Creating DSM to apply
SIX-EASY-STEPS ameliorant and nutrient guidelines

Maryem Arshad, Nan Li,
Michael Sefton, Lawrence Di Bella, Rod Nielson, John Trianatfils

Problem definition:
SIX-EASY-STEPS

Digital Soil Mapping
DSM

Case Studies:
CEC, ESP and Exch. Ca + Exch. Mg

DSM
SIX-EASY-STEPS
Australian Sugarcane

Sugarcane (*Saccharum officinarum* L.) occupies ~545,000 ha

70% cultivation in alluvial-estuarine areas, however there are problems because soil infertile (sandy > 60 %), Acidic (pH < 5.5) and sodic (ESP > 15 %)

Implications with regard to;

- Cation Exchange Capacity (CEC)
- Nutrients (*Exch. Ca* + *Exch. Mg*)
- Unstable (i.e. ESP)
Introduction – An industry “Soil”ution?

Six-Easy-Steps
Nutrient management guidelines

Step 1: Knowing and understanding our soils.
Step 2: Understanding and managing nutrient processes and losses.
Step 3: Soil testing regularly.
Step 4: Adopting soil-specific nutrient management guidelines.
Step 5: Checking on the adequacy of nutrient inputs.
Step 6: Keeping good records to interpret trends and modify nutrient inputs when/where required.

Six-Easy-Steps
Soil Ameilorants
Lime
Gypsum

Soil Nutrients
- Calcium (Ca)
- Magnesium (Mg)
- Nitrogen (N)
- Phosphorus (P)
- Potassium (K)
- Sulphur
- Micronutrients
**Introduction – An industry “Soil”ution?**

**Six-Easy-Steps Nutrient management guidelines**

<table>
<thead>
<tr>
<th>Soil calcium (meq/100g)</th>
<th>Lime application (tonnes/ha)</th>
<th>ESP (%)</th>
<th>Gypsum rate (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 - 0.4</td>
<td>2.5</td>
<td>&lt; 5</td>
<td>0</td>
</tr>
<tr>
<td>0.6 - 0.8</td>
<td>1.5</td>
<td>5 - 10</td>
<td>5</td>
</tr>
<tr>
<td>0.8 - 1.1</td>
<td>1</td>
<td>10 - 15</td>
<td>7.5</td>
</tr>
<tr>
<td>1.1 - 1.5</td>
<td>0.5</td>
<td>&gt; 15</td>
<td>10</td>
</tr>
</tbody>
</table>

**Table 3 – Gypsum guidelines for sodic soils**

**Six-Easy-Steps (Burdekin Valley) Ameliorants**

- **Lime**
  - Infertility
  - CEC (cmol(+)/kg)
  - Apply

- **Gypsum**
  - Sodictiy
  - ESP (%)
  - Apply
Introduction – An industry problem?

Six-Easy-Steps (Soil data not so cheap)
DSM – An innovative “Soil”ution?

Digital Soil Mapping
Creation and population of spatial information using Soil and Digital data coupled with Models either Spatial or Non-spatial inference

Three components: Soil and Digital data Models
Gamma-ray spectrometer - RS700

Passive proximal sensor which detects gamma-rays from radioactive isotopes

Measures:

- K
- U
- Th
- TC

Depth of measurement

0-0.45 m

Related:

- clay
- mineralogy

Table 1. IAEA recommended windows for conventional 3-channel airborne gamma-ray spectrometry (IAEA 1991).

<table>
<thead>
<tr>
<th>Element analysed</th>
<th>Isotope used</th>
<th>Gamma ray energy MeV</th>
<th>Energy window MeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium</td>
<td>$^{40}$K</td>
<td>1.46</td>
<td>1.370–1.570</td>
</tr>
<tr>
<td>Uranium</td>
<td>$^{218}$Bi</td>
<td>1.76</td>
<td>1.660–1.860</td>
</tr>
<tr>
<td>Thorium</td>
<td>$^{208}$Tl</td>
<td>2.61</td>
<td>2.410–2.810</td>
</tr>
</tbody>
</table>
Operating Frequency: 9.0 kHz

**Electromagnetic induction: DUALEM-421**

Single frequency multi-coil array electromagnetic (EM) instrument

Measures:
Apparent electrical conductivity ($EC_a$ – mS/m) Perpendicular (Pcon) and Horizontal coplanar (Hcon)

Depth of measurement
- $1mPcon$ (0-0.5 m) $1mHCon$ (0-1.5)
- $2mPcon$ (0-1 m) $2mPcon$ (0-3)

Related:
- moisture,
- salinity,
- clay and mineralogy
Comparing management zone maps to address infertility and sodicity in sugarcane fields

Maryem Arshad,
Nan Li, Sam Lamari, Michael Sefton, John Triantafilis
DSM – An innovative “Soil”ution?

<table>
<thead>
<tr>
<th>DSM</th>
<th>Herbert - HCPSL</th>
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<tbody>
<tr>
<td><strong>Step 1: Meeting</strong></td>
<td><strong>Soil:</strong> CEC ESP</td>
</tr>
<tr>
<td><strong>Step 2: Measurement</strong></td>
<td><strong>Digital:</strong> Digital Elevation Model γ-ray spectrometry Electromagnetic EM</td>
</tr>
<tr>
<td><strong>Step 3: Modelling</strong></td>
<td><strong>Model:</strong> Clustering Digital data</td>
</tr>
<tr>
<td><strong>Step 4: Mapping</strong></td>
<td><strong>Comparison:</strong> DSM Traditional soil texture map Field delineations</td>
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<tr>
<td><strong>Step 5: Management</strong></td>
<td>Infertility CEC (cmol(+)/kg) Sodictiy ESP (%)</td>
</tr>
<tr>
<td><strong>Step 6: Monitoring</strong></td>
<td>Apply Apply</td>
</tr>
</tbody>
</table>

Digital data: 
- Digital Elevation Model
- γ-ray spectrometry
- Electromagnetic EM

Comparison:
- DSM Traditional soil texture map Field delineations
- Infertility CEC (cmol(+)/kg) Sodictiy ESP (%)
Introduction – An industry “Soil”ution?

Six-Easy-Steps
Nutrient management guidelines

<table>
<thead>
<tr>
<th>Table 1 - Lime guidelines for acid soils (when pH water &lt; 5.5)</th>
<th>Table 4 - Gypsum guidelines for sodic soils</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CEC (meq/100g)</strong></td>
<td><strong>Lime application (tonnes/ha)</strong></td>
</tr>
<tr>
<td>&lt; 3.0</td>
<td>2.25</td>
</tr>
<tr>
<td>3.0 - 6.0</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 6.1</td>
<td>5</td>
</tr>
</tbody>
</table>

Six-Easy-Steps (Herbert Valley)

**Soil ameliorants**

- **Lime**
  - Infertility CEC (cmol(+)/kg)
  - Apply

- **Gypsum**
  - Sodictiy ESP (%)
  - Apply
Management zones: **Traditional/Field**

**Herbert Sugarcane**

Alluvial soil varies and has been mapped using **Traditional Soil texture map**

- Clay
- Silty Clay
- Terrace Silt Loam

Best-practice requires knowledge of variation to max. yield and min. losses

When soil texture map is unavailable, farmers use **Field delineations**

- Field 1
- Field 2
- Field 3
In multiple fields at HCPSL:

a) Can we generate a DSMs of management zones to manage Soil:
   i) Infertility (CEC) and
   ii) Sodicity (ESP)
using mathematical models and proximally sensed Digital data

b) Which method of creating management zones is optimal
   i) DSM (DEM, γ-ray and EM)
   ii) Traditional soil texture map
   iii) Field delineations
Data collection: Digital & Soil

Digital data was collected from 21 transects (6 m apart) using Digital Elevation Model γ-ray spectrometry Electromagnetic EM

Soil samples were collected from 50 sites Topsoil (0-0.3 m)
Digital data

Gamma-ray spectrometer - RS700

K, U and Th
Digital data

Electromagnetic induction: DUALEM-421

1mPcon, 2mPcon and 1mHcon
Soil data

Analysis: time consuming

Chemical (CEC and ESP) ~24 hours

Washing
Extraction
Analysis
Calculations

$180
Soil data

Test data to compare

Clay

CEC and

ESP
Model: Clustering digital data

DSM - zones
Management zones

DSM = Digital data + clustering

Traditional map = Soil Texture

Field delineation = 3 fields
Which one best to manage Soil infertility?

Mean square prediction error (MSPE)

<table>
<thead>
<tr>
<th>Properties</th>
<th>DSM k = 2</th>
<th>DSMk k = 3</th>
<th>DSM k = 4</th>
<th>Traditional (k = 3)</th>
<th>Field (k = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC ([cmol(+)/kg])</td>
<td>2.20</td>
<td>2.21</td>
<td>2.34</td>
<td>2.37</td>
<td>2.41</td>
</tr>
</tbody>
</table>
Lime application rate to DSM

Six-Easy-Step (Herbert Valley)
Infertility
CEC (cmol(+)/kg)
Apply

Table 1 – Lime guidelines for acid soils (when pH water < 5.5)

<table>
<thead>
<tr>
<th>CEC (meq/100g)</th>
<th>Lime application (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3.0</td>
<td>2.25</td>
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Which one best to manage Soil sodicity?

Mean square prediction error (MSPE)

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<th>DSM k = 4</th>
<th>Traditional (k = 3)</th>
<th>Field (k = 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP (%)</td>
<td>5.76</td>
<td>5.60</td>
<td>6.91</td>
<td>7.04</td>
<td>6.2</td>
</tr>
</tbody>
</table>
Gypsum application rate to DSM

Six-Easy-Step (Herbert Valley)
Sodicity ESP (%) Apply

Table 4 – Gypsum guidelines for sodic soils

<table>
<thead>
<tr>
<th>ESP (%)</th>
<th>Gypsum rate (tonnes/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5</td>
<td>0</td>
</tr>
<tr>
<td>5 - 10</td>
<td>2</td>
</tr>
<tr>
<td>10 - 15</td>
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</tr>
<tr>
<td>&gt; 15</td>
<td>6</td>
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</table>
Determining an optimal mathematical model, sample size and ancillary data for mapping Exch. Ca and Mg

Nan Li,
Michael Sefton, John Triantafilis
DSM – An innovative “Soil”ution?

<table>
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<tr>
<th>DSM</th>
<th>Burdekin – DAVCO Pty Ltd.</th>
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<tbody>
<tr>
<td><strong>Step 1: Meeting</strong></td>
<td>Soil:</td>
</tr>
<tr>
<td></td>
<td>Calcium (Ca)</td>
</tr>
<tr>
<td></td>
<td>Magnesium (Mg)</td>
</tr>
<tr>
<td><strong>Step 2: Measurement</strong></td>
<td>Digital:</td>
</tr>
<tr>
<td></td>
<td>$\gamma$-ray spectrometry</td>
</tr>
<tr>
<td></td>
<td>Electromagnetic EM</td>
</tr>
<tr>
<td><strong>Step 3: Modelling</strong></td>
<td>Model:</td>
</tr>
<tr>
<td></td>
<td>Correlate Digital + Soil</td>
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<tr>
<td><strong>Step 4: Mapping</strong></td>
<td>Comparison:</td>
</tr>
<tr>
<td></td>
<td>LMM, RK, RF, SVM</td>
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<tr>
<td><strong>Step 5: Management</strong></td>
<td>Exch. Ca (cmol(+)kg)</td>
</tr>
<tr>
<td></td>
<td>Apply</td>
</tr>
<tr>
<td><strong>Step 6: Monitoring</strong></td>
<td>Exch. Mg (cmol(+)kg)</td>
</tr>
<tr>
<td></td>
<td>Apply</td>
</tr>
</tbody>
</table>
Introduction

Why Ca and Mg

Ca is important:
   i) plant roots and leaves
   ii) neutralize excess acid or alkaline soil

Mg is central component of chlorophyll
   i) drive photochemistry
   ii) harvest solar energy
   iii) major role in N uptake

Soil deficient in Ca and Mg leads to issues like chlorosis, necrosis, curling of plant leaves with ultimate cessation of plant growth
Problem definition

Burdekin Sugarcane growing area

Sugarcane farmers apply fertilisers for \( \text{Ca} \) and \( \text{Mg} \) using “One rate fits all” approach.

It could be using ‘One rate fits all’ approach based on Soil Order map

In Burdekin, this is done using six-easy-steps nutrient management guidelines

<table>
<thead>
<tr>
<th>Lime guidelines based on Exch. Ca</th>
<th>Lime (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exch. Ca (meq/100g)</td>
<td></td>
</tr>
<tr>
<td>&lt;0.2</td>
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</tr>
<tr>
<td>0.2-0.4</td>
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<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Magnesium guidelines based on Exch. Mg</th>
<th>Mg (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exch. Mg (meq/100g)</td>
<td></td>
</tr>
<tr>
<td>&lt;0.05</td>
<td>150</td>
</tr>
<tr>
<td>0.06-0.10</td>
<td>125</td>
</tr>
<tr>
<td>0.11-0.15</td>
<td>100</td>
</tr>
<tr>
<td>0.16-0.20</td>
<td>75</td>
</tr>
<tr>
<td>0.21-0.25</td>
<td>50</td>
</tr>
<tr>
<td>&gt;0.25</td>
<td>0</td>
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</tbody>
</table>
Moreover, information are required across the field to optimise yield and productivity. Problem definition

Nutrient Management

Fertilizer application practice requires prior soil information about

- Exch. Ca
- Exch. Mg

Unfortunately, obtaining these information using traditional method is time-consuming and expensive.

Moreover, information are required across the field to optimise yield and productivity.
In a sugarcane field in Burdekin Valley:
Generate DSMs of
Exch. Ca and
Exch. Mg

1) Which mathematical model is best?

2) How many soil samples do we need?

3) Which digital data is superior?
Soil sampling and analysis

Soil samples: 182
Calibration: 140 samples
Validation: 42 samples

Laboratory analysis
Tucker’s method (1974)
1) Which **model** is best?

**Mathematical models**

- Linear Mixed Model (LMM)
- Regression Kriging (RK)
- Random Forests (RF)
- Supportive Vector Machine (SVM)

**Equation:**

\[ Y_i = \beta_0 + \beta_1 X_i + \epsilon_i \]
2) How many soil samples?

Conditioned Latin hypercube

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>60</td>
<td>80</td>
<td>100</td>
<td>120</td>
</tr>
</tbody>
</table>
3) Which digital data is best?

Digital data

Gamma-ray spectrometry: RS700
Potassium (K), Uranium (U), Thorium (Th) and Total count (TC)

DUALEM-421
1mPcon (0-0.6 m) 1mHcon (0-1.0 m) 2mPcon (0-1.2 m) 2mHcon (0-3.0 m)
Results: **Soil data**

Exch. Ca and Exch. Mg
Results: Digital data (γ-ray)

Gamma-ray spectrometry: RS700
Potassium(K),
Uranium(U),
Thorium(Th) and
Total count (TC)

Measures γ-rays in topsoil (0-0.45 m)
Results: Digital data (EM)

Electromagnetic induction: DUALEM-421

1m coils
Measures ECₐ in topsoil
1mPcon 0-0.6 m
1mHcon 0-1.0 m

2m coils
Measures ECₐ in subsurface
2mPcon 0-1.2 m
2mHcon 0-3.0 m

Measures ECₐ
1. Which **model** is best?

Exch. Ca: LMM
2. How many soil samples?

Exch. Ca: 60 / 20
3. Which digital data: $\gamma$-ray or EM

Exch. Ca: $\gamma$-ray+EM > EM > $\gamma$-ray

- a) Lin's concordance = 0.79
  $R^2 = 0.69$
  ME = 0.006
  RMSE = 0.08

- b) Lin's concordance = 0.85
  $R^2 = 0.79$
  ME = 0.003
  RMSE = 0.06

- c) Lin's concordance = 0.87
  $R^2 = 0.82$
  ME = 0.003
  RMSE = 0.05
Conclusions

In a sugarcane field in Burdekin Valley:
We can generate DSMs of
  i) Exch. Ca and
  ii) Exch. Mg
using easier to acquire $\gamma$-ray and EM data

1) Which mathematical model is best
   LMM > RK > RF > SVM

2) How many soil samples do we need
   Exch. Ca: 60 / 20+LMM
   Exch. Mg: 40 / 30+LMM

3) Which digital data is superior
   $\gamma$-ray + EM
   EM
   $\gamma$-ray
Conclusions

In a sugarcane field in Burdekin Valley:
Calcium (Ca)

Table 1 – Lime guidelines based on exchangeable calcium (Ca)

<table>
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<th>Soil calcium (meq/100g)</th>
<th>Lime application (t/ha)</th>
</tr>
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<tbody>
<tr>
<td>&lt;0.2</td>
<td>3</td>
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<td>1.1-1.5</td>
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</tr>
</tbody>
</table>
Conclusions

In a sugarcane field in Burdekin Valley:
Magnesium (Mg)

<table>
<thead>
<tr>
<th>Soil Mg (amm-acet) (meq/100g)</th>
<th>Mg rate (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.05</td>
<td>150</td>
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Conclusions

**DSM:** Management zone
CEC and
ESP
Individual *soil* properties
Calcium (Ca) and
Magnesium (Mg)

Whether this increases yield and has economic benefit? Cost-benefit of doing DSM and SIX-EASY-STEPS?

Yield data (satellite, airborne, proximal)?

Train and retain (international) students who understand needs of industry.

What is working?

What do we still not know?

What constraints?

Immediate priorities?
Acknowledgements
Monitoring soil water dynamics using electromagnetic conductivity imaging and the ensemble Kalman Filter

Jingyi Huang, Alex B. McBratney, Budiman Minasny, John Triantafilis
3-d regolith mapping of clay using inversion of EM38 and EM34

Zhao, X, Wang, J, Zhao, D, Li, N, Zare, E, Khongnawang, T, Muzzamal, M, Triantafilis, J.

prior stream

clay floodplain

palaeo channel

DSM in 3-d for mapping clay