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

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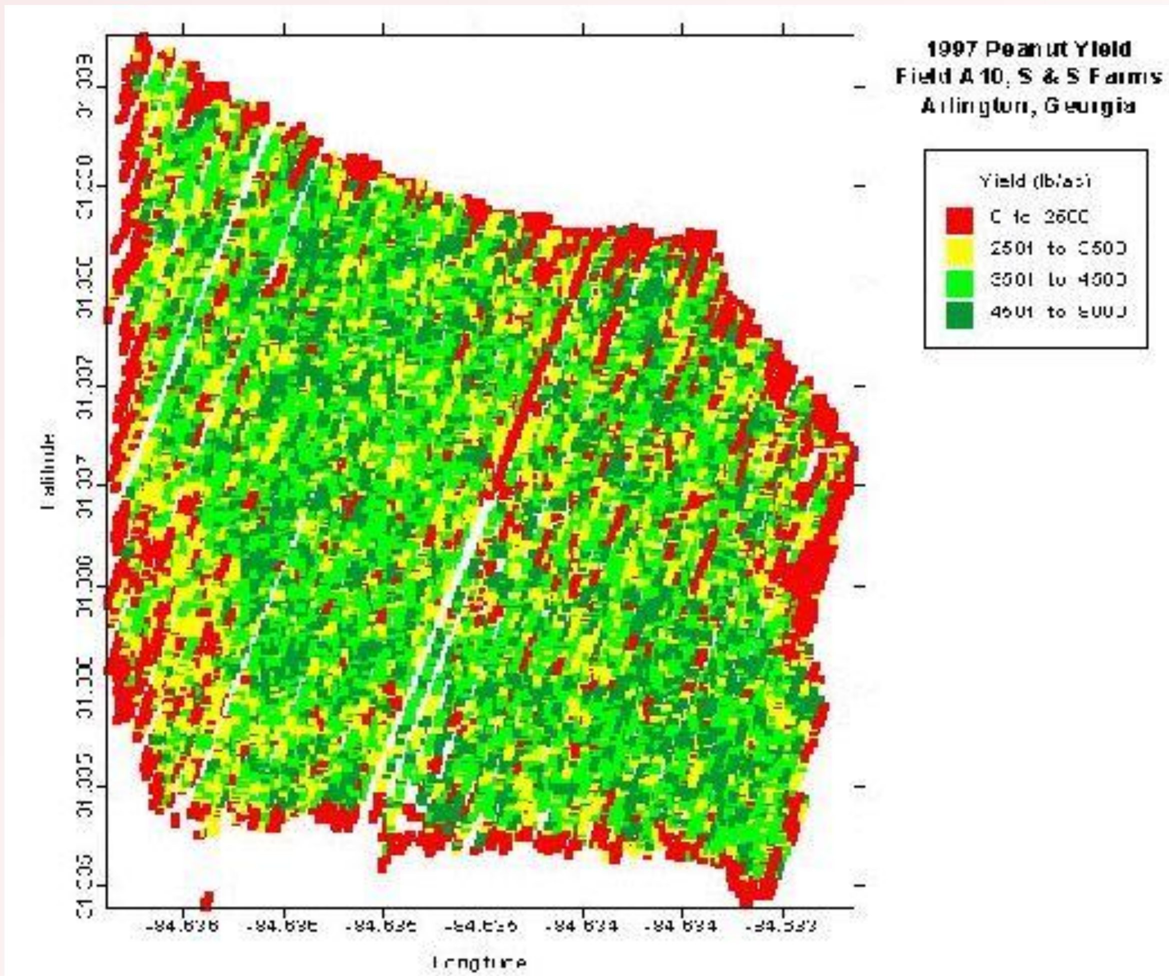
Precision Agriculture (PA) ?

- **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

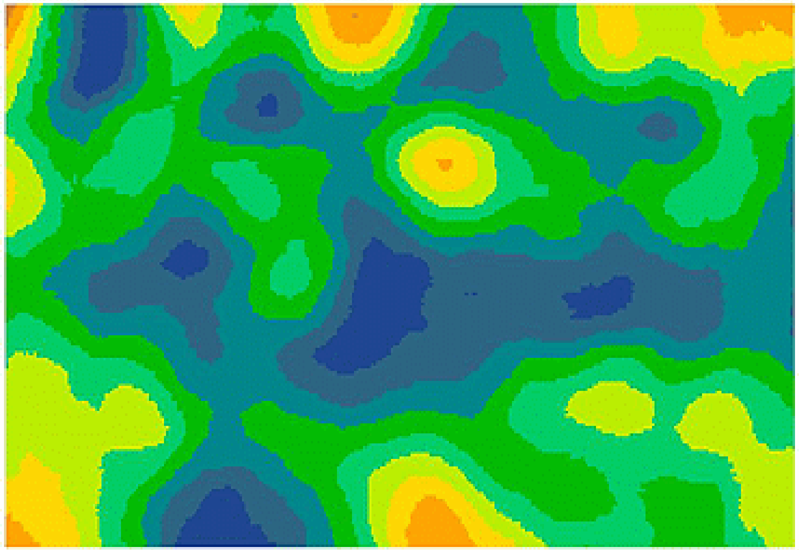
⇨ differences across space/distance



Temporal variability

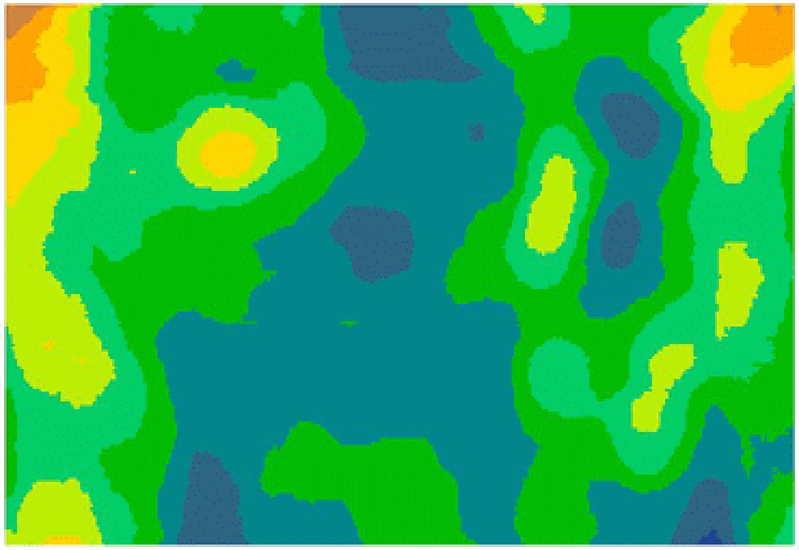
⇨ differences across time/season

Corn grain yield - 1997



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

Corn grain yield - 1998

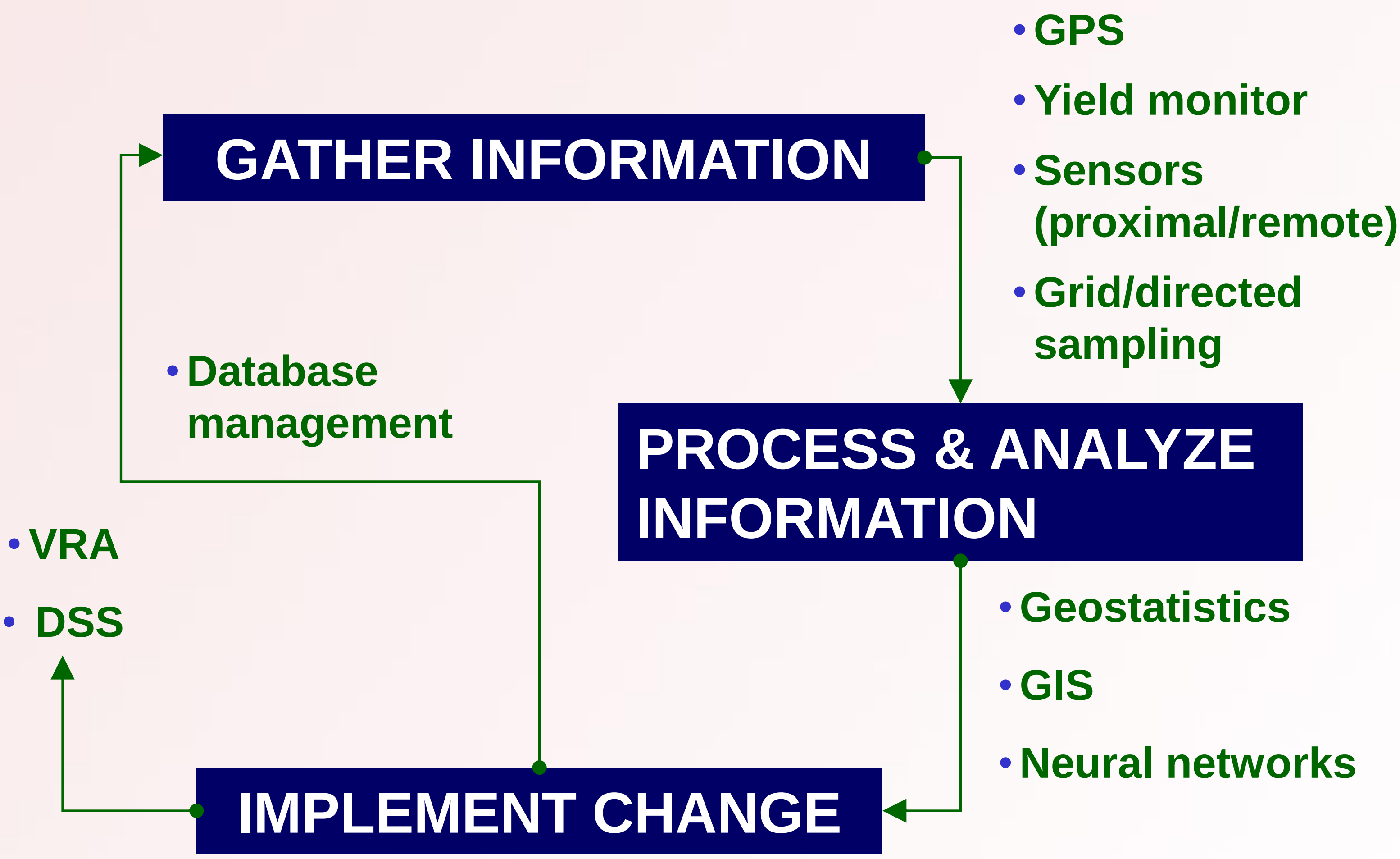


Field M1 (30 ac.), Davis-Purdue Ag. Center

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 …



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?

	Benefit Occurs	No Benefit Occurs
ACT	Correct action	Type II error: Loss caused
DON'T ACT	Type I error: Lost opportunity	Correct inaction

- ⇨ PA minimizes Type I & Type II errors

A decade of PA research in oil palm (2006-15)

Technological domain	Scope of investigation	Keywords
Geo-spatial modeling	FFB yields Leaf and soil nutrients Fertilizer trials Soil organic carbon	Spatial variability, management zones, nearest-neighbor analysis, operational zones
Decision support system	Oil yield Oil quality	FFB harvesting, image processing, surface color, degree of bleachability index
Remote and proximal sensing	FFB yields Disease detection Oil quality Stand density	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

SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Relationship between oil palm yield and soil fertility as affected by topography in an Indonesian plantation. *Communications in Soil Science and Plant Analysis*, 37(9&10): 1321-1337.

Comparison of variables (leaf and soil) and the corresponding yield across topography (Sri Gunung Estate – site # 2)

Variables	Toeslope	Sideslope	Summit
Leaf			
N	2.75[a]	2.75[a]	2.73[a]
P	0.18[a]	0.15[c]	0.16[b]
K	0.98[a]	0.93[b]	0.96[a]
Mg	0.40[b]	0.43[a]	0.42[ab]
Ca	0.78[a]	0.72[b]	0.71[b]
Soil (0-20 cm)			
pH	4.78[a]	4.27[b]	4.16[c]
OM	2.59[a]	2.22[b]	2.33[ab]
P	79.38[a]	77.98[a]	7.14[b]
K	0.23[a]	0.20[a]	0.20[a]
Mg	0.65[a]	0.70[a]	0.61[a]
Ca	1.63[a]	1.49[a]	1.19[b]
ECEC	5.46[a]	5.80[a]	5.02[a]
Texture	SC	LC	LC
Yield	**4.43[a]**	**3.60[b]**	**3.13[c]**

SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Relationship between oil palm yield and soil fertility as affected by topography in an Indonesian plantation. *Communications in Soil Science and Plant Analysis*, 37(9&10): 1321-1337.

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

Topographic position	Regression model[§]	R^2	Adjusted R^2
Toeslope	(1) Yield = 5.22 – 2.53*Leaf Mg	0.76	0.70
	(2a) Yield = 3.19 + 0.15*Leaf (N:Mg)	0.80	0.75
	(2b) Yield = 3.04 + 2.66*Leaf (P:Mg)	0.79	0.74
	(3) Yield = 3.66 + 0.10*pH	0.66	0.58
Sideslope	(3) Yield = 8.78 – 0.70*ECEC – 19.03*log (Subsoil Mg)	0.89	0.82
Summit	(1) Yield = 28.25 – 9.28*Leaf N	0.89	0.86
	(4) Yield = 3.88 – 2.57*Soil (K:Mg)	0.75	0.68

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

SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Relationship between oil palm yield and soil fertility as affected by topography in an Indonesian plantation. *Communications in Soil Science and Plant Analysis*, 37(9&10): 1321-1337.

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

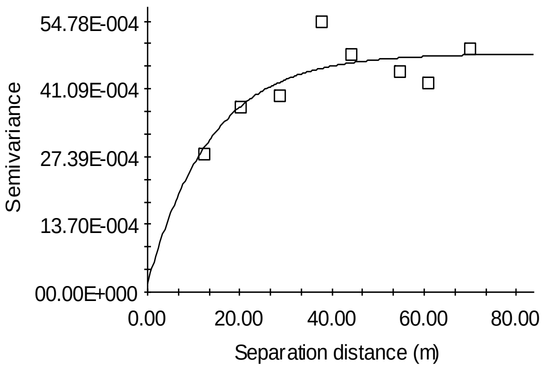
→ Increasing sample size (n)

- K showed a clear demarcation of zones with high, moderate or low values – good candidate for variable rate management

SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Spatial variability of soil fertility variables influencing yield in oil palm (Elaeis guineensis Jacq.). *Asian Journal of Plant Sciences*, 5(2): 397-408.

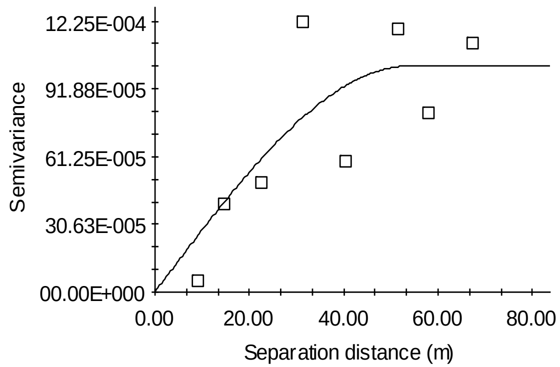
Semivariograms of YIVs at the summit (Sri Gunung Estate – site # 2)

Leaf N (%)



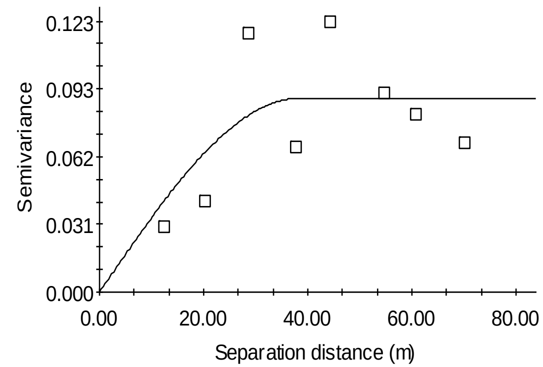
Model: Exponential; Spatial dependence: Strong
Nugget=$1.7x10^{-4}$; Sill=$4.8x10^{-3}$; Effective range=41m

Topsoil K (m.e. 100 g^{-1})



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

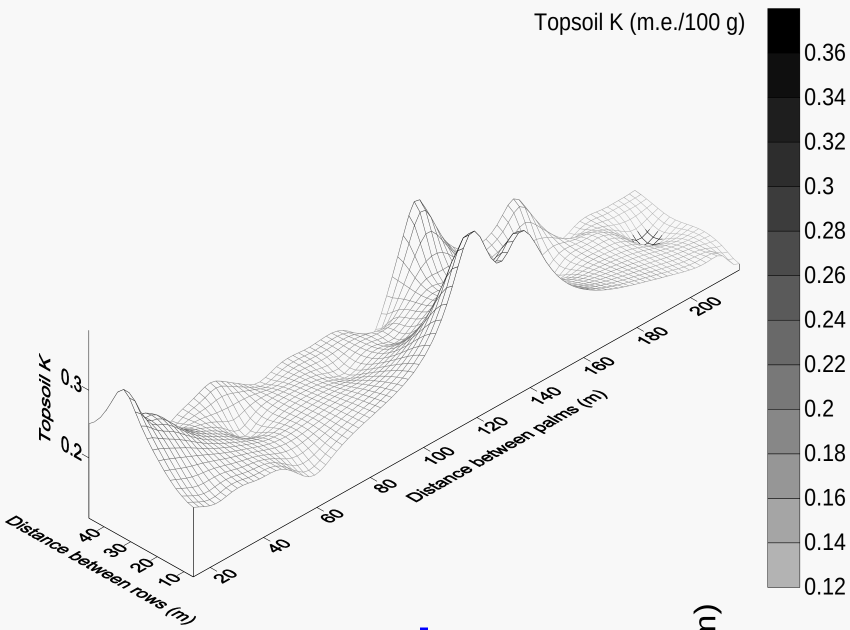
Topsoil Mg (m.e. 100 g^{-1})

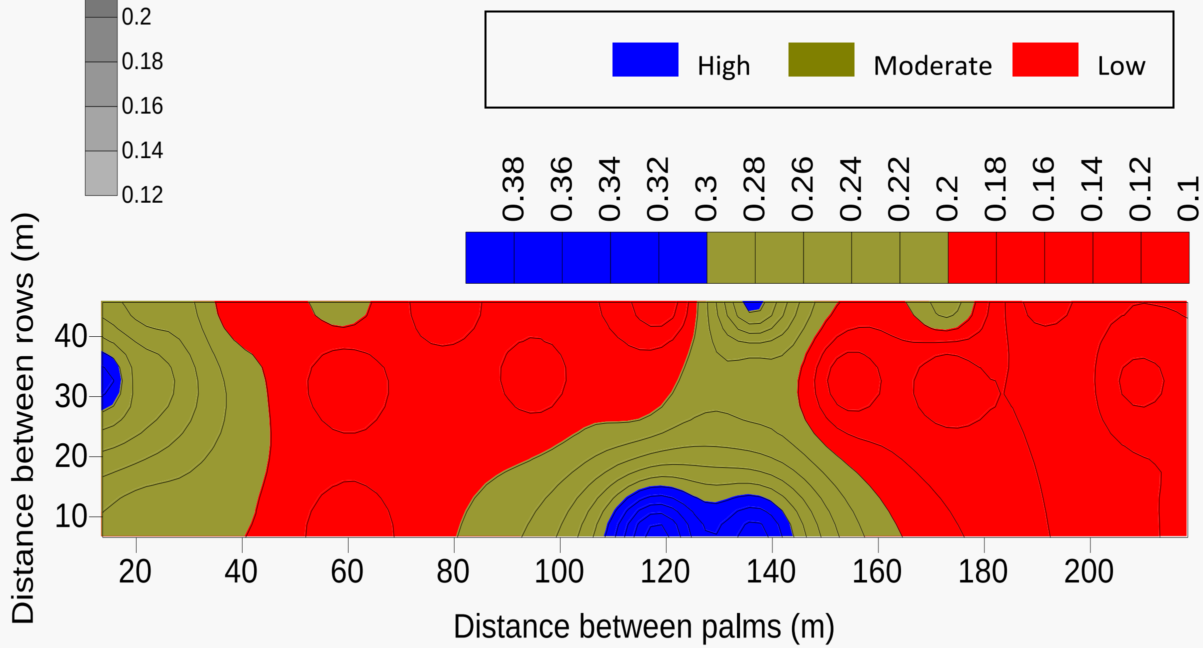


Model: Spherical; Spatial dependence: Strong
Nugget=$1x10^{-4}$; Sill=$8.8x10^{-2}$; Effective range=38m

SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Spatial variability of soil fertility variables influencing yield in oil palm (Elaeis guineensis Jacq.). *Asian Journal of Plant Sciences*, 5(2): 397-408.

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





SK Balasundram, PC Robert, DJ Mulla and DL Allan. 2006. Spatial variability of soil fertility variables influencing yield in oil palm (Elaeis guineensis Jacq.). *Asian Journal of Plant Sciences*, 5(2): 397-408.

Geo-spatial modeling – Study 3

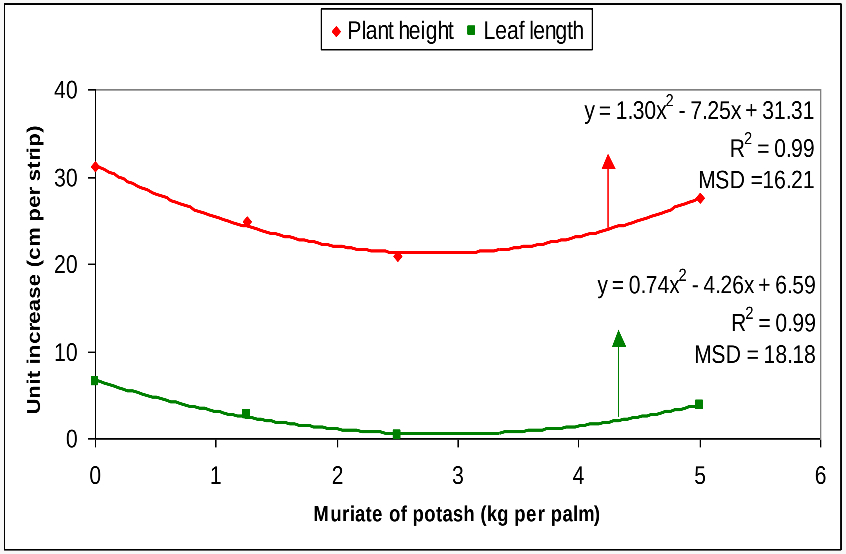
- Evaluation of oil palm growth response to K application
- Treatment effects adjusted using Nearest-neighbor Analysis (NNA) so as to remove spatial trends

Results:

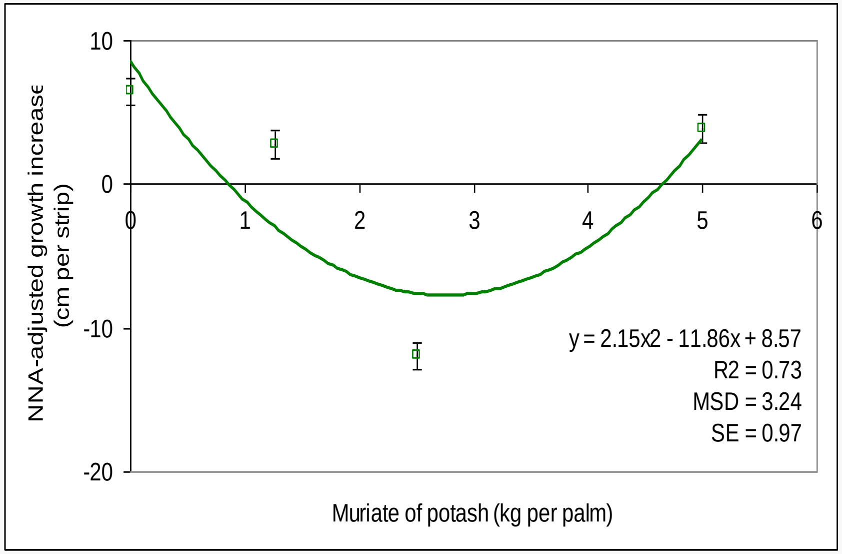
- Before removal of spatial trends, treatment effects on plant growth were not significant
- Following NNA adjustment, growth variables varied significantly among treatments

SK Balasundram, DJ Mulla and PC Robert. 2006. Accounting for spatial variability in a short-term fertilizer trial for oil palm. *International Journal of Soil Science*, 1(3): 184-195.

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)

SK Balasundram, DJ Mulla and PC Robert. 2006. Accounting for spatial variability in a short-term fertilizer trial for oil palm. *International Journal of Soil Science*, 1(3): 184-195.

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)

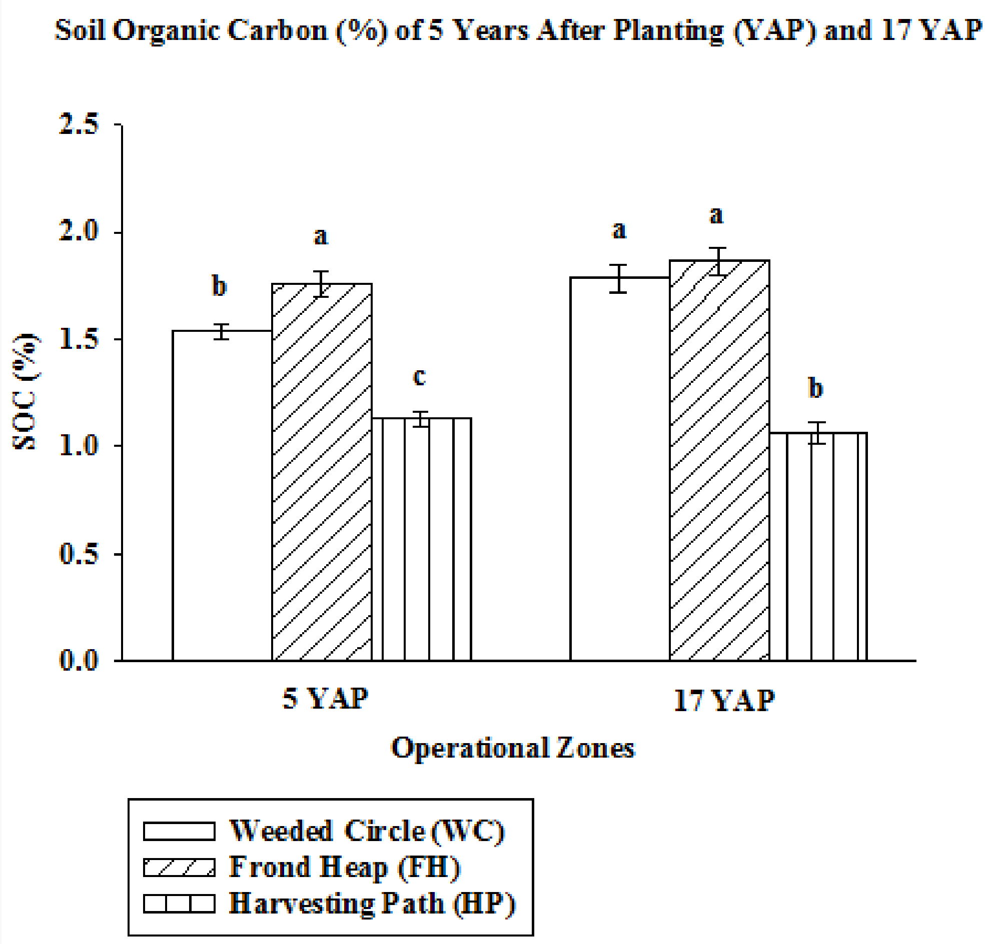
  HP < WC < FH

  → 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

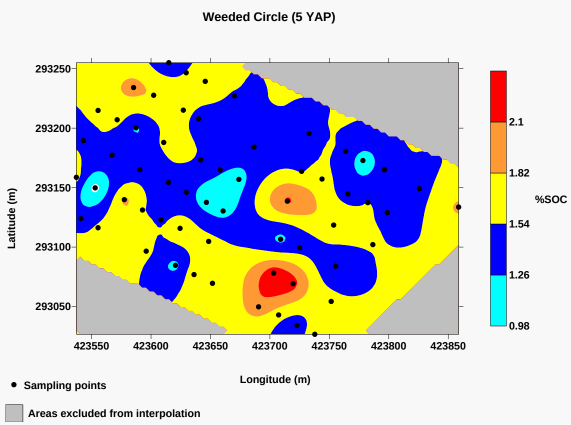
MC Law, SK Balasundram, MHA Husni, OH Ahmed and MH Harun. 2009. Spatial variability of soil organic carbon in oil palm: A comparison between young and mature stands. *International Journal of Agricultural Research*, 4(12): 402-417.

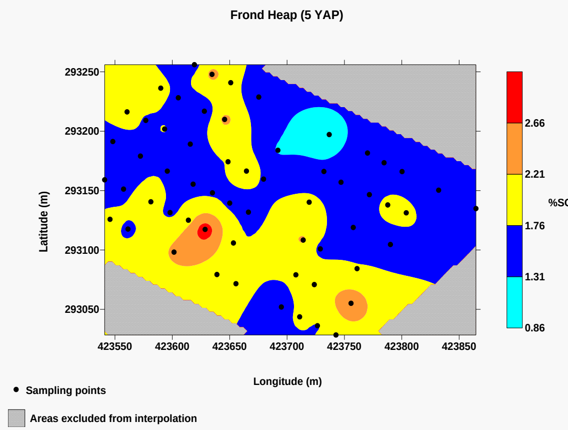
Soil organic carbon content (%) across three operational zones (WC, FH and HP) at 5 and 17 Years After Planting (YAP)

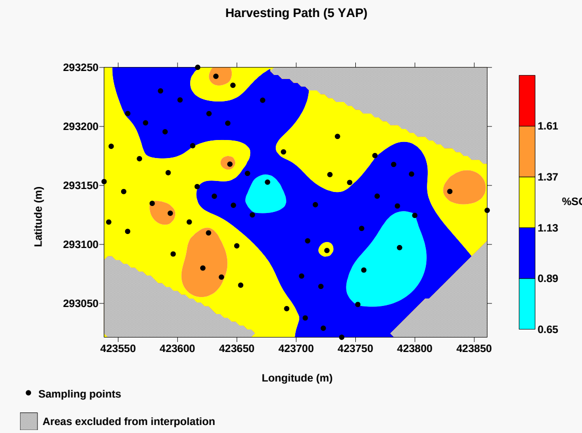


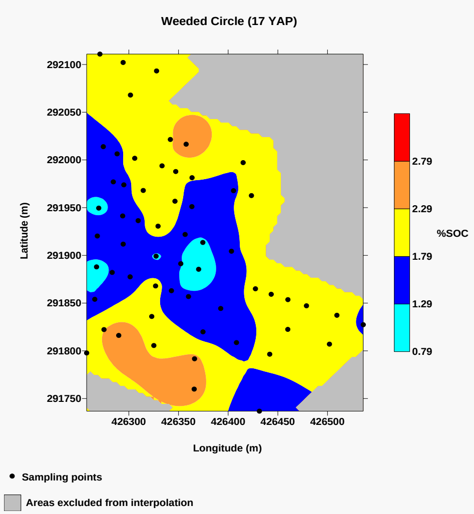
MC Law, SK Balasundram, MHA Husni, OH Ahmed and MH Harun. 2009. Spatial variability of soil organic carbon in oil palm: A comparison between young and mature stands. *International Journal of Agricultural Research*, 4(12): 402-417.

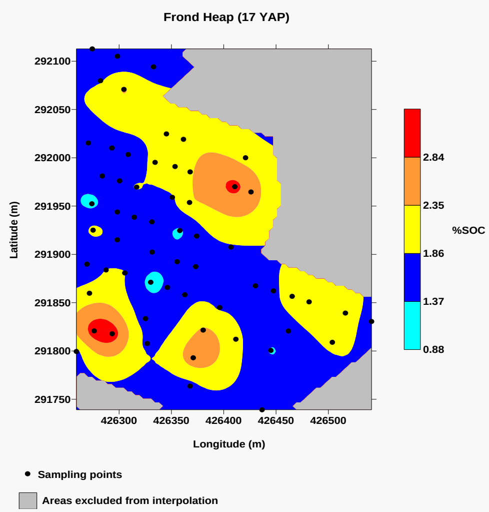
Spatial variability of soil organic carbon across WC, FH and HP at 5 and 17 Years After Planting (YAP)

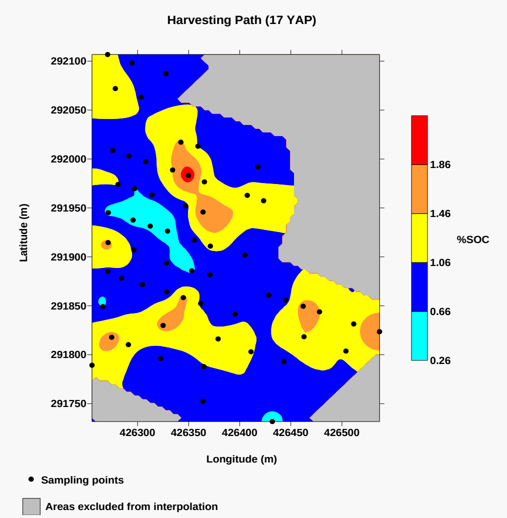












MC Law, SK Balasundram, MHA Husni, OH Ahmed and MH Harun. 2009. Spatial variability of soil organic carbon in oil palm: A comparison between young and mature stands. *International Journal of Agricultural Research*, 4(12): 402-417.

Decision support system – Study 5

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

Results:

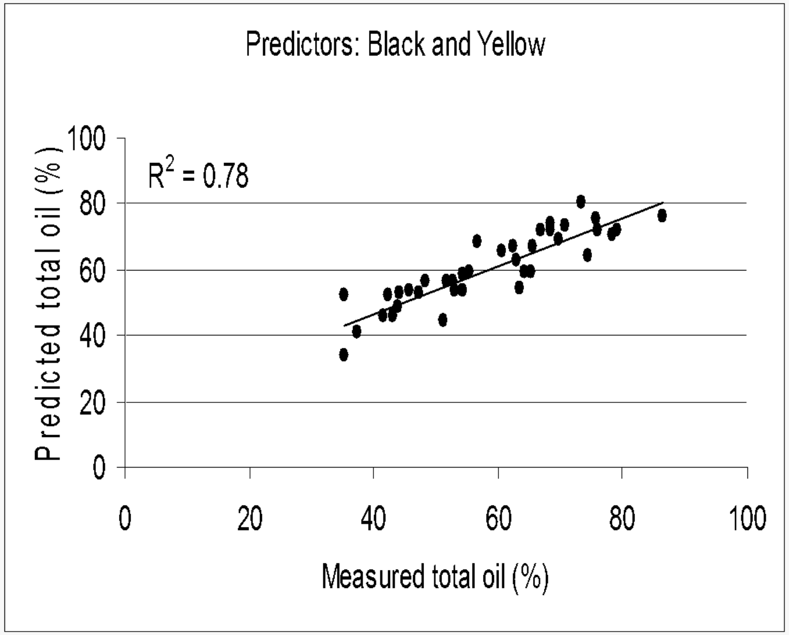
- Significant correlation between total oil and color components; black (r=-0.85), red (r=0.81), orange (r=0.62), yellow (r=0.48)

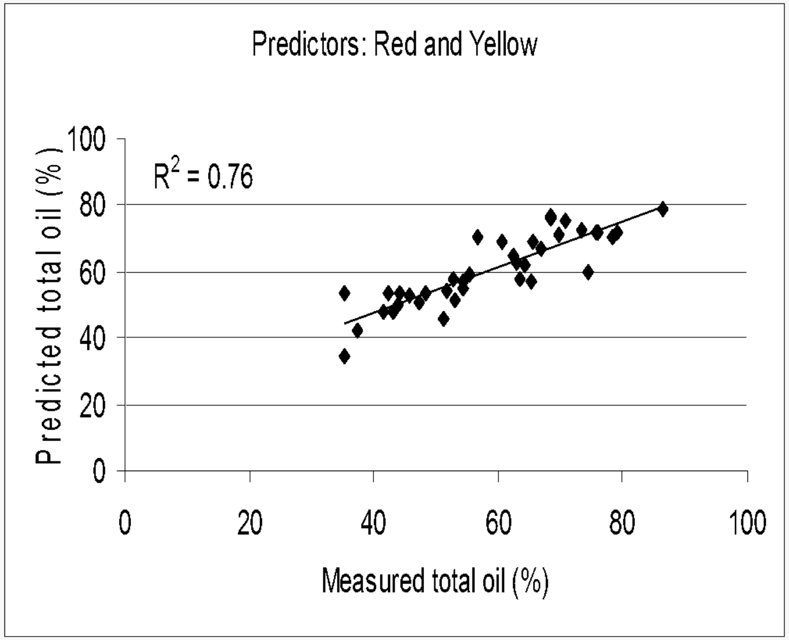
% Total oil = 88.08 – 0.52 (% Black) + 1.30 log (% Yellow)
% Total oil = 36.84 + 0.63 (% Red) + 1.52 log (% Yellow)

- 73-75% accuracy

SK Balasundram, PC Robert and DJ Mulla. 2006. Relationship between oil content and fruit surface color in oil palm (Elaeis guineensis Jacq.). *Journal of Plant Sciences*, 1(3): 217-227.

Measured versus predicted total oil content



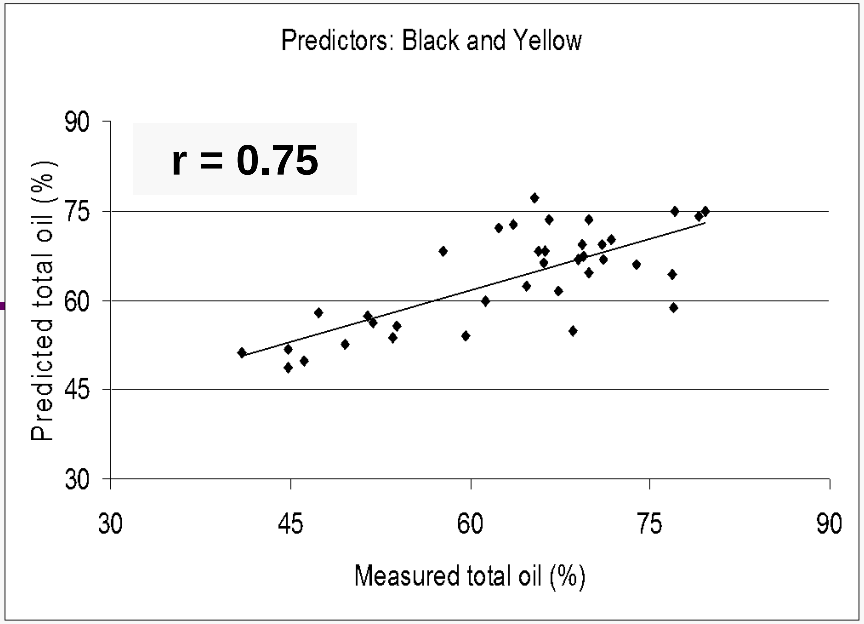


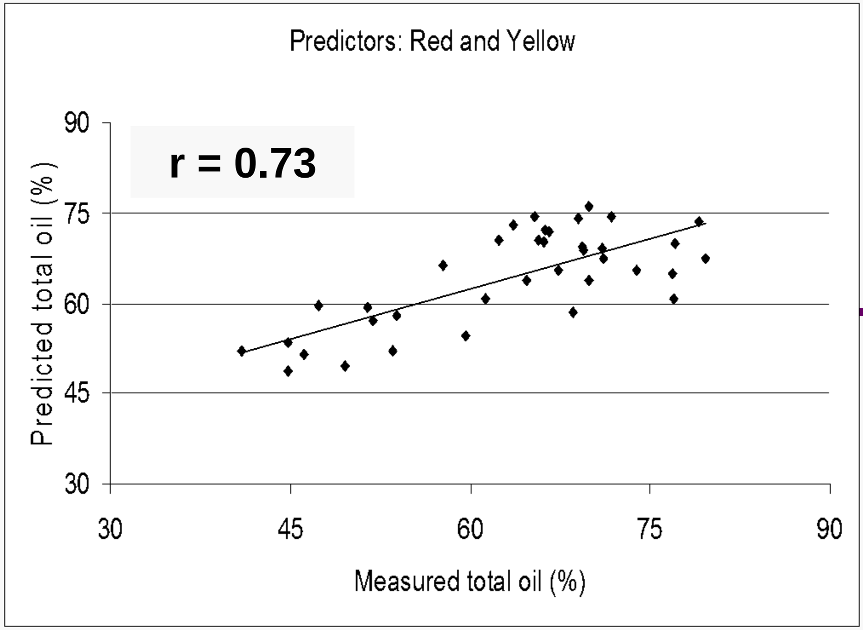
%Total oil = 88.1 - 0.5 (%Black) + 1.3 log (%Yellow)

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

SK Balasundram, PC Robert and DJ Mulla. 2006. Relationship between oil content and fruit surface color in oil palm (Elaeis guineensis Jacq.). *Journal of Plant Sciences*, 1(3): 217-227.

Model validation





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

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SK Balasundram, PC Robert and DJ Mulla. 2006. Relationship between oil content and fruit surface color in oil palm (Elaeis guineensis Jacq.). *Journal of Plant Sciences*, 1(3): 217-227.

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

	Scenario 1			Scenario 2		
[1]Model		TO=88.08-(0.52*B)+(1.30*logY)			TO=36.84+(0.63*R)+(1.52*logY)	
Input	B=30, Y=0.9	B=48, Y=0.9	B=66, Y=0.9	R=29, Y=0.9	R=43, Y=0.9	B=58, Y=0.9
Predicted total oil (%)	72.42	63.06	53.70	55.04	63.86	73.31
[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

Benefit (value per tree per year) comparison matrix:

Model input	B_{30} $Y_{0.9}$	B_{48} $Y_{0.9}$	B_{66} $Y_{0.9}$
R_{29} $Y_{0.9}$	-3.27		
R_{43} $Y_{0.9}$		0.15	
R_{58} $Y_{0.9}$			3.69

[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

SK Balasundram, PC Robert and DJ Mulla. 2006. Relationship between oil content and fruit surface color in oil palm (Elaeis guineensis Jacq.). *Journal of Plant Sciences*, 1(3): 217-227.

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)**

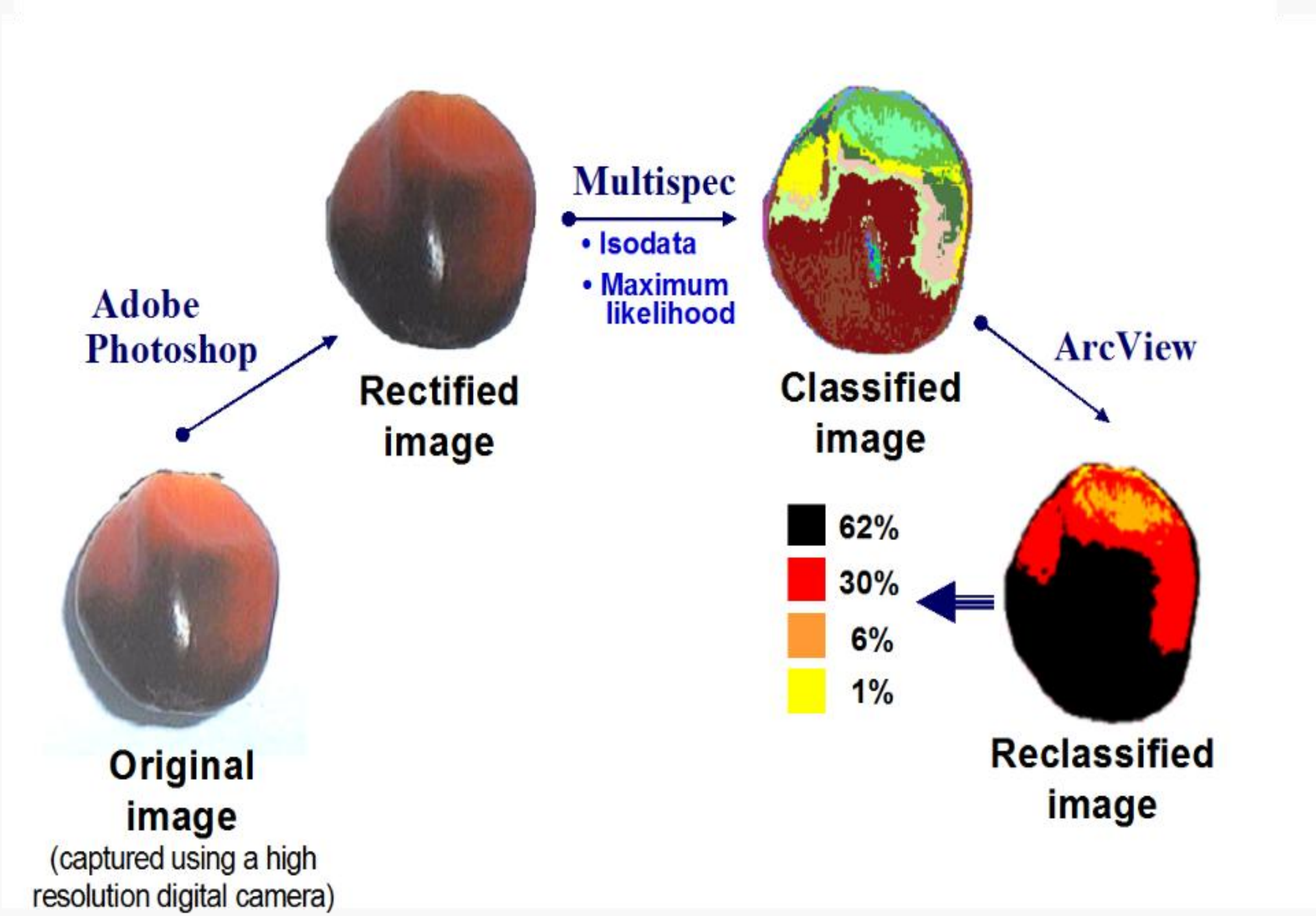
Results:

➡ 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

SK Balasundram, MHA Husni and AR Anuar. 2008. A computerized digital imaging technique to estimate crude palm oil based on fruit surface color. Copyright document (stamped on March 10, 2008), Kuala Lumpur, Malaysia.

Image analysis protocol developed from Study 5



SK Balasundram, MHA Husni and AR Anuar. 2008. A computerized digital imaging technique to estimate crude palm oil based on fruit surface color. Copyright document (stamped on March 10, 2008), Kuala Lumpur, Malaysia.

Regression of DOBI on fruit surface color

Palm age	DOBI	Model
< 5 (young)	< 4	DOBI = 4.1 – 0.03*%O
	> 4	DOBI = 6.6 + 1.52*log %R
> 5 (mature)	< 4	DOBI = 3.6 + 0.02*%R
	> 4	DOBI = 4.4 + 2.49*log %R – 2.08*log %(RY)

Note: O = Orange, R = Red, Y = Yellow

A computerized technique to estimate oil palm fruit quality

Load fruit image(s)

↓

Ilwis 3.2

- Import raster image (.jpg)
- Color separation
- Clustering
- Export clustered image (.bmp)

↓

Cluster re-identification

↓

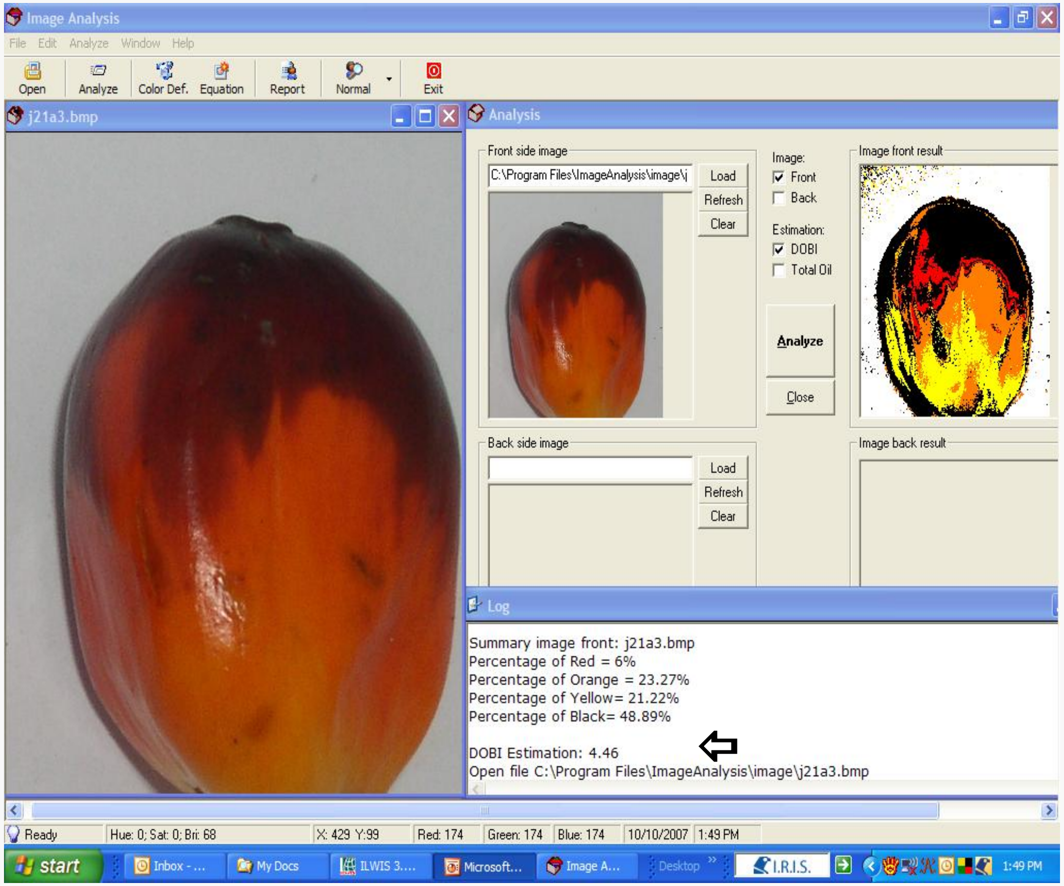
Cluster re-coloring

↓

Image re-construction

↓

Computation of color distribution



SK Balasundram, MHA Husni and AR Anuar. 2008. A computerized digital imaging technique to estimate crude palm oil based on fruit surface color. Copyright document (stamped on March 10, 2008), Kuala Lumpur, Malaysia.

Remote and proximal sensing – Study 7

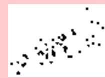
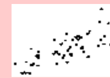
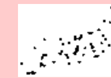
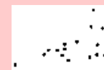
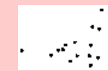
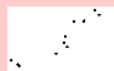
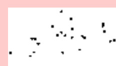
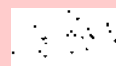
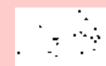
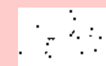
- Empirical oil palm yield models based on a single-date archived QuickBird satellite imagery and oil palm yield data collected over a 12-year time series

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

SK Balasundram, H Memarian and R Khosla. 2013. Estimating oil palm yields using QuickBird-derived vegetation indices. *Life Science Journal*, 10(4): 851-860.

Correlation between oil palm yield and vegetation indices across different planting periods

Planting year	*n*	RVI	NDVI	MSAVI	GNDVI
1990-2002	56	0.789^{**} 	0.762^{**} 	0.744^{**} 	0.713^{**} 
1990-1997	17	0.380 	0.522^{*} 	0.398 	0.311 
1998-1999	12	0.895^{**} 	0.831^{**} 	0.761^{**} 	0.884^{**} 
2000-2002	27	0.617^{**} 	0.599^{**} 	0.611^{**} 	0.559^{**} 

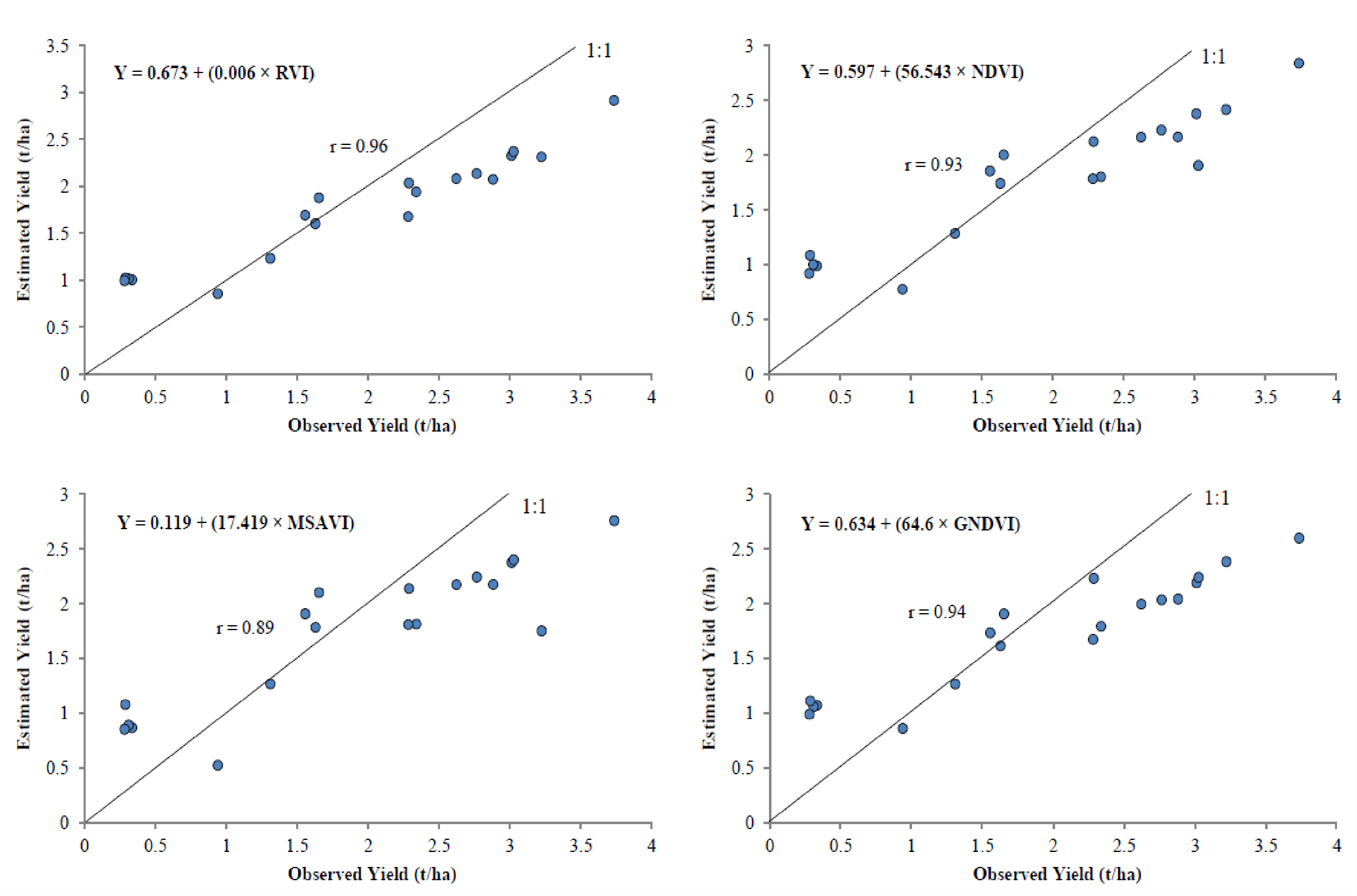
*Significant at $p < 0.05$, **Significant at $p < 0.01$

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

<u>Note</u>: Data cloud for each correlation is given next to the respective correlation value

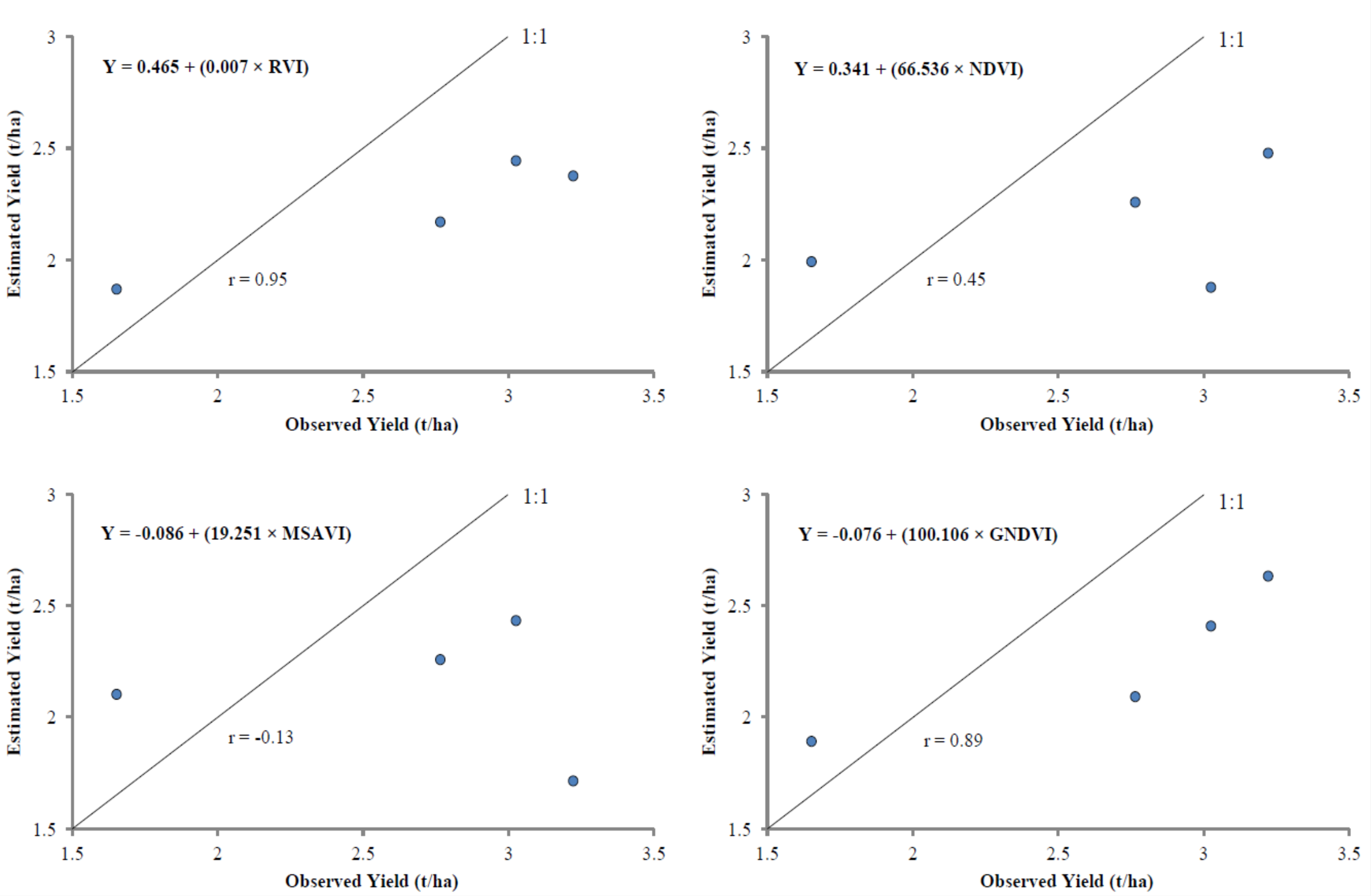
SK Balasundram, H Memarian and R Khosla. 2013. Estimating oil palm yields using QuickBird-derived vegetation indices. *Life Science Journal*, 10(4): 851-860.

Fit between observed yield and estimated oil palm yields (1990-2002)



SK Balasundram, H Memarian and R Khosla. 2013. Estimating oil palm yields using QuickBird-derived vegetation indices. *Life Science Journal*, 10(4): 851-860.

Fit between observed yield and estimated oil palm yields (1998-1999)



SK Balasundram, H Memarian and R Khosla. 2013. Estimating oil palm yields using QuickBird-derived vegetation indices. *Life Science Journal*, 10(4): 851-860.

Remote and proximal sensing – Study 8

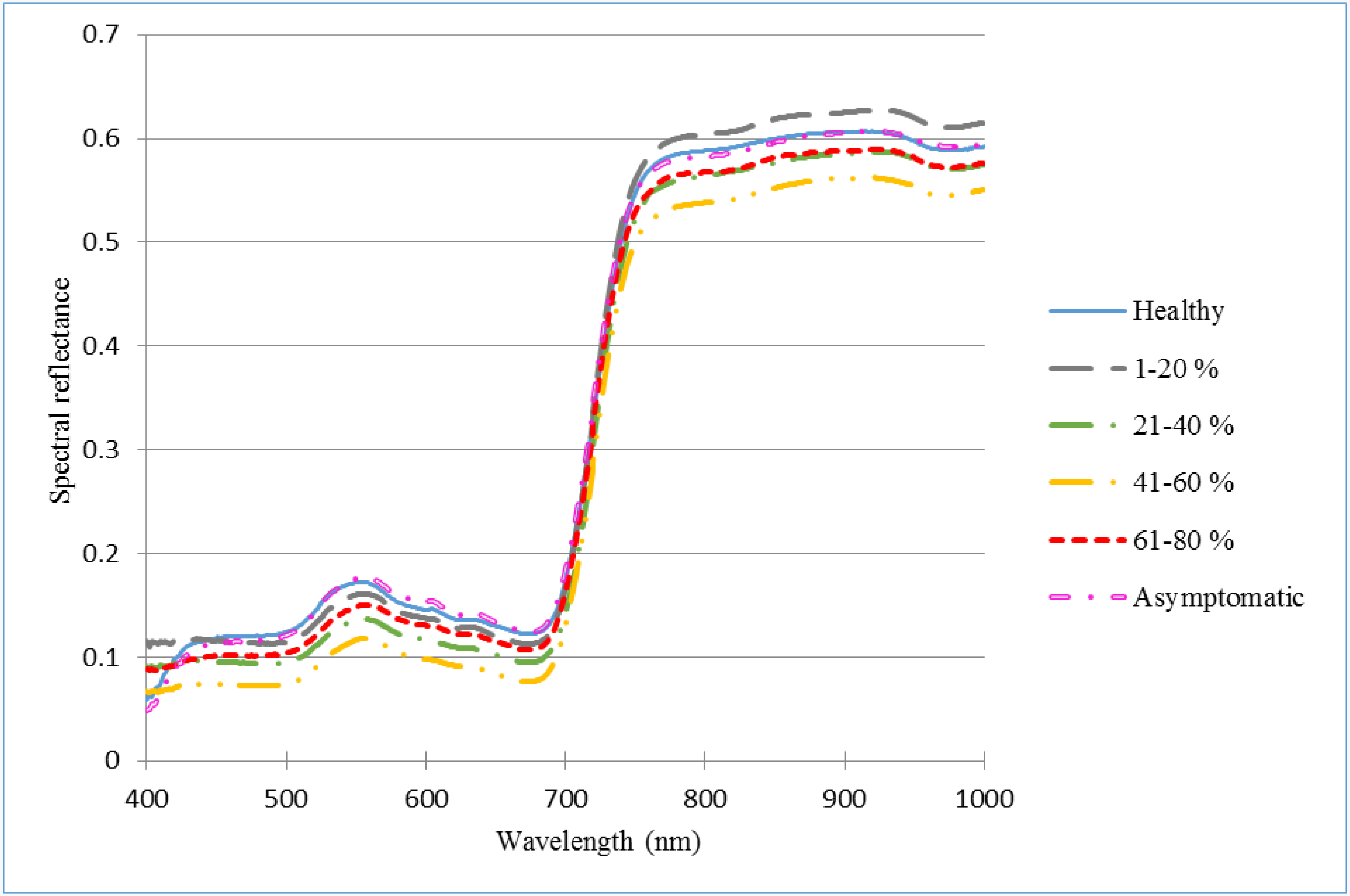
- Use of spectral reflectance as a tool to detect Orange Spotting (OS) disease, to classify OS disease severity and to predict OS disease severity based on vegetation indices

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

S Selvaraja, SK Balasundram , G Vadamalai, MHA Husni and R Khosla. 2014. Remote sensing as a tool to assess orange spotting disease in oil palm (Elaies guineensis). *Mitteilungen Klosterneuburg*, 64(4): 12-26.

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



S Selvaraja, SK Balasundram , G Vadamalai, MHA Husni and R Khosla. 2014. Remote sensing as a tool to assess orange spotting disease in oil palm (Elaies guineensis). *Mitteilungen Klosterneuburg*, 64(4): 12-26.

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

AK Norul Husna, SK Balasundram and CP Tan. 2015. Fluorescence sensing as a tool to estimate palm oil quality and yield. *Ciência e Técnica Vitivinícola Journal*, 30(4): 58-65.

Correlation between fluorescence indices (ANTH and FLAV) and measured concentrations of anthocyanin (TAC) and flavonol (TFC) across different palm ages

Year of planting (Age)	Fluorescence index	TAC (mg g^{-1})	TFC (mg g^{-1})
2002 (12)	ANTH	0.56*	-
	FLAV	-	0.79*
2005 (9)	ANTH	0.57*	-
	FLAV	-	0.76*
2008 (6)	ANTH	0.62*	-
	FLAV	-	0.54*

*****Significant at p=0.05

AK Norul Husna, SK Balasundram and CP Tan. 2015. Fluorescence sensing as a tool to estimate palm oil quality and yield. *Ciência e Técnica Vitivinícola Journal*, 30(4): 58-65.

Correlation between fluorescence indices (ANTH and FLAV) from different parts of the scanned oil palm (bunch and loose fruit) across different palm ages

Year of planting (Age)	Scanned part	ANTH	FLAV
		Loose fruit	
2002 (12)	Bunch (FFB)	0.59*	0.59*
2005 (9)		0.54*	0.59*
2008 (6)		0.79*	0.60*

*Significant at p=0.05

AK Norul Husna, SK Balasundram and CP Tan. 2015. Fluorescence sensing as a tool to estimate palm oil quality and yield. *Ciência e Técnica Vitivinícola Journal*, 30(4): 58-65.

Correlation between fluorescence indices (ANTH, FLAV and NBI) and palm oil quality (DOBI) and yield (OER) attributes across different palm ages

Year of Planting (Age)	Fluorescence index	DOBI	OER
2002 (12)	ANTH	0.15	0.53*
	FLAV	0.28	0.57*
	NBI	-0.71*	0.28
2005 (9)	ANTH	0.63*	0.65*
	FLAV	0.52*	0.53*
	NBI	-0.13	0.17
2008 (6)	ANTH	0.77*	0.45
	FLAV	0.67*	0.16
	NBI	-0.44	0.20

*****Significant at p=0.05

DOBI = Degree of Bleachability Index, OER = Oil Extraction Rate
ANTH = Anthocyanin, FLV = Flavonol, NBI = Nitrogen Balance Index

AK Norul Husna, SK Balasundram and CP Tan. 2015. Fluorescence sensing as a tool to estimate palm oil quality and yield. *Ciência e Técnica Vitivinícola Journal*, 30(4): 58-65.

Remote and proximal sensing – Study 10

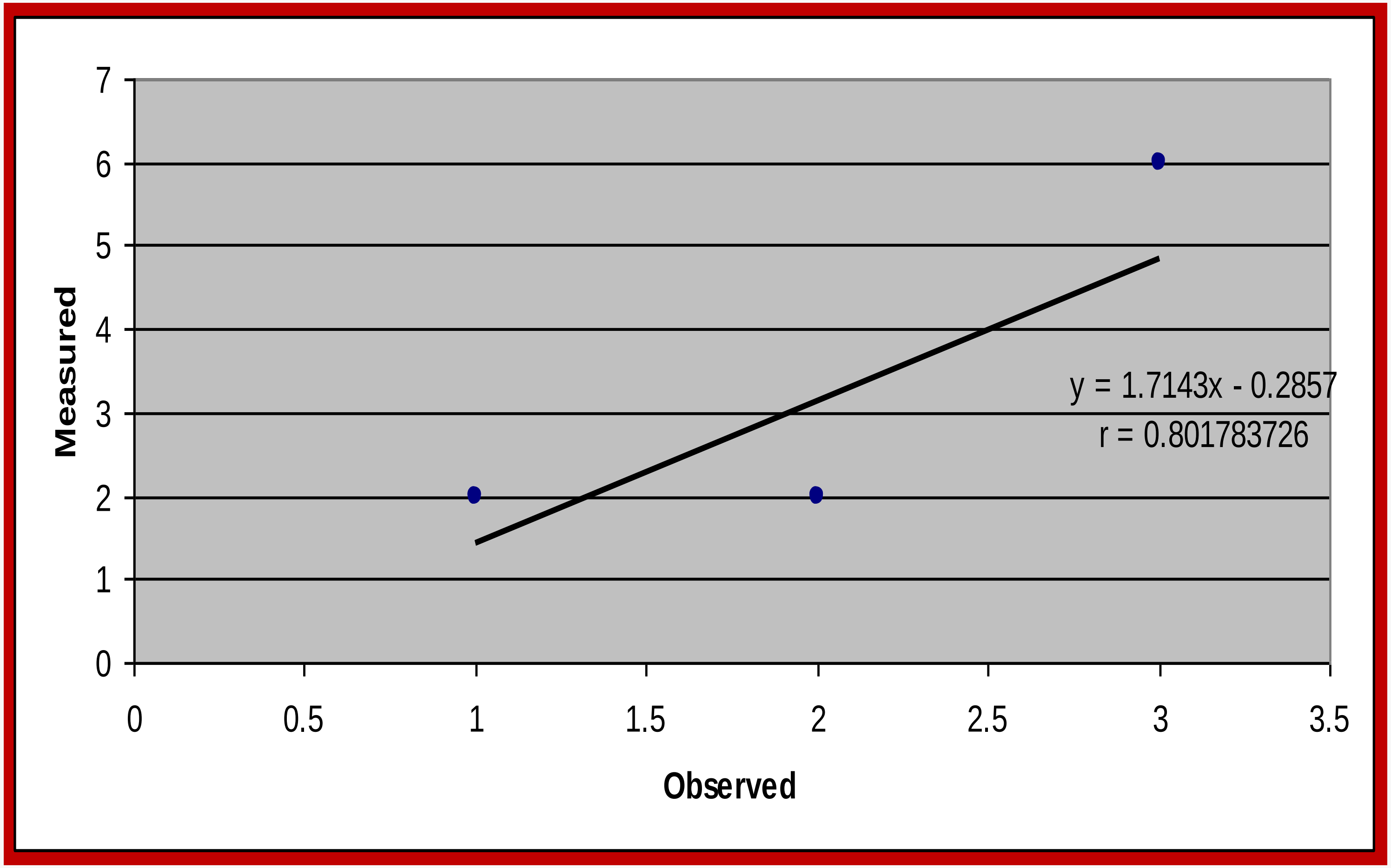
- Use of archived satellite imagery (Quickbird; 4 m spatial resolution) obtained via Google Earth as a means to perform tree counting in oil palm

Result:

- High correlation between the number of trees counted on Google Earth imagery and that counted on the ground

SK Balasundram, KI Ahmad Fadhlil and Nini Sopian. 2009. A remote sensing approach to estimate stand density in oil palm. *Journal of ISSAAS* (International Society of Southeast Asian Agricultural Sciences), 15(1): 188 (Abstract)

Count of unplanted points: observed (via satellite) versus measured (on the ground)



SK Balasundram, KI Ahmad Fadhlil and Nini Sopian. 2009. A remote sensing approach to estimate stand density in oil palm. *Journal of ISSAAS* (International Society of Southeast Asian Agricultural Sciences), 15(1): 188 (Abstract)

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