Precision Agriculture Research in Oil Palm: A 10-year Summary

Siva K Balasundram, PhD
Dept of Agriculture Technology
Faculty of Agriculture
Universiti Putra Malaysia
(siva@upm.edu.my)
Precision Agriculture (PA)?

- A holistic farm management strategy which allows adjustment of agricultural inputs so as to match varying soil/crop needs and field attributes (Robert, 1995)

  → Quantification of spatial and/or temporal variability
  
  → Linking such variability to management actions
Spatial variability

⇒ differences across space/distance
Temporal variability

⇒ differences across time/season

Corn grain yield - 1997

Field M1 (30 ac.), Davis-Purdue Ag. Center

Corn grain yield - 1998

Field M1 (30 ac.), Davis-Purdue Ag. Center
The goal of PA is …

- to manage variability in the spatial-temporal continuum so as to:
  - maximize net economic return
  - increase sustainability
  - minimize environmental degradation
PA is a cyclic process …

GATHER INFORMATION
- Database management

PROCESS & ANALYZE INFORMATION
- Geostatistics
- GIS
- Neural networks

IMPLEMENT CHANGE
- VRA
- DSS

• GPS
• Yield monitor
• Sensors (proximal/remote)
• Grid/directed sampling
Possible outcomes from using PA

- Higher yield with the same level of inputs
- The same yield with reduced inputs
- Higher yield with reduced inputs
Why is PA practical?

<table>
<thead>
<tr>
<th></th>
<th>Benefit Occurs</th>
<th>No Benefit Occurs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACT</strong></td>
<td>Correct action</td>
<td>Type II error: Loss caused</td>
</tr>
<tr>
<td><strong>DON’T ACT</strong></td>
<td>Type I error: Lost opportunity</td>
<td>Correct inaction</td>
</tr>
</tbody>
</table>

⇒ PA minimizes Type I & Type II errors
## Technological domain

### Geo-spatial modeling

- FFB yields
- Leaf and soil nutrients
- Fertilizer trials
- Soil organic carbon

### Decision support system

- Oil yield
- Oil quality

### Remote and proximal sensing

- FFB yields
- Disease detection
- Oil quality
- Stand density

### Keywords

- Spatial variability, management zones, nearest-neighbor analysis, operational zones
- FFB harvesting, image processing, surface color, degree of bleachability index
- Vegetation indices, spectral reflectance, sensor, geographical information system, Google Earth
Geo-spatial modeling – Study 1

- Effects of topography on soil fertility and oil palm yields
- Empirical production functions were defined for each topographic position (toeslope, sideslope, summit)

Results:

» Yields and soil fertility varied with topographic position
» Measured leaf and soil variables showed varying levels of optimality/sufficiency across topographic positions
Comparison of variables (leaf and soil) and the corresponding yield across topography (Sri Gunung Estate – site # 2)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Toeslope</th>
<th>Sideslope</th>
<th>Summit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leaf</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>2.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.73&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>P</td>
<td>0.18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.15&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.16&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>K</td>
<td>0.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.93&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.96&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mg</td>
<td>0.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.42&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ca</td>
<td>0.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.72&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.71&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Soil (0-20 cm)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>4.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.27&lt;sup&gt;b&lt;/sup&gt;</td>
<td>4.16&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>OM</td>
<td>2.59&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.22&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.33&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>P</td>
<td>79.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.98&lt;sup&gt;a&lt;/sup&gt;</td>
<td>7.14&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>K</td>
<td>0.23&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.20&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.20&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mg</td>
<td>0.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.61&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Ca</td>
<td>1.63&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.19&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>ECEC</td>
<td>5.46&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.02&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Texture</td>
<td>SC</td>
<td>LC</td>
<td>LC</td>
</tr>
<tr>
<td><strong>Yield</strong></td>
<td>4.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.60&lt;sup&gt;b&lt;/sup&gt;</td>
<td>3.13&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Relationship between yield and leaf/soil variables across topography (Sri Gunung Estate – site # 2)

<table>
<thead>
<tr>
<th>Topographic position</th>
<th>Regression model§</th>
<th>R²</th>
<th>Adjusted R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toeslope</td>
<td>(1) Yield = 5.22 – 2.53*Leaf Mg</td>
<td>0.76</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>(2a) Yield = 3.19 + 0.15*Leaf (N:Mg)</td>
<td>0.80</td>
<td>0.75</td>
</tr>
<tr>
<td></td>
<td>(2b) Yield = 3.04 + 2.66*Leaf (P:Mg)</td>
<td>0.79</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>(3) Yield = 3.66 + 0.10*pH</td>
<td>0.66</td>
<td>0.58</td>
</tr>
<tr>
<td>Sideslope</td>
<td>(3) Yield = 8.78 – 0.70<em>ECEC – 19.03</em>log (Subsoil Mg)</td>
<td>0.89</td>
<td>0.82</td>
</tr>
<tr>
<td>Summit</td>
<td>(1) Yield = 28.25 – 9.28*Leaf N</td>
<td>0.89</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>(4) Yield = 3.88 – 2.57*Soil (K:Mg)</td>
<td>0.75</td>
<td>0.68</td>
</tr>
</tbody>
</table>

§Developed separately using the following group as yield predictors:
(1) leaf variables, (2) leaf nutrient ratios, (3) soil variables, and (4) topsoil nutrient ratios

Geo-spatial modeling – Study 2

- Spatial variability of oil palm yield-influencing variables (YIVs) at varying topographic positions

Results:

- Optimum sampling strategy was found to depend on the type of variable being investigated and its topographic position
- Sample size requirement varied according to leaf/soil variables in the following order:
  
  (Leaf) N/P < Mg  
  pH < ECEC < subsoil Mg < topsoil K < topsoil Mg

- K showed a clear demarcation of zones with high, moderate or low values – good candidate for variable rate management
Semivariograms of YIVs at the summit (Sri Gunung Estate – site # 2)

Leaf N (%)

Model: Exponential; Spatial dependence: Strong
Nugget=1.7x10^{-4}; Sill=4.8x10^{-3}; Effective range=41m

Topsoil K (m.e. 100 g⁻¹)

Model: Spherical; Spatial dependence: Strong
Nugget=1x10^{-5}; Sill=1x10^{-3}; Effective range=54m

Topsoil Mg (m.e. 100 g⁻¹)

Model: Spherical; Spatial dependence: Strong
Nugget=1x10^{-4}; Sill=8.8x10^{-2}; Effective range=38m

Spatial variability of topsoil K at the summit and the corresponding re-classed variability map (Sri Gunung Estate – site # 2)

Geo-spatial modeling – Study 3

- Evaluation of oil palm growth response to K application
- Treatment effects adjusted using Nearest-neighbor Analysis (NNA) so as to remove spatial trends

Results:

- Before removal of spatial trends, treatment effects on plant growth were not significant
- Following NNA adjustment, growth variables varied significantly among treatments
Growth response to K treatments before and after spatial trend removal (Sungai Pelepah Estate – site # 1)

Before NNA adjustment

After NNA adjustment

(Note: MSD = Minimum Significance Difference based on the Waller-Duncan K-ratio t Test; means that are separated by values smaller or equal to the MSD are not significantly different at p=0.05)

Geo-spatial modeling – Study 4

- Spatial variability of Soil Organic Carbon (SOC) in young and mature oil palm stands

**Results:**

- SOC heterogeneity evident among operational zones – Frond Heap (FH), Weeded Circle (WC), Harvesting Path (HP)

  
  \[ HP < WC < FH \]

  Increasing SOC (%)

- All operational zones exhibited strong spatial dependence. SOC concentration in mature palms was found to be more stable than that from young palms

Soil organic carbon content (%) across three operational zones (WC, FH and HP) at 5 and 17 Years After Planting (YAP)

Spatial variability of soil organic carbon across WC, FH and HP at 5 and 17 Years After Planting (YAP)

Decision support system – Study 5

- Relationship between oil content in oil palm fruit and its surface color distribution

Results:

- Significant correlation between total oil and color components; black ($r=-0.85$), red ($r=0.81$), orange ($r=0.62$), yellow ($r=0.48$)

% Total oil = $88.08 - 0.52 \times (\%) \text{ Black} + 1.30 \times \log(\%) \text{ Yellow}$

% Total oil = $36.84 + 0.63 \times (\%) \text{ Red} + 1.52 \times \log(\%) \text{ Yellow}$

- 73-75% accuracy
Measured versus predicted total oil content

%Total oil = 88.1 - 0.5 (%Black) + 1.3 log (%Yellow)

%Total oil = 36.8 + 0.6 (%Red) + 1.5 log (%Yellow)

Model validation

Predictors: Black and Yellow

$r = 0.75$

Predictors: Red and Yellow

$r = 0.73$

%Total oil = 88.1 - 0.5 (%Black) + 1.3 log (%Yellow)

%Total oil = 36.8 + 0.6 (%Red) + 1.5 log (%Yellow)

Financial implication of using these empirical models to estimate palm oil content

<table>
<thead>
<tr>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model</strong></td>
<td>TO = 88.08 - (0.52<em>B) + (1.30</em>\log(Y))</td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td>B = 30, Y = 0.9</td>
</tr>
<tr>
<td><strong>Predicted total oil (%)</strong></td>
<td>72.42</td>
</tr>
</tbody>
</table>

2 Value (USD):

- **per tree per year**
  - 13.62
  - 11.86
  - 10.10
  - 10.35
  - 12.01
  - 13.78

- **per ha per year**
  - 1851.65
  - 1612.33
  - 1373.01
  - 1407.27
  - 1632.78
  - 1874.40

<table>
<thead>
<tr>
<th>Benefit (value per tree per year) comparison matrix:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model input</td>
</tr>
<tr>
<td>R_{29} Y_{0.9}</td>
</tr>
<tr>
<td>R_{43} Y_{0.9}</td>
</tr>
<tr>
<td>R_{58} Y_{0.9}</td>
</tr>
</tbody>
</table>

1 Where: TO = % Total oil, B = % Black, R = % Red, Y = % Yellow
2 Extrapolated to represent an FFB based on a sample mean of two fruits
Decision support system – Study 6

- Development of a computerized image analysis and palm oil yield/quality estimation protocol (extension of Study 5)
- Additional variable ➔ Degree of Bleachability Index (DOBI), which is used by the industry as a standard measure of palm oil quality (cutoff value for DOBI: 3.5-4.0)

**Results:**

- Positive relationship between DOBI and %Red; more pronounced in the upper limit (DOBI>4.0), especially in mature palms
- Computerization of the image analysis and oil quality estimation protocols was done using Visual Basic 6.0 and Ilwis 3.2
Image analysis protocol developed from Study 5

Regression of DOBI on fruit surface color

<table>
<thead>
<tr>
<th>Palm age</th>
<th>DOBI</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5 (young)</td>
<td>&lt; 4</td>
<td>DOBI = 4.1 – 0.03*%O</td>
</tr>
<tr>
<td></td>
<td>&gt; 4</td>
<td>DOBI = 6.6 + 1.52*log %R</td>
</tr>
<tr>
<td>&gt; 5 (mature)</td>
<td>&lt; 4</td>
<td>DOBI = 3.6 + 0.02*%R</td>
</tr>
<tr>
<td></td>
<td>&gt; 4</td>
<td>DOBI = 4.4 + 2.49<em>log %R – 2.08</em>log %(RY)</td>
</tr>
</tbody>
</table>

Note: O = Orange, R = Red, Y = Yellow
A computerized technique to estimate oil palm fruit quality

Remote and proximal sensing – Study 7

- Empirical oil palm yield models based on a single-date archived QuickBird satellite imagery and oil palm yield data collected over a 12-year time series

Results:

- Strong positive correlation between vegetation indices and oil palm yields, across different planting periods
- Ratio Vegetation Index (RVI) gave the best correlation with oil palm yield
- Empirical models were significant for the 1990-2002 and the 1998-1999 planting periods
- Models built using RVI showed a strong fit between estimated yield and observed yield
Correlation between oil palm yield and vegetation indices across different planting periods

<table>
<thead>
<tr>
<th>Planting year</th>
<th>n</th>
<th>RVI</th>
<th>NDVI</th>
<th>MSAVI</th>
<th>GNDVI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-2002</td>
<td>56</td>
<td>0.789**</td>
<td>0.762**</td>
<td>0.744**</td>
<td>0.713**</td>
</tr>
<tr>
<td>1990-1997</td>
<td>17</td>
<td>0.380</td>
<td>0.522*</td>
<td>0.398</td>
<td>0.311</td>
</tr>
<tr>
<td>1998-1999</td>
<td>12</td>
<td>0.895**</td>
<td>0.831**</td>
<td>0.761**</td>
<td>0.884**</td>
</tr>
<tr>
<td>2000-2002</td>
<td>27</td>
<td>0.617**</td>
<td>0.599**</td>
<td>0.611**</td>
<td>0.559**</td>
</tr>
</tbody>
</table>

*Significant at p < 0.05, **Significant at p < 0.01

RVI: Ratio Vegetation Index, NDVI: Normalized Difference Vegetation Index, MSAVI: Modified Soil-Adjusted Ratio Vegetation Index, GNDVI: Green Normalized Difference Vegetation Index

Note: Data cloud for each correlation is given next to the respective correlation value.
Fit between observed yield and estimated oil palm yields (1998-1999)

\[ Y = 0.465 + (0.007 \times \text{RVI}) \]
\[ r = 0.95 \]

\[ Y = 0.341 + (66.536 \times \text{NDVI}) \]
\[ r = 0.45 \]

\[ Y = -0.086 + (19.251 \times \text{MSAVI}) \]
\[ r = -0.13 \]

\[ Y = -0.076 + (100.106 \times \text{GNDVI}) \]
\[ r = 0.89 \]

Remote and proximal sensing – Study 8

- Use of spectral reflectance as a tool to detect Orange Spotting (OS) disease, to classify OS disease severity and to predict OS disease severity based on vegetation indices

Results:

- Spectral reflectance of symptomatic leaves was significantly lower than that of non-symptomatic leaves at the 465-711 nm wavelength region
- In symptomatic leaves, spectral reflectance showed a decreasing trend with an increase in OS disease severity of up to 60% at the 555 nm and 780-1000 nm wavelengths
- MCARI1 and mSR705 performed best in predicting OS disease severity

Spectral reflectance of symptomatic (with four severity clusters; 1-20%, 21-40%, 41-60%, 61-80%), asymptomatic and healthy leaves

Remote and proximal sensing – Study 9

- Estimation of palm oil quality and yield using a multi-parametric fluorescence sensor (Multiplex®)
- Multiplex® allows quantification of secondary metabolites (i.e. anthocyanin and flavonol)

Results:

- In 6- and 9-year old palms, the estimation strength of secondary metabolites was more pronounced toward oil quality
- In 9- and 12-year palms, the estimation strength of secondary metabolites was more pronounced toward oil yield
- Secondary metabolites such as anthocyanin and flavonol are reliable indicators of palm oil quality and yield
Correlation between fluorescence indices (ANTH and FLAV) and measured concentrations of anthocyanin (TAC) and flavonol (TFC) across different palm ages

<table>
<thead>
<tr>
<th>Year of planting (Age)</th>
<th>Fluorescence index</th>
<th>TAC (mg g(^{-1}))</th>
<th>TFC (mg g(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 (12)</td>
<td>ANTH</td>
<td>0.56*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FLAV</td>
<td>-</td>
<td>0.79*</td>
</tr>
<tr>
<td>2005 (9)</td>
<td>ANTH</td>
<td>0.57*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FLAV</td>
<td>-</td>
<td>0.76*</td>
</tr>
<tr>
<td>2008 (6)</td>
<td>ANTH</td>
<td>0.62*</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FLAV</td>
<td>-</td>
<td>0.54*</td>
</tr>
</tbody>
</table>

*Significant at p=0.05
Correlation between fluorescence indices (ANTH and FLAV) from different parts of the scanned oil palm (bunch and loose fruit) across different palm ages

<table>
<thead>
<tr>
<th>Year of planting (Age)</th>
<th>Scanned part</th>
<th>ANTH</th>
<th>FLAV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002 (12)</td>
<td>Bunch (FFB)</td>
<td>0.59*</td>
<td>0.59*</td>
</tr>
<tr>
<td>2005 (9)</td>
<td>Bunch (FFB)</td>
<td>0.54*</td>
<td>0.59*</td>
</tr>
<tr>
<td>2008 (6)</td>
<td>Bunch (FFB)</td>
<td>0.79*</td>
<td>0.60*</td>
</tr>
</tbody>
</table>

*Significant at p=0.05
Correlation between fluorescence indices (ANTH, FLAV and NBI) and palm oil quality (DOBI) and yield (OER) attributes across different palm ages

<table>
<thead>
<tr>
<th>Year of Planting (Age)</th>
<th>Fluorescence index</th>
<th>DOBI</th>
<th>OER</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 (12)</td>
<td>ANTH, FLAV, NBI</td>
<td>0.15</td>
<td>0.53*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.28</td>
<td>0.57*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.71*</td>
<td>0.28</td>
</tr>
<tr>
<td>2005 (9)</td>
<td>ANTH, FLAV, NBI</td>
<td>0.63*</td>
<td>0.65*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.52*</td>
<td>0.53*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>2008 (6)</td>
<td>ANTH, FLAV, NBI</td>
<td>0.77*</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.67*</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.44</td>
<td>0.20</td>
</tr>
</tbody>
</table>

*Significant at p=0.05

DOBI = Degree of Bleachability Index, OER = Oil Extraction Rate
ANTH = Anthocyanin, FLV = Flavonol, NBI = Nitrogen Balance Index
Remote and proximal sensing – Study 10

- Use of archived satellite imagery (Quickbird; 4 m spatial resolution) obtained via Google Earth as a means to perform tree counting in oil palm

Result:

- High correlation between the number of trees counted on Google Earth imagery and that counted on the ground
Emerging research fronts for precision oil palm management

- **Drone technology** for detection and monitoring of crop stress
- **Artificial Neural Network (ANN)** for agronomic data analysis
- **Hyperspectral remote sensing** for carbon monitoring
- **Robotics** for agronomic management and crop harvesting
- **Radio Frequency Identification (RFID)** for logistical intelligence
Thanks for your attention