure
Salinity	EC of soil extract (Rowell, 1994)
Stoniness (%)	Standard charts (Hodgson, 1976)
Texture (% sand, silt, clay)	Laser methods/finger-texturing
Volumetric water content (VWC) (%)	Delta-T theta probe (5 replicates within 1 m^2) calibrated for soil type

Salinity not measured at England sites

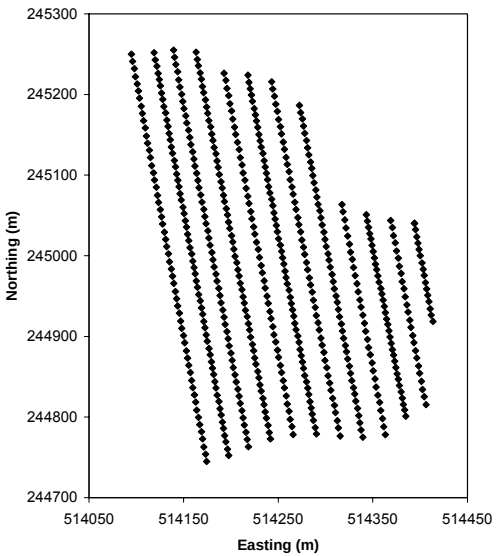
EC_a Collection

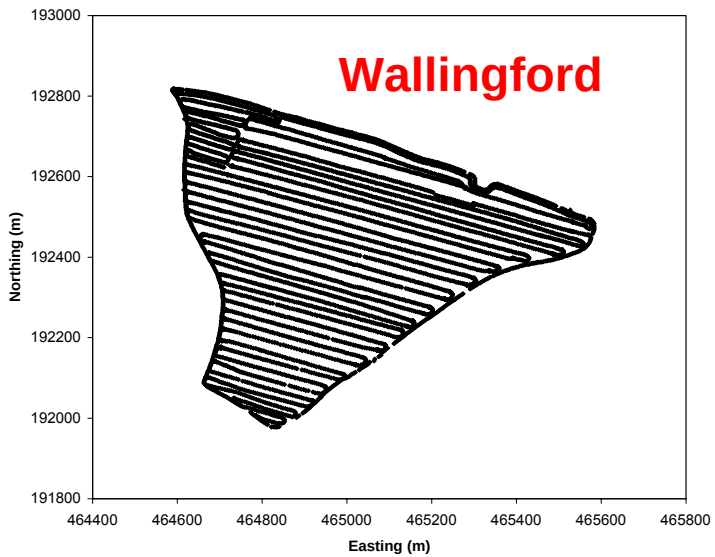
- Geonics EM38 in the vertical position used
- EC_a is measured to a depth of about 1.5m, but the main signal is received from the top 30-50 cm of soil
- EC_a is affected by moisture so data was collected when the soil was at about field capacity



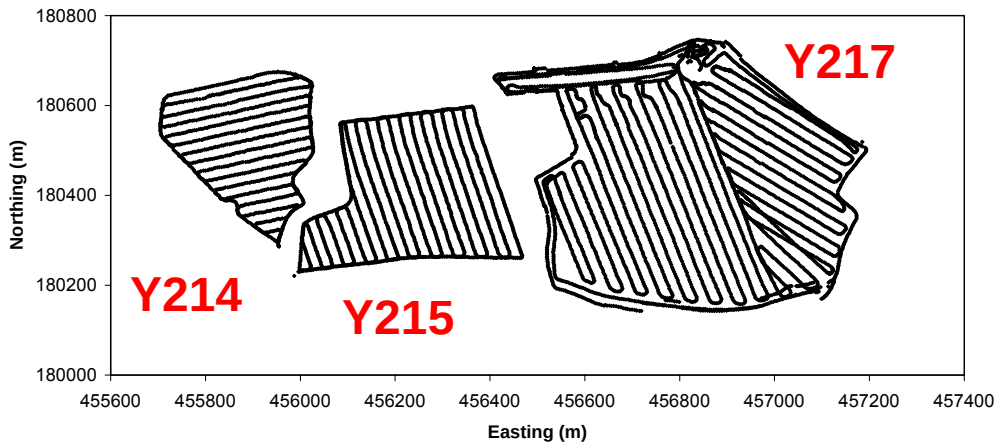
EC_a Collection

Shuttleworth



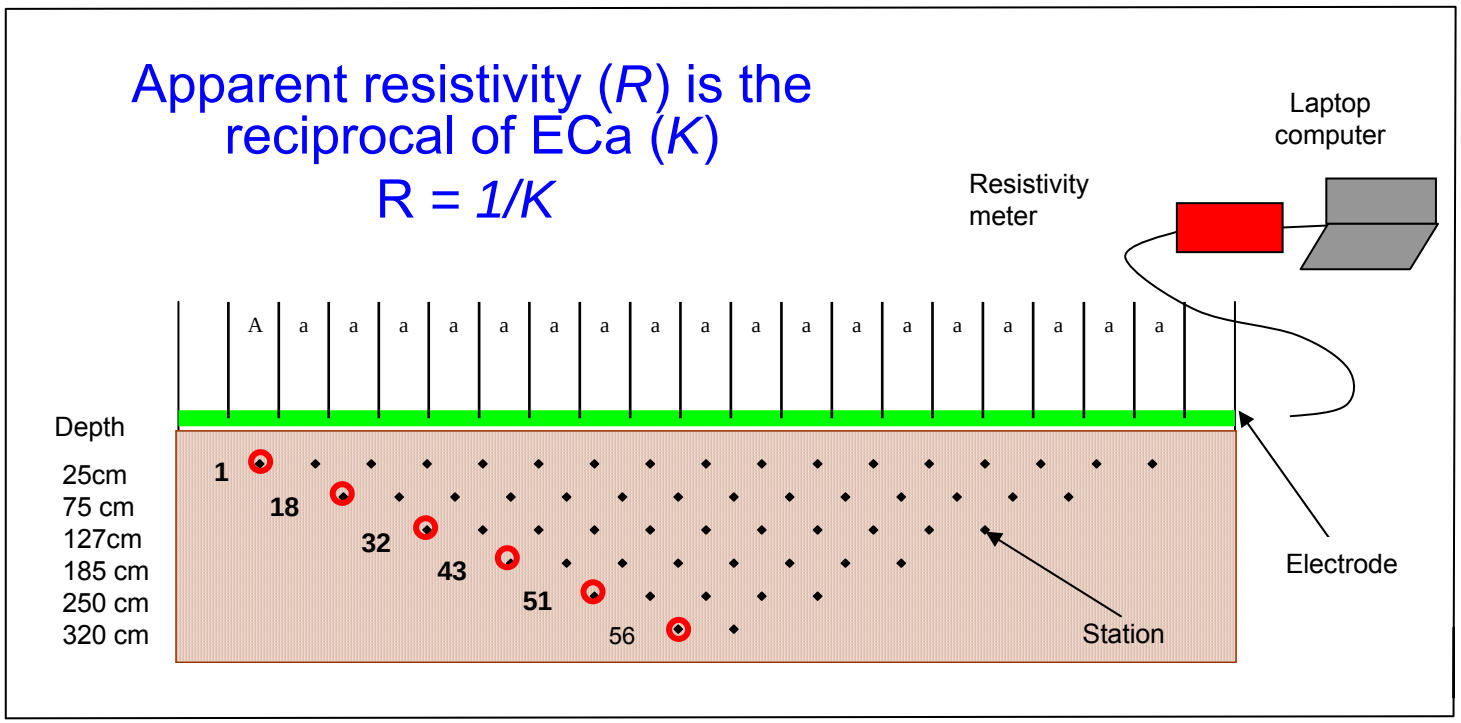


- EC_a values collected on transects about 20 m apart
- position and measurement recorded every 2 seconds



Resistivity Collection

- The resistivity of the soil (its resistance per unit length) was measured in Ω.m using a GEOPULSE resistivity meter under computer control with 20 electrodes spaced 1 m apart
- Effective measurement depths = 25, 75, 127, 185, 250 and 320 cm
- Resistivity data shows how the ECa changes with depth



Data Analysis

- Average of all points within 20 or 30m of a soil sampling grid node (Kerry and Oliver, 2003) calculated to get EC_a values for correlation with soil properties

- Moving correlations were calculated between soil properties and EC_a at each soil sampling point using a (5 x 5) moving window

- Correlations > 0.381 are significant at the 0.05 level, and correlations > 0.45 moderate

Data Analysis

- Indicator (binary, 0 or 1) variables were made from correlations between EC_a and the soil properties
- Correlation coefficients > 0.45, indicator = 1, else = 0
- Indicator variables made for each condition of McBratney *et al*.'s (2005) model :
  - (1) EC_a:clay ratio >5, indicator = 1, else = 0
  - (2) Soil depth < 30 or 50cm, indicator = 1, else = 0
  - (3) Soil compacted, indicator = 1, else = 0
- Indicators variograms computed and maps produced by indicator kriging (Goovaerts, 1997).

RESULTS

Results: Summary all Sites

Site	Proportion of sampling points meeting conditions 1-3 of McBratney et al.'s (2005) model			
	1) Hyper-electrolytic (%)	2) <30cm deep (%)	2) <50cm deep (%)	3) no compaction (%)
Shuttleworth	0	*	*	94
Wallingford	0	9	51	75
Y214	0	52	87	67
Y215	0	70	98	68
Y217	0	18	31	47
Utah		*	*	*

* Variable not measured at site

Results: Summary all Sites

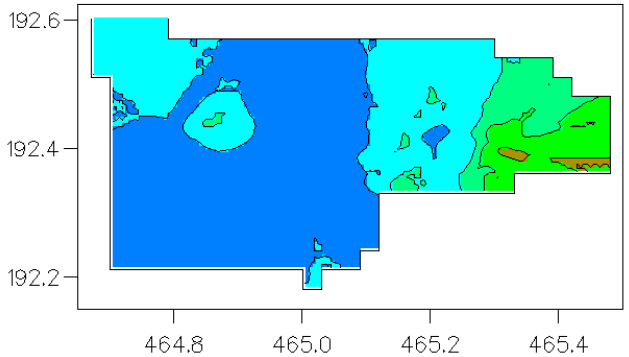
Site	Relationships between EC_a and selected soil properties														
	Depth			Clay			VWC			Sand			Stones		
	P	R^{all}	R^{max}	*P*	R^{all}	R^{max}	*P*	R^{all}	R^{max}	*P*	R^{all}	R^{max}	*P*	R^{all}	R^{max}
Shuttleworth	*	*	*	38	0.38	0.77	19	0.46	0.72	51	-0.51	-0.85	25	0.23	0.74
Wallingford	3	0.36	0.61	39	0.57	0.86	38	0.59	0.91	44	-0.65	-0.89	27	-0.54	-0.92
Y214	50	0.47	0.72	9	0.06	-0.66	31	0.57	0.59	37	0.55	0.85	35	-0.52	-0.69
Y215	0	0.16	*	2	0.07	-0.51	20	0.53	0.55	3	0.18	0.56	22	-0.39	-0.66
Y217	20	0.38	0.65	30	-0.05	0.74	6	0.10	-0.49	0	0.05	*	41	-0.28	-0.83
Utah	*	*	*												

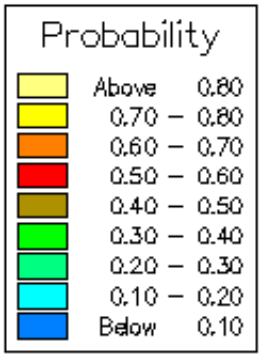
P - proportion (%) of sampling points with moderate correlation >0.45
R^{all} - correlation coefficient for the whole dataset
$R^{max.}$- maximum correlation coefficient observed for a sampling point

*** Variable not measured at site or no values with correlation greater than 0.45**

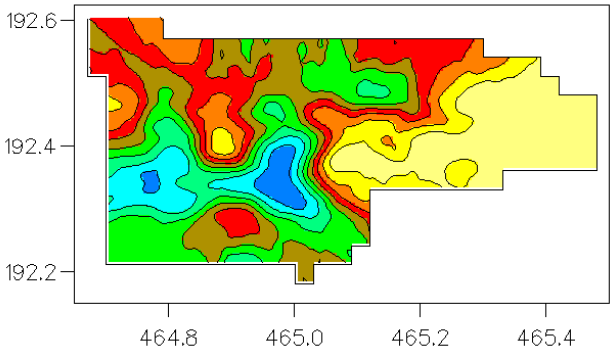
Results: Wallingford (Condition 2)

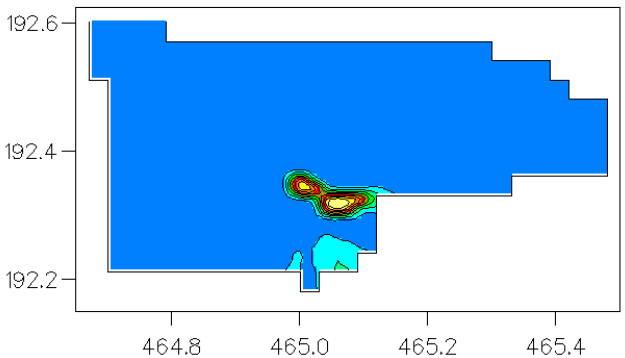
Probability of depth < 30 cm



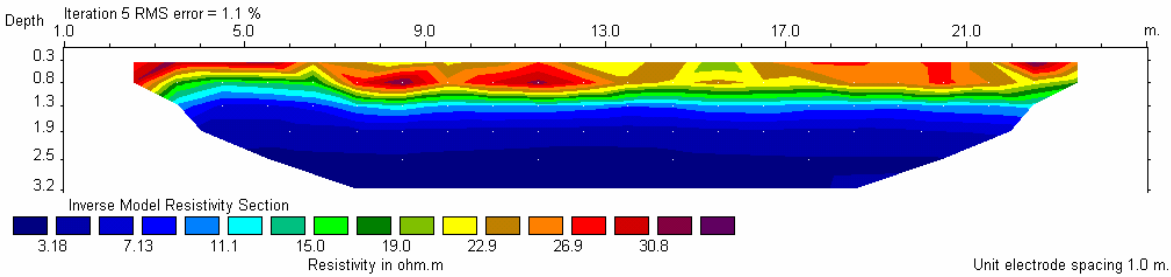


Probability of depth < 50 cm





Probability of > 0.45 correlation between EC_a and depth



- Resistivity decreases with depth
- ECa increases with depth
- Condition (2) of model is not met

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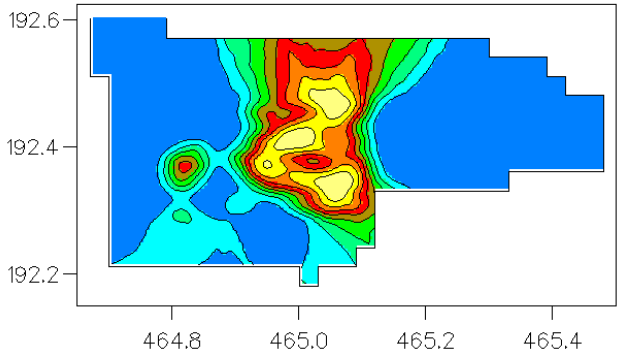
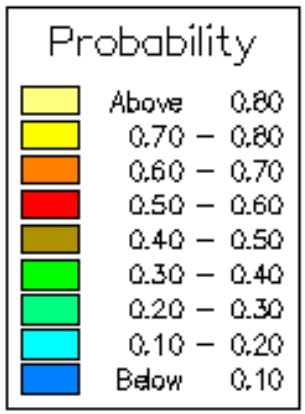
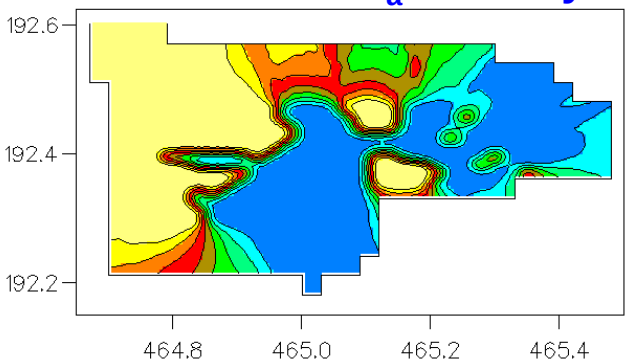
Results: Wallingford (Condition 3)

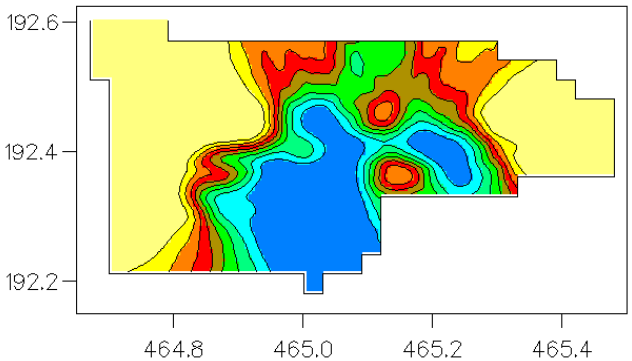
Probability of compaction



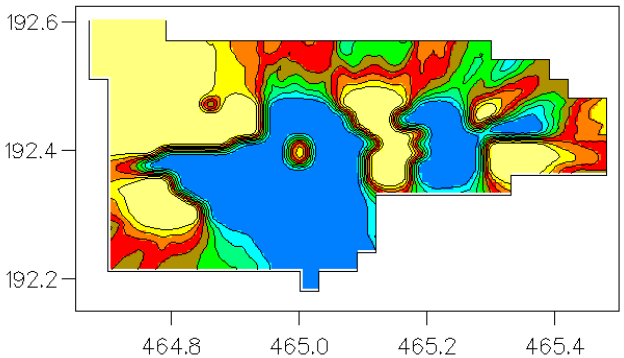


Probability of > 0.45 correlation between EC_a and clay





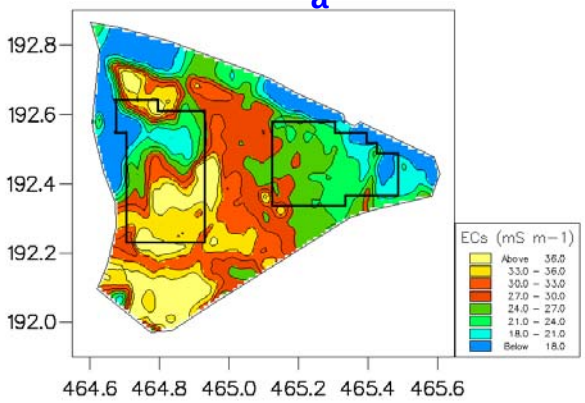
Probability of > 0.45 correlation between EC_a and sand



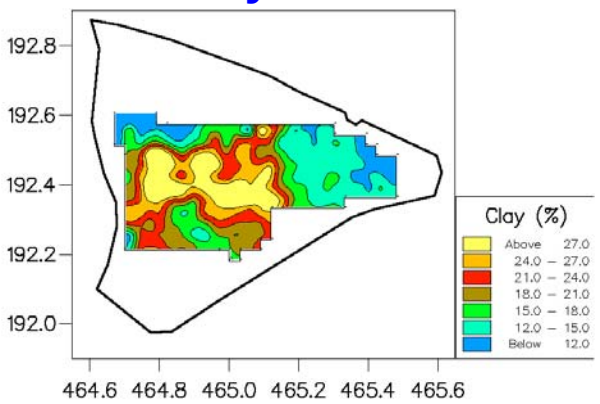
Probability of > 0.45 correlation between EC_a and VWC

Results: Wallingford

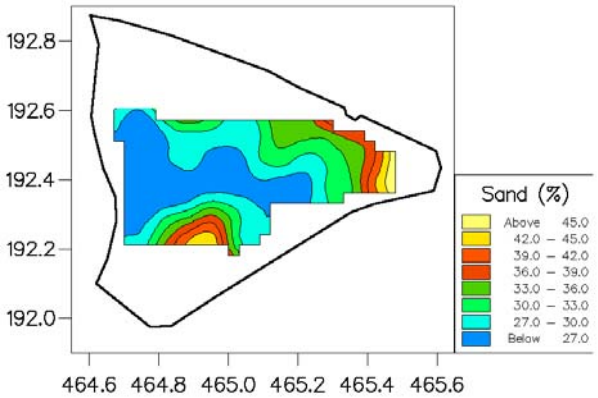
EC_a

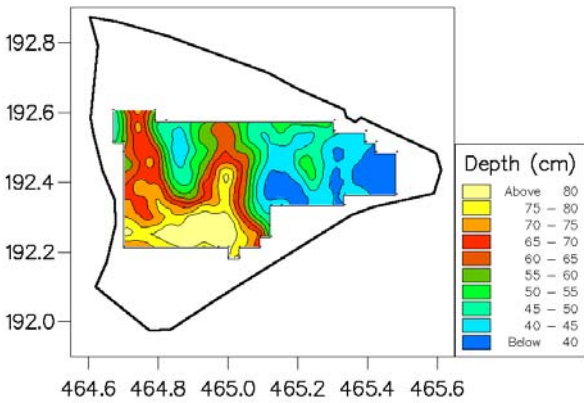


Clay

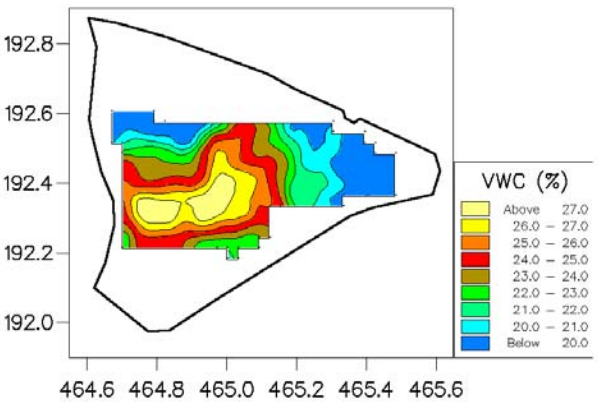


Sand

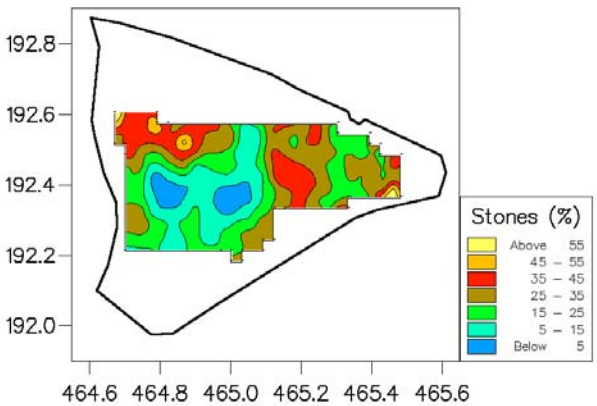




Depth



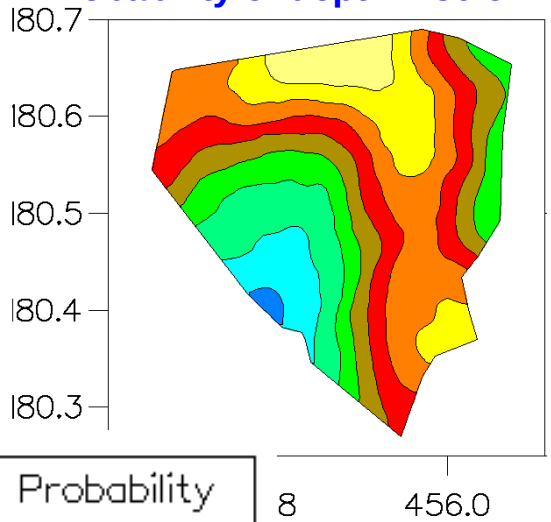
VWC



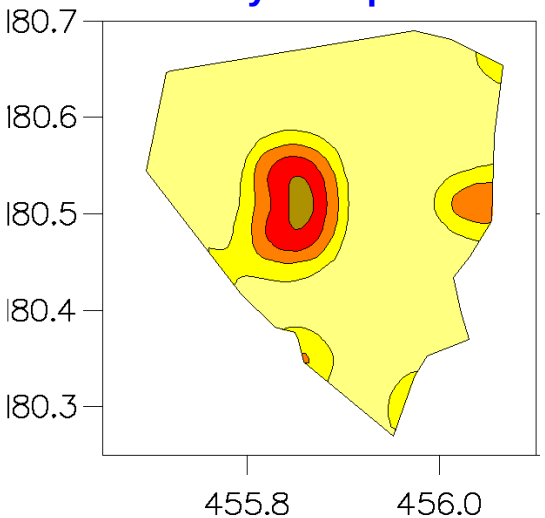
Stones

Results: Yattendon 214 (Condition 2)

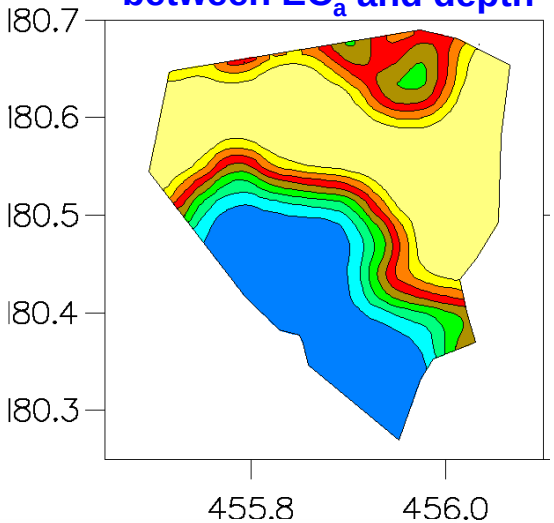
Probability of depth < 30 cm

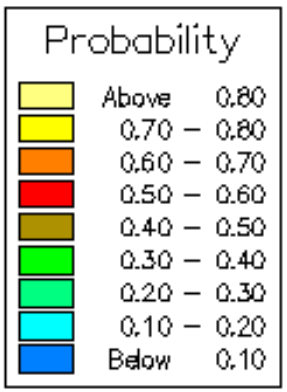


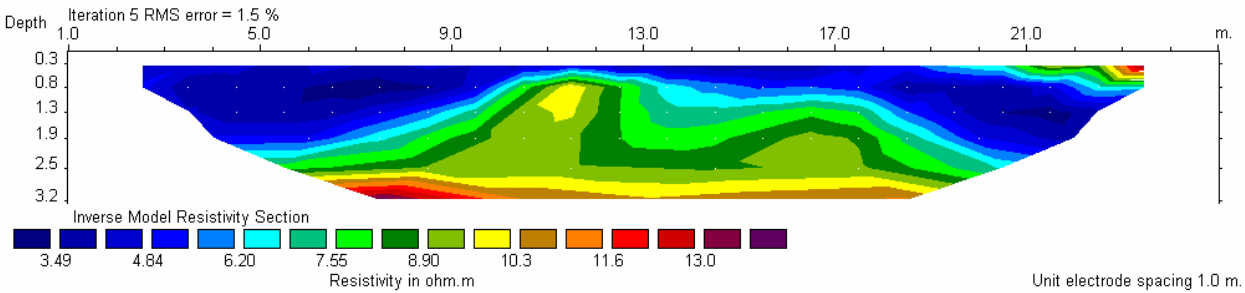
Probability of depth < 50 cm



Probability of > 0.45 correlation between EC_a and depth



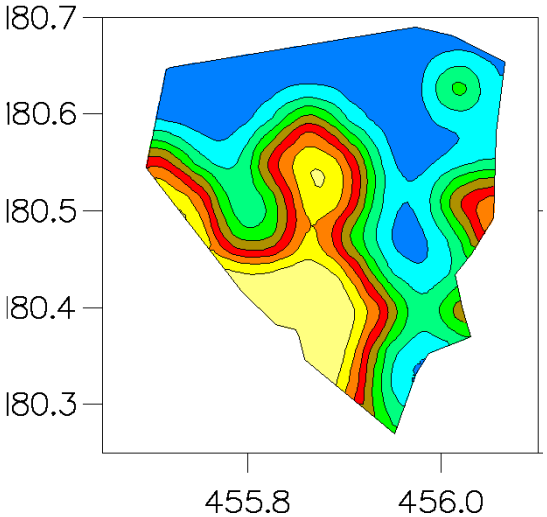




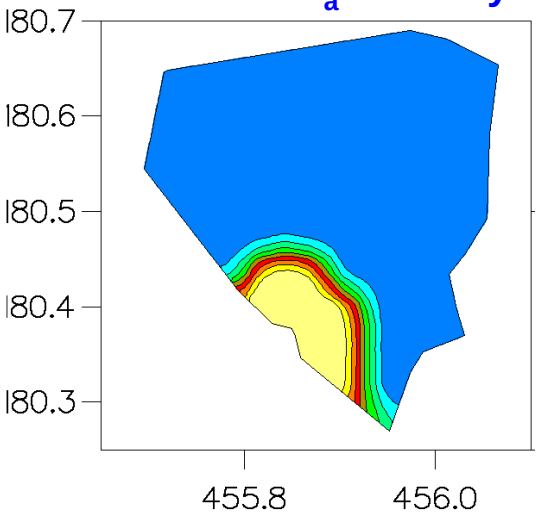
- Resistivity increases with depth
- EC decreases with depth
- Condition (2) of model is met

Results: Yattendon 214 (Condition 3)

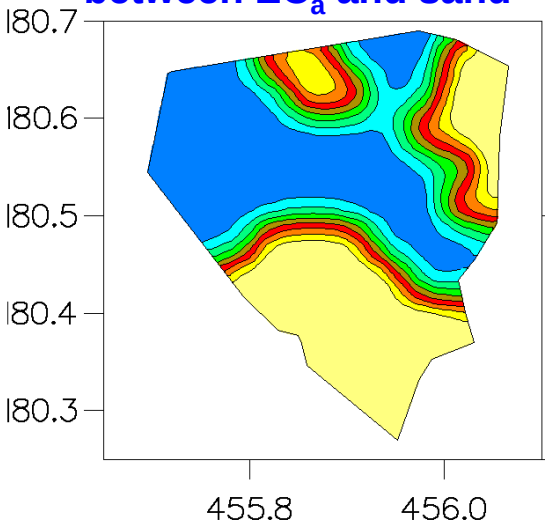
Probability of compaction

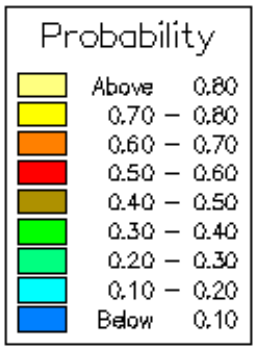


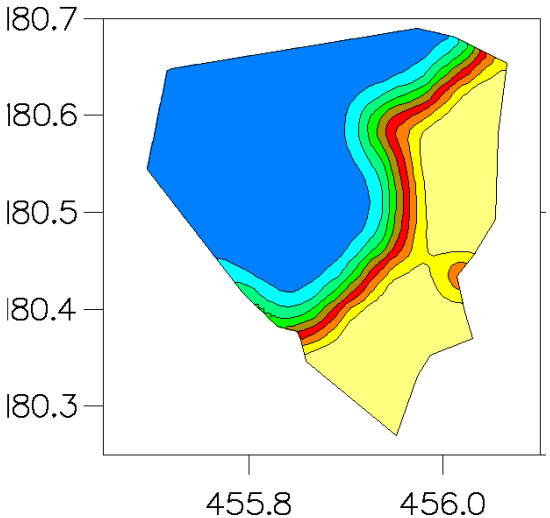
Probability of > 0.45 correlation between EC_a and clay



Probability of > 0.45 correlation between EC_a and sand







Probability of > 0.45 correlation between EC_a and VWC

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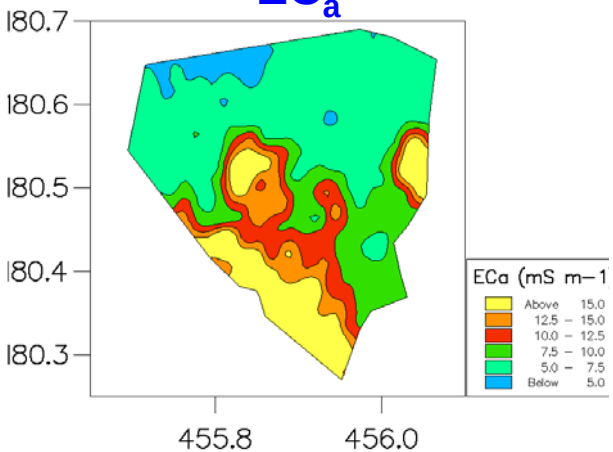
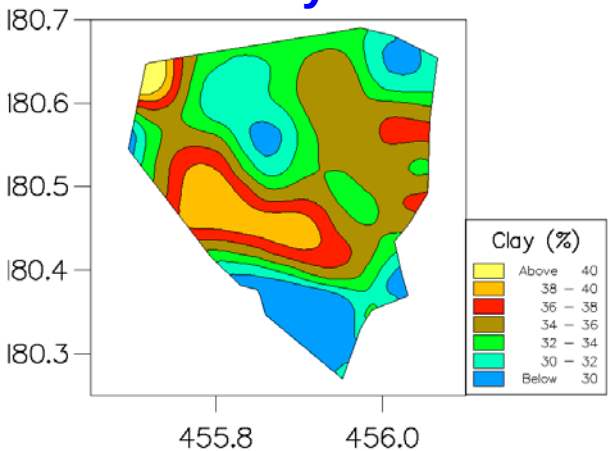
Results: Yattendon Field 214

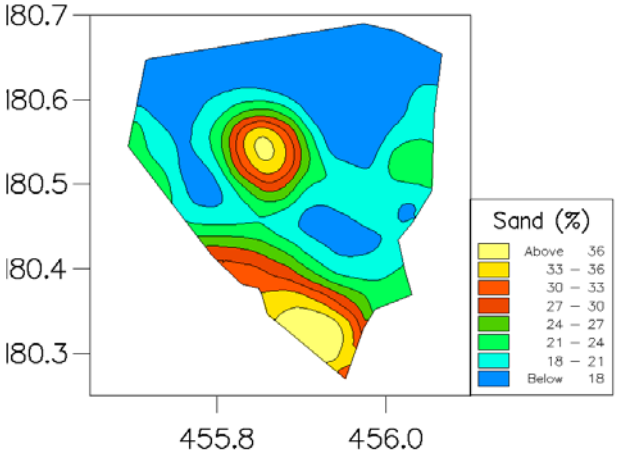
EC_a

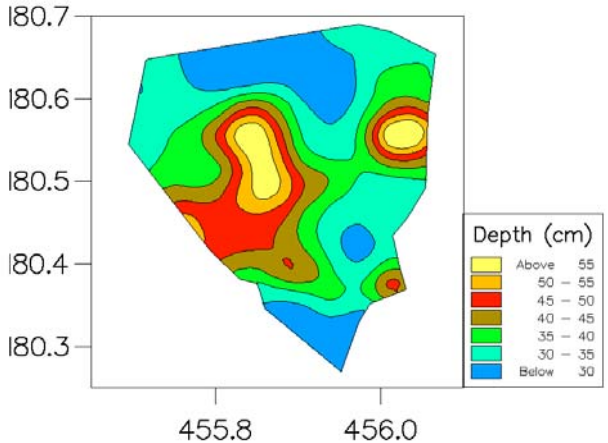


Clay

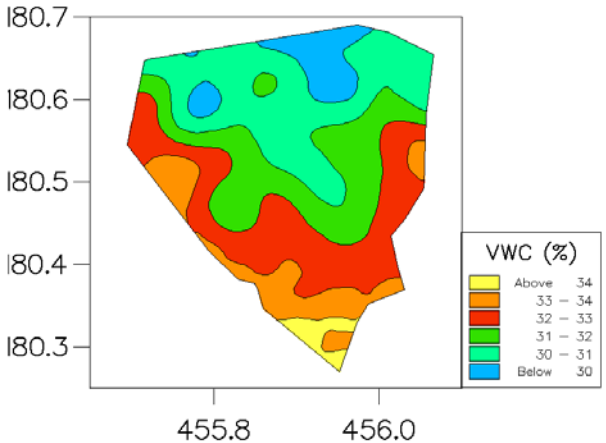


Sand

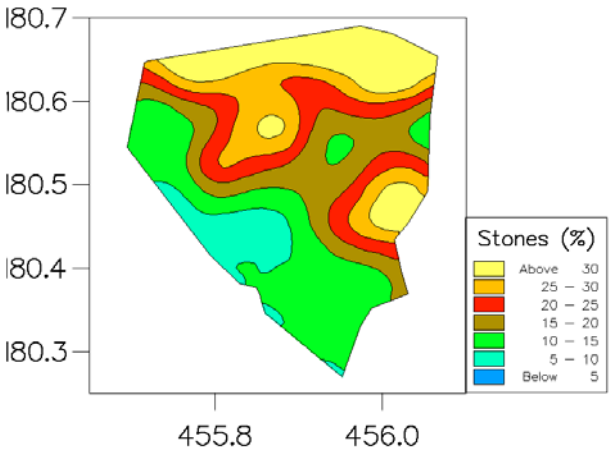




Depth



VWC



Stones

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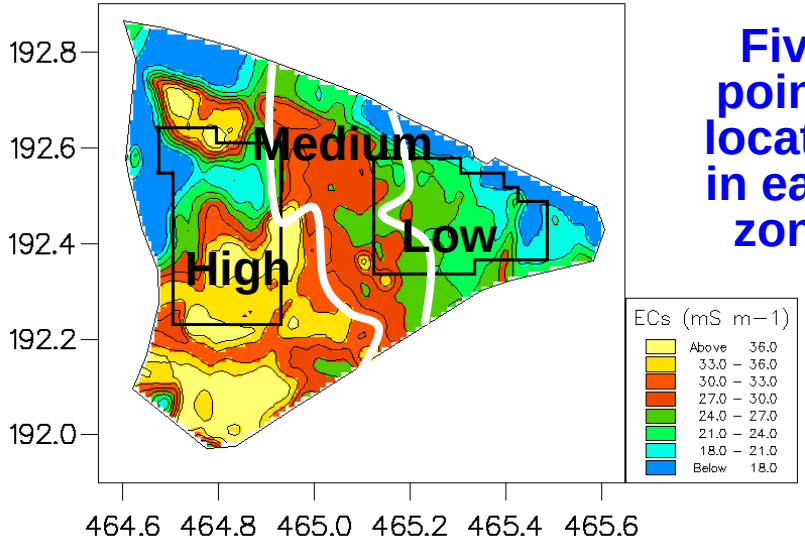
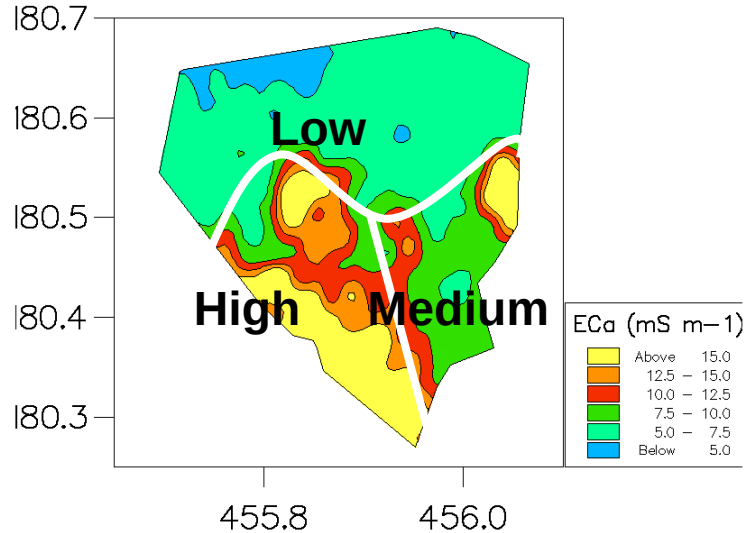
Practical Method



Five points located in each zone



Zone	Conditions of McBratney *et al.*'s (2005) model			
	Hyper-electrolytic	Depth < 30cm		No compaction
	Number of points	Depth of points (cm)	Number of points	Number of points
Wallingford - High	0	26,36,37,56,72	1	5
Wallingford - Medium	0	67,70,73,79,82	0	1
Wallingford – Low	0	30,34,34,42,52	1	5
Yattendon – High	0	24,38,43,63,67	1	0
Yattendon - Medium	0	27,33,34,34,120	1	5
Yattendon - Low	0	23,23,32,33,42	2	5

Standard charts suggest ECa decreases with depth at both sites

Conclusions

- Within most fields different conditions from the model apply in different parts of the field
- In some fields or parts of fields, none of the conditions from the theory apply
- A depth of 30 cm is useful as an effective depth of measurement for the Geonics EM38 at Wallingford and Yattendon sites
- Perhaps soil stoniness should be included in the model
- Summary results helpful: the proportion of sampling points that met a condition was similar to the proportion of points where there was a > 0.45 correlation with EC_a and Kriging of indicators was helpful to determine where these tended to coincide spatially

Conclusions

- McBratney *et al*.'s (2005) model can provide interpretative insight into what EC_a data is measuring

- There are gaps in this model which need to be addressed:
  - What is EC_a measuring when none of the three model conditions applies?
  - How should one test if the electrolyte is in balance with the soil charge?
  - Practical problems of using the model effectively - intensive soil analysis for this study has shown that testing each model condition at many sampling points would be impractical defeating the object of the model which is to save time and money for soil survey by interpreting EC_a data correctly

Conclusions

- Practical method of using model:
  - use the EC_a data to identify zones of different conductivity in the fields
  - sample and analyse soil at five targeted locations in each zone
  - determine which conditions of the model are met – consulting standard charts to determine whether EC_a of parent material is greater than of less than soil is unreliable, resistivity measurement is recommended at one location in each zone
  - Use patterns of EC_a data as a proxy for salinity, depth and texture in appropriate zones

- Assuming that when there is salty, shallow or uncompacted soil in general at a site that EC_a is measuring salt content, depth or clay content of the soil for the whole site is not sound and could lead to poor management decisions

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