Airborne Imaging Spectroscopy Workshop
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BruHyp'04

Stress Detection in Crops with Hyperspectral Remote Sensing and Physical Simulation Models

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IAS/CSIC
GOA-UVA
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Outline

1. Introduction & Rationale

2. Data Collection and Processing

3. C_{ab} estimation using combined Optical Indices and Radiative Transfer Simulation

4. Results

5. Conclusions

1. Introduction

- The European Union occupies a world leading position on the two high-value crops
  - EU is the largest olive oil producer with 50% of the area in Spain and 25% in Italy
  - The EU wine market accounts for 45% of wine-growing areas, world leader in terms of area, production and consumption

- Radiative Transfer-based methods can be used to interpret hyperspectral imagery to estimate biochemical / biophysical variables in olive and vine canopies:
  - Leaf chlorophyll *a+b* (C_{a+b})
  - Dry matter content (C_m)
  - Water content (C_w)
  - Leaf Area Index (LAI)
  - Percent cover

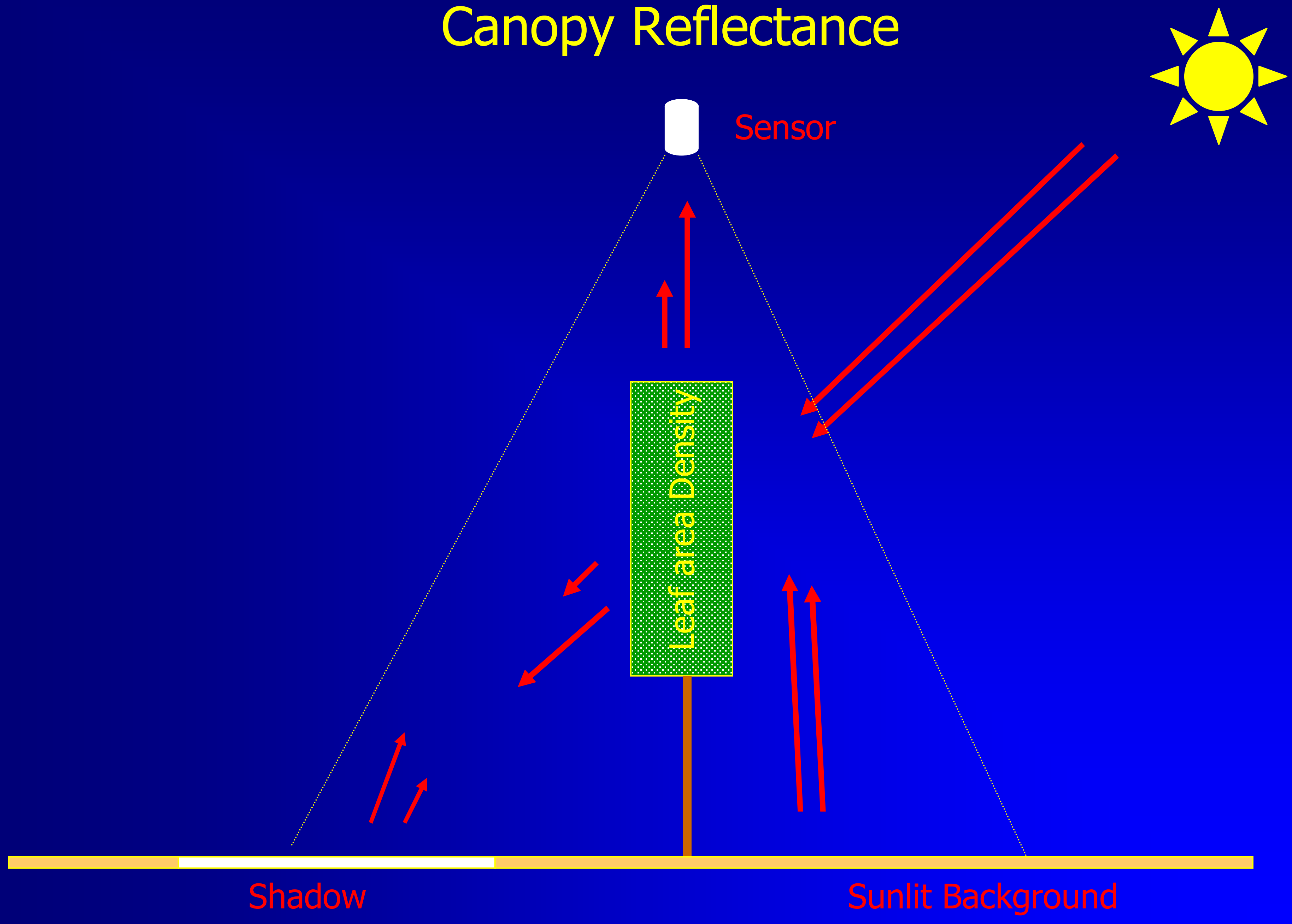
indicators of stress and growth

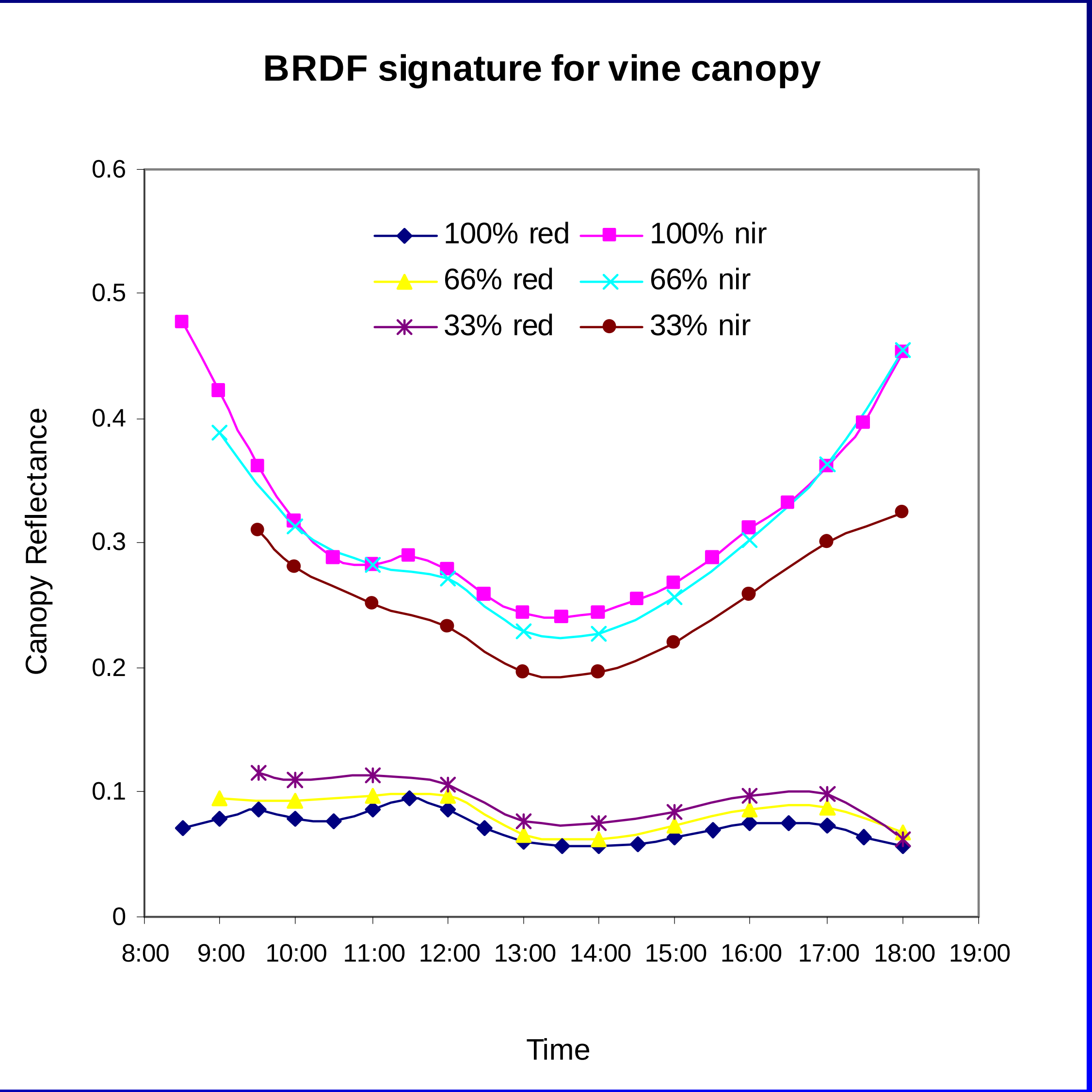

11/10/2002

Differences in

- crown shape & density
- soil properties
- canopy geometry
- large effect of shadows

Canopy Reflectance




BRDF signature for vine canopy
Canopy Reflectance
Time
0
0.1
0.2
0.3
0.4
0.5
0.6
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
18:00
19:00
100% red
100% nir
66% red
66% nir
33% red
33% nir

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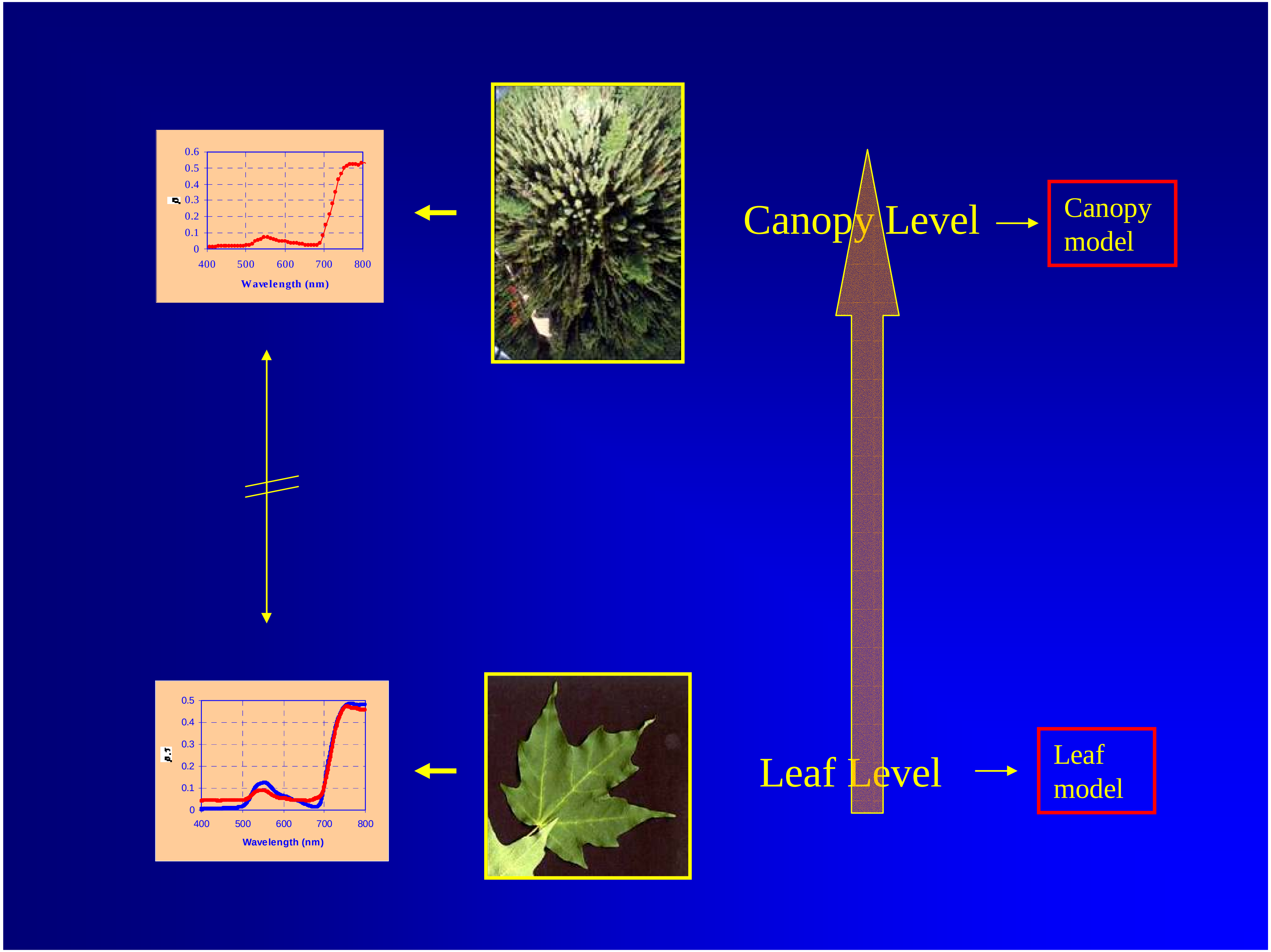
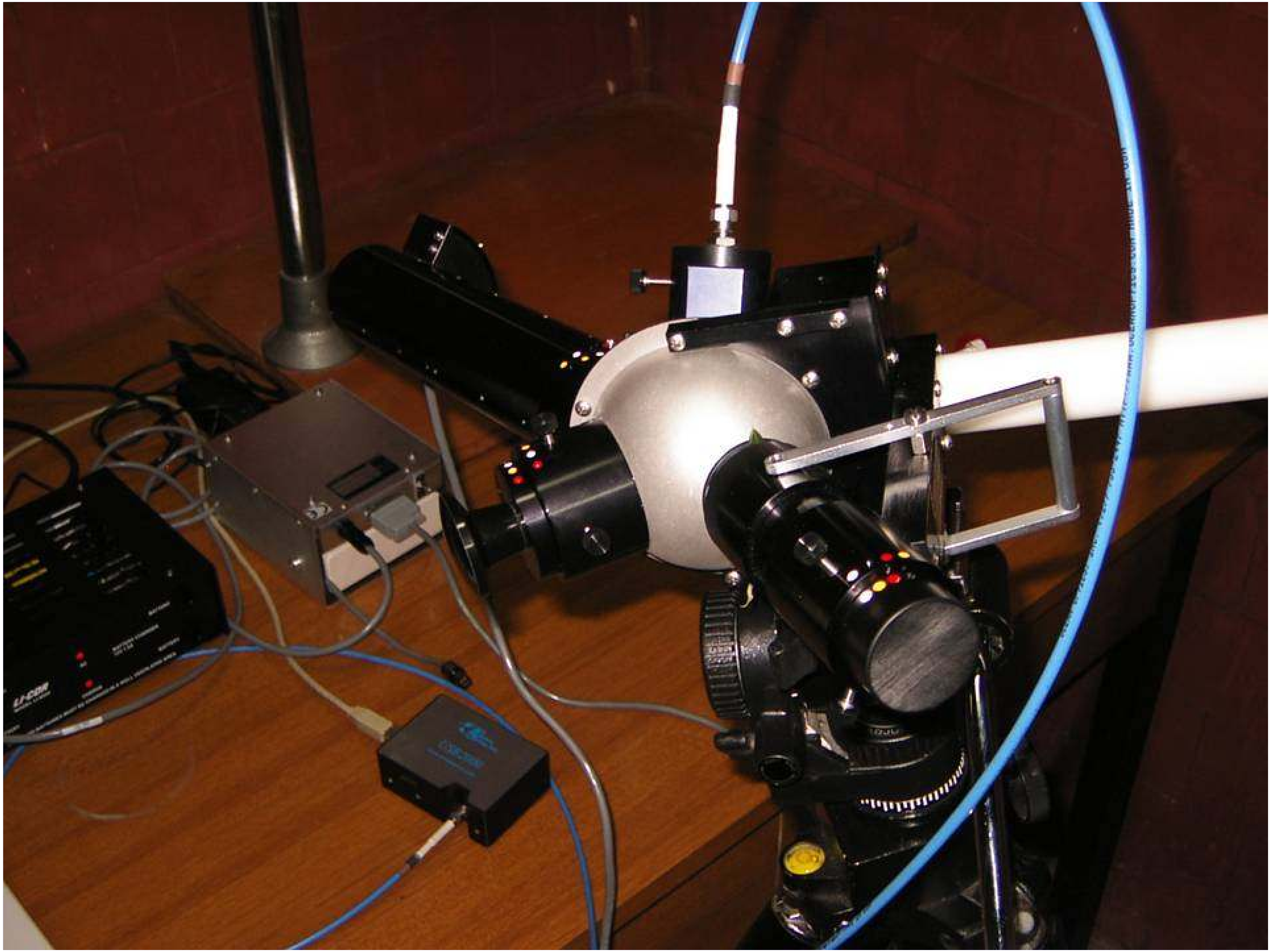
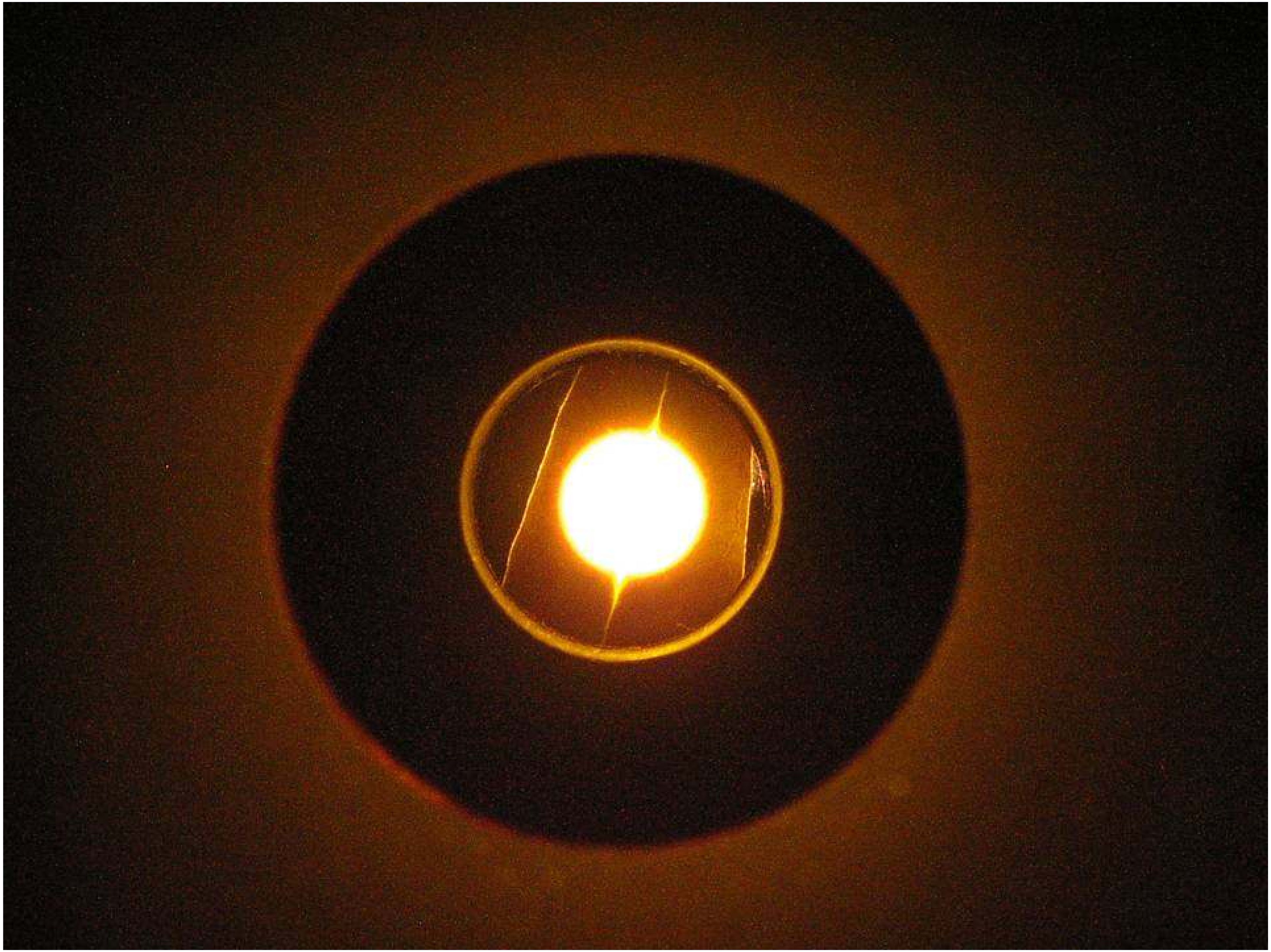
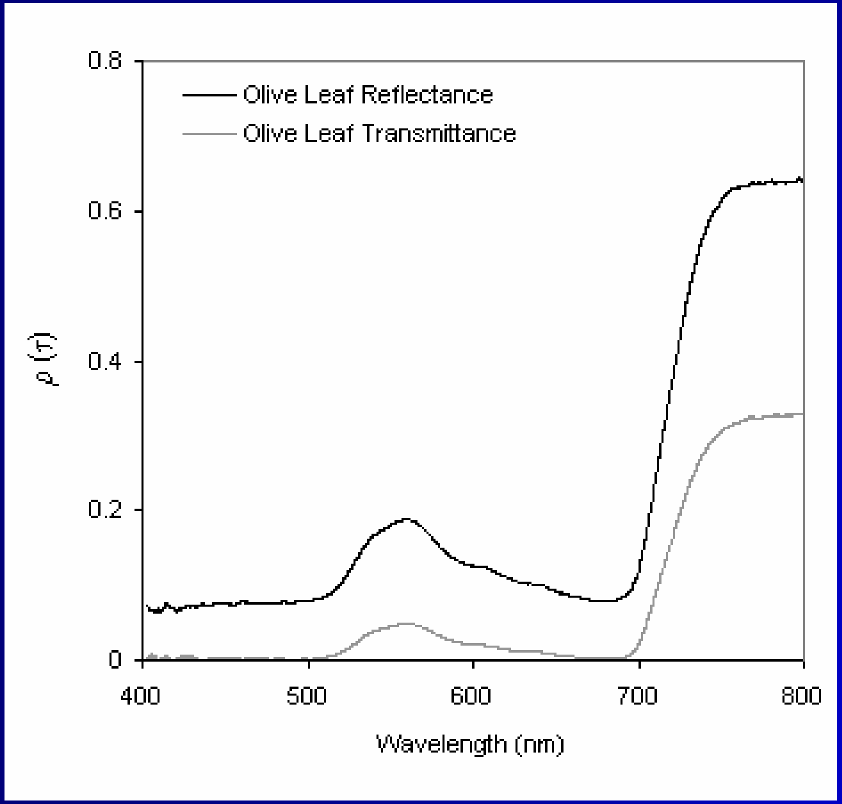


0.6
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
800
Wavelength (nm)
Canopy Level
Canopy
model
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
800
Wavelength (nm)
Leaf Level
Leaf
model

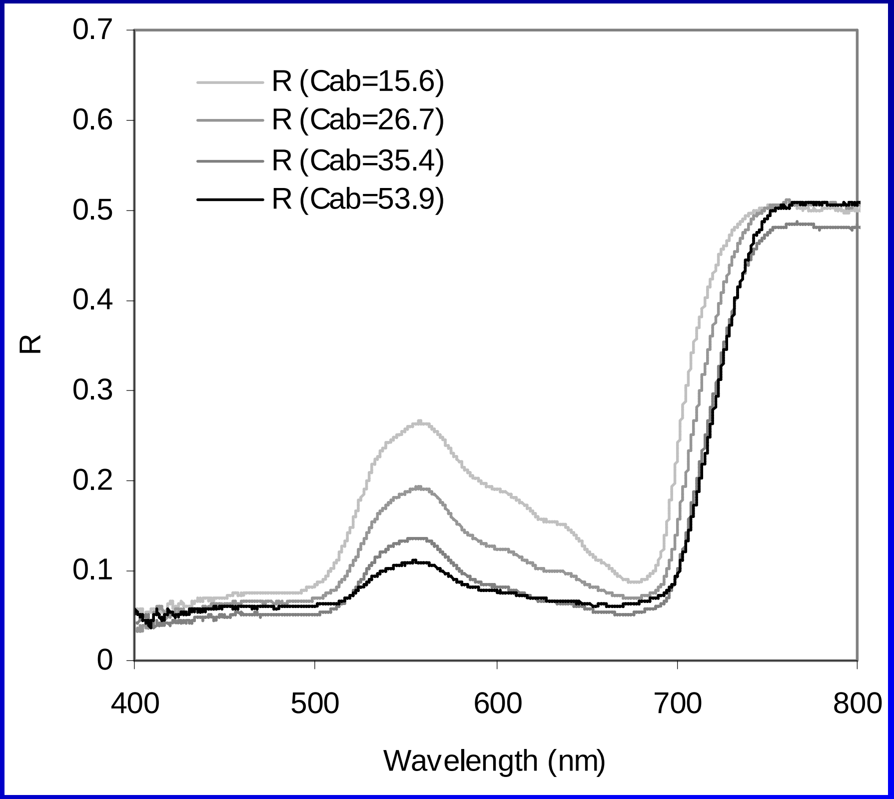

LI-COR



Olive & Vine Leaf Reflectance & Transmittance measurements



Olive ρ & τ



Vine ρ

Vegetation Index	Equation	Reference
Structural Indices		
Normalized Difference Vegetation Index (NDVI)	$NDVI = (R_{NIR} - R_{red})/(R_{NIR} + R_{red})$	Rouse *et al.* (1974)
Modified Triangular Vegetation Index (MTVI1)	$MTVI1 = 1.2 * [1.2 * (R_{800} - R_{550}) - 2.5 * (R_{670} - R_{550})]$	Haboudane *et al.* (2004)
Modified Triangular Vegetation Index (MTVI2)	$MTVI2 = \frac{1.5 * [1.2 * (R_{800} - R_{550}) - 2.5 * (R_{670} - R_{550})]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{800} - 5 * \sqrt{R_{670}}) - 0.5}}$	Haboudane *et al.* (2004)
Renormalized Difference Vegetation Index (RDVI)	$RDVI = (R_{800} - R_{670}) / \sqrt{(R_{800} + R_{670})}$	Rougean and Breon, (1995)
Simple Ratio Index (SR)	$SR = R_{NIR}/R_{red}$	Jordan (1969); Rouse *et al.* (1974)
Modified Simple Ratio (MSR)	$MSR = \frac{R_{NIR} / R_{red} - 1}{(R_{NIR} / R_{red})^{0.5} + 1}$	Chen (1996)
Modified Chlorophyll Absorption in Reflectance Index ($MCARI_1$)	$MCARI1 = 1.2 * [2.5 * (R_{800} - R_{670}) - 1.3 * (R_{800} - R_{550})]$	Haboudane *et al.* (2004)
Modified Chlorophyll Absorption in Reflectance Index ($MCARI_2$)	$MCARI2 = \frac{1.5 * [2.5 * (R_{800} - R_{670}) - 1.3 * (R_{800} - R_{550})]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{800} - 5 * \sqrt{R_{670}}) - 0.5}}$	Haboudane *et al.* (2004)
Soil Adjusted Vegetation Index (SAVI)	$SAVI = (1 + L) * (R_{800} - R_{670}) / (R_{800} + R_{670} + L)$ $[L \varepsilon (0,1)]$	Huete (1988) Qi *et al.* (1994)
Improved SAVI with self-adjustment factor L (MSAVI)	$MSAVI = \frac{1}{2}\left[2 * R_{800} + 1 - \sqrt{(2 * R_{800} + 1)^2 - 8 * (R_{800} - R_{670})}\right]$	Qi *et al.* (1994)
Optimized Soil-Adjusted Vegetation Index (OSAVI)	$OSAVI = (1 + 0.16) * (R_{800} - R_{670}) / (R_{800} + R_{670} + 0.16)$	Rondeaux *et al.* (1996)

Chlorophyll Indices

Greenness Index (G)	G = $(R_{554})/(R_{677})$	-
Modified Chlorophyll Absorption in Reflectance Index (MCARI)	MCARI = $[(R_{700} - R_{670}) - 0.2 * (R_{700} - R_{550})] * (R_{700} / R_{670})$	Daughtry *et al.* (2000)
Transformed CARI (TCARI)	TCARI = $3 * [(R_{700} - R_{670}) - 0.2 * (R_{700} - R_{550}) * (R_{700} / R_{670})]$	Haboudane *et al* (2002)
Triangular Vegetation Index (TVI)	$TVI = 0.5 * [120 * (R_{750} - R_{550}) - 200 * (R_{670} - R_{550})]$	Broge and Leblanc (2000)
Zarco-Tejada & Miller	ZTM = $(R_{750})/(R_{710})$	Zarco-Tejada *et al.* (2001)

Water Indices

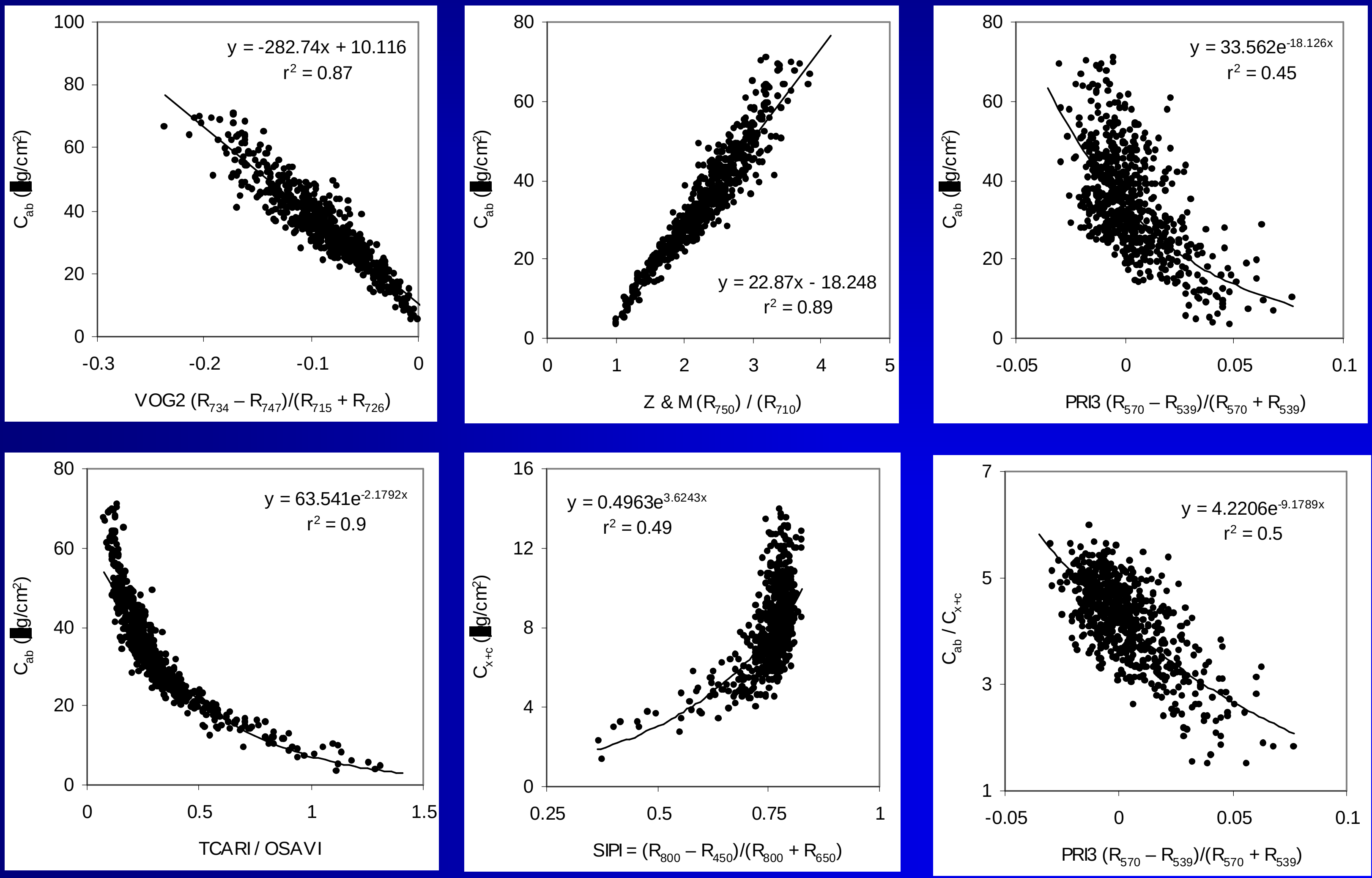
Normalized Difference Water Index (NDWI)	NDWI=$(R_{860}-R_{1240})/ (R_{860}+R_{1240})$	Gao, (1996)
Simple Ratio Water Index (SRWI)	SRWI=R_{858}/R_{1240}	Zarco-Tejada *et al.*, (2003)
Plant Water Index (PWI)	PWI= R_{970}/R_{900}	Peñuelas *et al.* (1997)

Red Edge Spectral Parameters

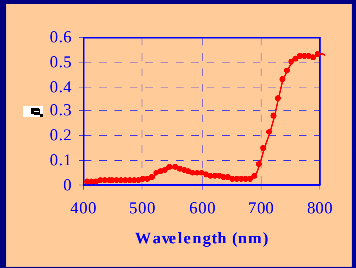
λ_p	$\lambda_{pr} = \lambda_{max[680\text{-}750]}$ $\lambda_{p1g} = \lambda_{max[500\text{-}600]}$ $\lambda_{p2g} = \lambda_{min[500\text{-}600]}$	*Hare et al*. (1984); *Bonham-Carter* (1988)
R_o	$R_o = R_{min[650\text{-}700]}$	*Hare et al*. (1984); *Bonham-Carter* (1988)
R_s	$R_s = R_{max[700\text{-}770]}$	*Hare et al*. (1984); *Bonham-Carter* (1988)
σ	σ = shape parameter as defined by the inverted-gaussian curve-fit model	*Hare et al*. (1984); *Bonham-Carter* (1988)

Simple Ratio Pigment Index (SRPI)	$SRPI = (R_{430})/(R_{680})$	Peñuelas *et al.* (1995)
Normalized Phaeophytinization Index (NPQI)	$NPQI = (R_{415} - R_{435})/ (R_{415} + R_{435})$	Barnes *et al.* (1992)
Photochemical Reflectance Index (PRI)	$PRI_1 = (R_{528} - R_{567})/(R_{528} + R_{567})$ $PRI_2 = (R_{531} - R_{570})/(R_{531} + R_{570})$	Gamon *et al.* (1992)
Normalized Pigment Chlorophyll Index (NPCI)	$NPCI = (R_{680} - R_{430})/ (R_{680} + R_{430})$	Peñuelas *et al.* (1994)
Carter Indices	$Ctr1 = (R_{695})/(R_{420})$ $Ctr2 = (R_{695})/(R_{760})$	Carter (1994) Carter *et al.* (1996)
Lichtenthaler indices	$Lic1 = (R_{800} - R_{680})/ (R_{800} + R_{680})$ $Lic2 = (R_{440})/(R_{690})$ $Lic3 = (R_{440})/(R_{740})$ $Lic4 = \int_{450}^{680} R$	Lichtenthaler *et al.* (1996)
Structure Intensive Pigment Index (SIPI)	$SIPI = (R_{800} - R_{450})/ (R_{800} + R_{650})$	Peñuelas *et al.* (1995)
Vogelmann indices	$Vog1 = (R_{740})/(R_{720})$ $Vog2 = (R_{734} - R_{747})/(R_{715} + R_{726})$ $Vog3 = (R_{734} - R_{747})/(R_{715} + R_{720})$ $Vog4 = D_{715}/D_{705}$	Vogelmann *et al.* (1993); Zarco-Tejada *et al.* (1999)
Gitelson and Merzlyak	$G\_M1 = (R_{750})/(R_{550})$ $G\_M2 = (R_{750})/(R_{700})$	Gitelson and Merzlyak (1997)
Curvature Index (Fluorescence)	$CUR = (R_{675} \cdot R_{690})/(R_{683}^2)$	Zarco-Tejada *et al.* (2000)
Double-Peak Ratio Indices	$DPR1 = D_{\lambda p[680\text{-}750]}/D_{\lambda 0+12}$ $DPR2 = D_{\lambda p[680\text{-}750]}/D_{\lambda 0+22}$ $DP21 = D_{\lambda p[680\text{-}750]}/D_{703}$ $DP22 = D_{\lambda p[680\text{-}750]}/D_{720}$	Zarco-Tejada *et al.* (2001)
Area Red Edge Peak (ADR)	$ADR = \int_{680}^{760} D$	Zarco-Tejada *et al.* (2001)

Relationships between C_{ab}, C_{x+c} & Indices at Leaf Level in Vines

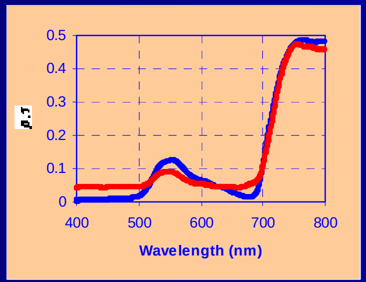


Leaf and Canopy RT models

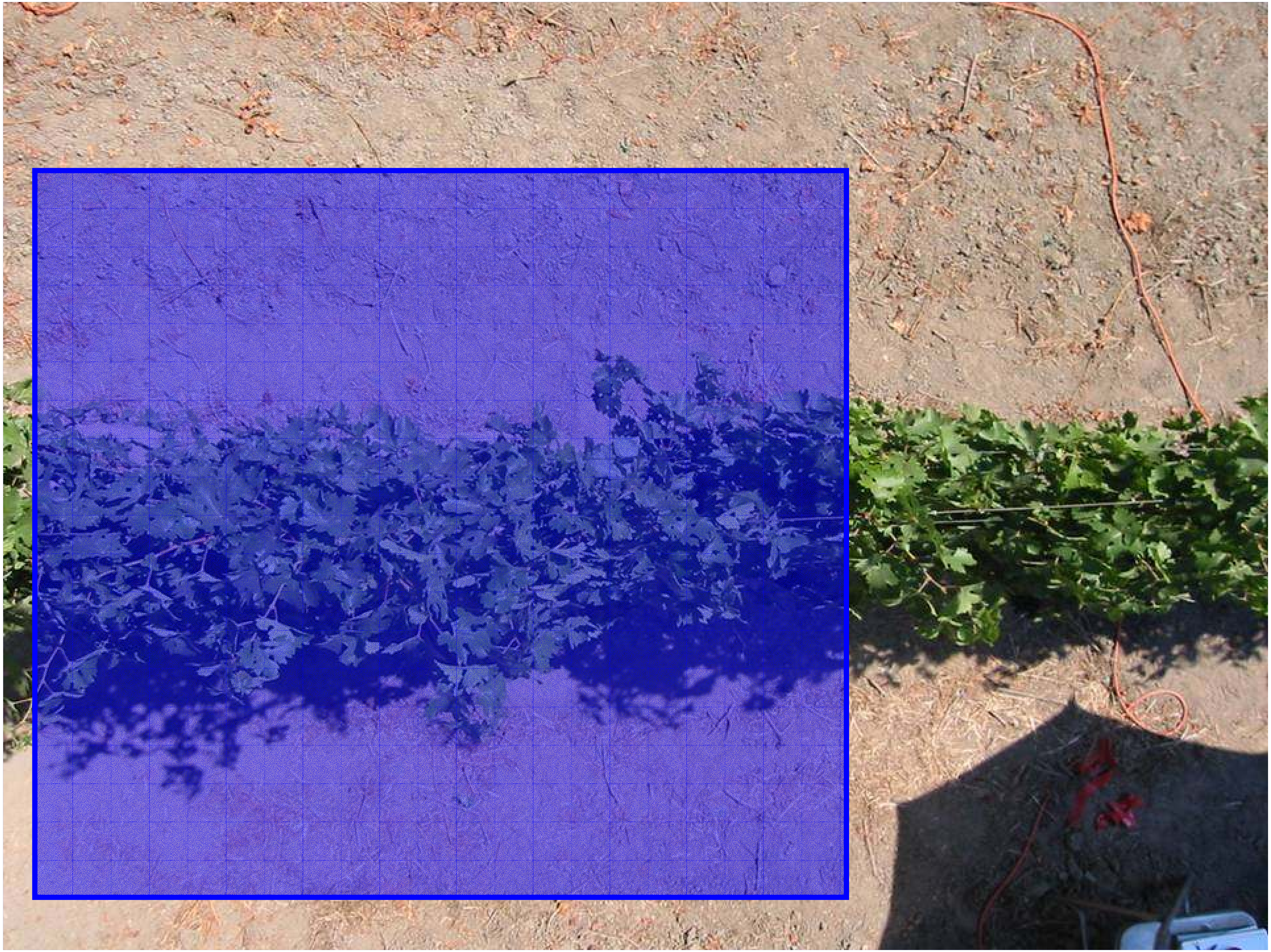


Canopy Level → Canopy model

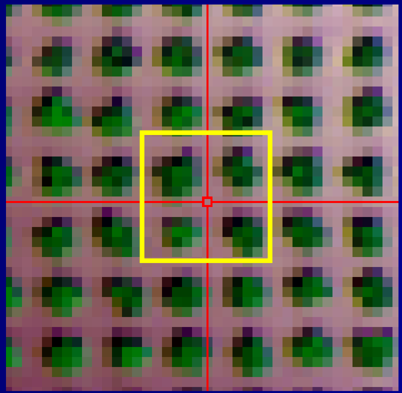
Scaling up

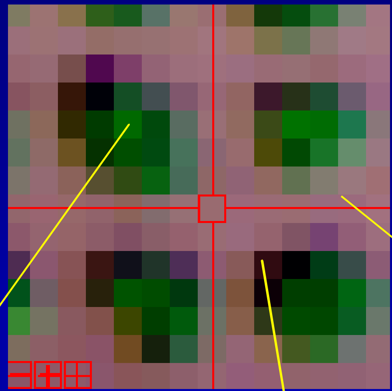


Leaf Level → Leaf model

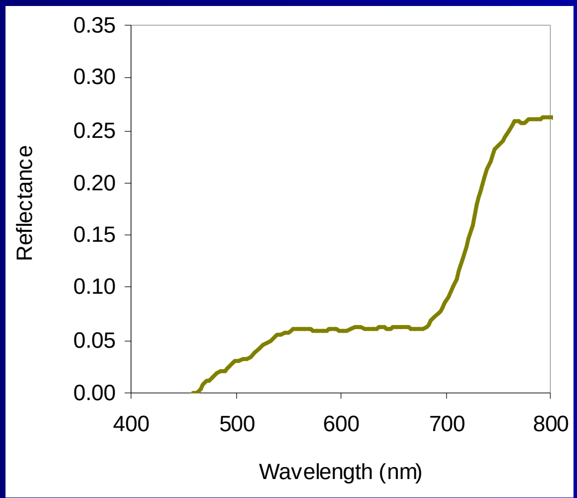


Scene components crown, shadow and soil reflectance extracted from ROSIS 1-m data

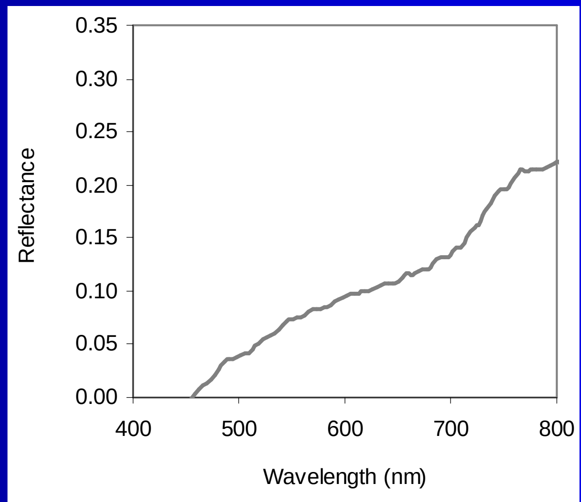




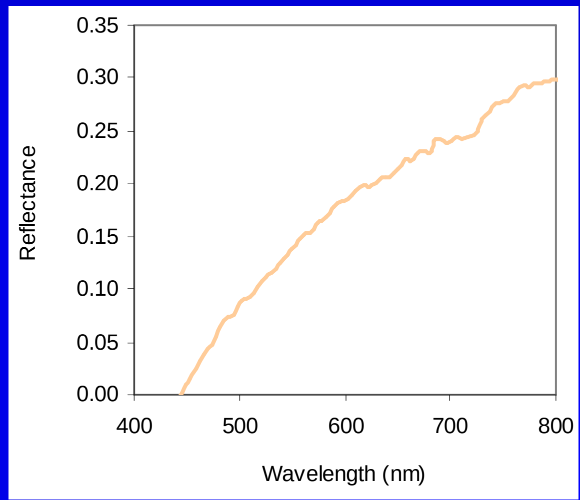
Crown



Shadow



Soil



Study Areas Vineyards (I)

VH7

VH6,VH5,VC2

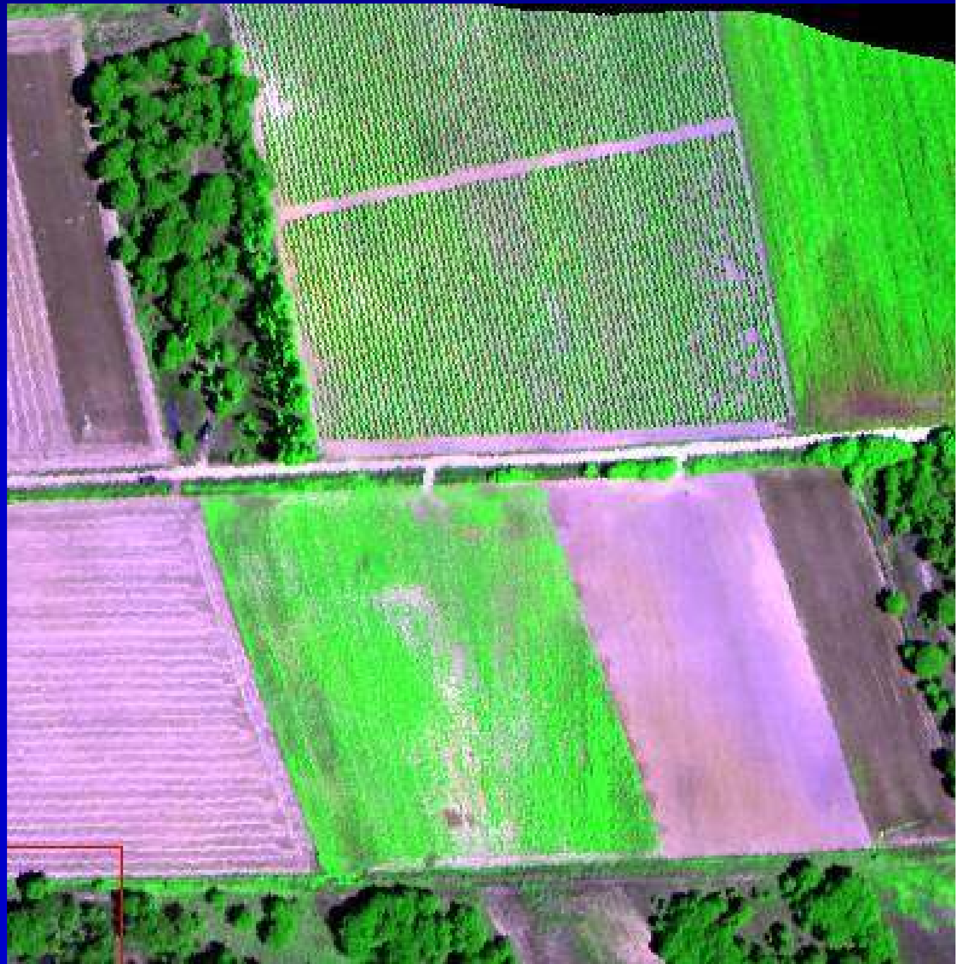
Study Areas Vineyards (II)

VC7

VC3,VC5

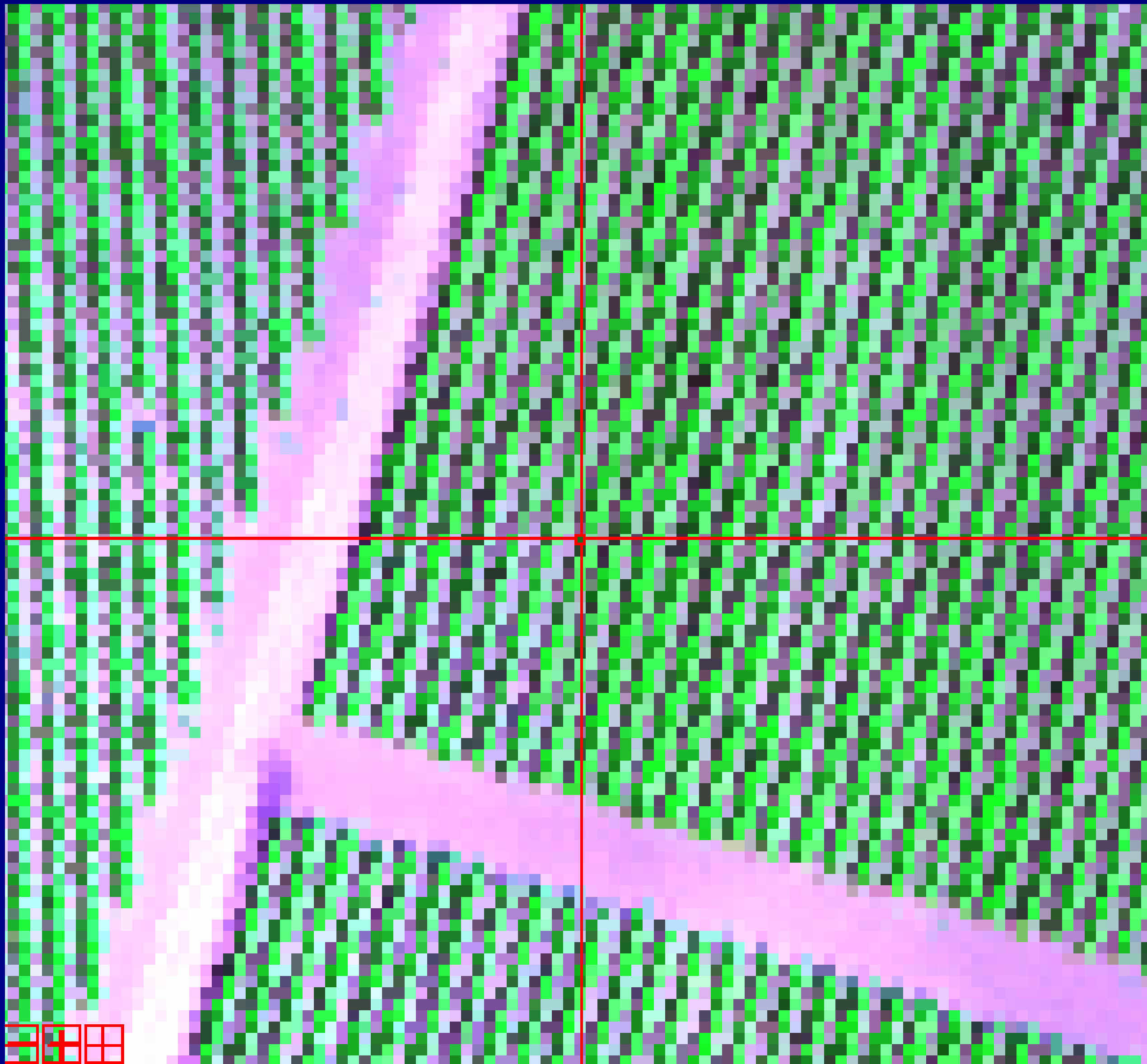
Study Areas Vineyards (III)

VC4

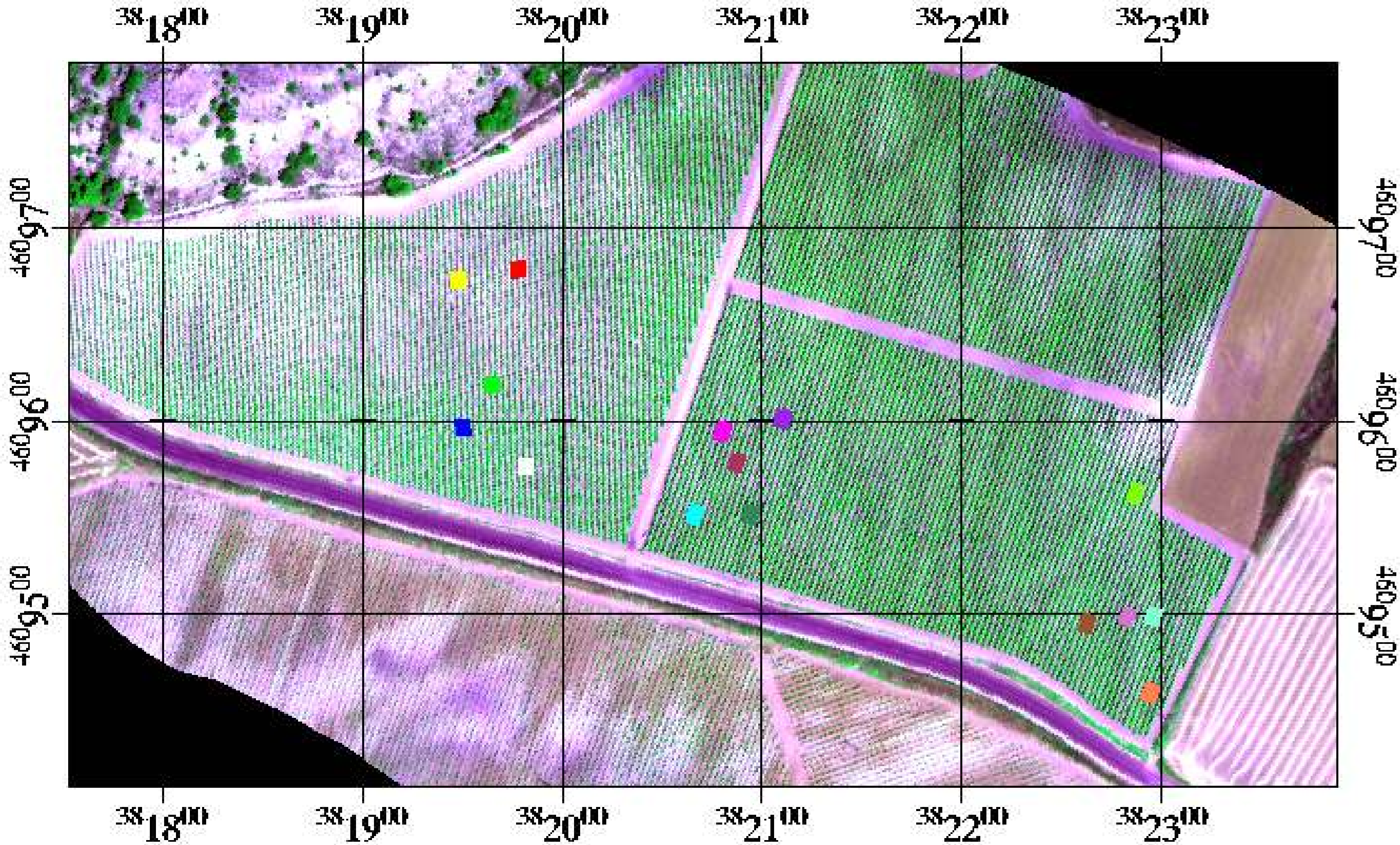


VH6

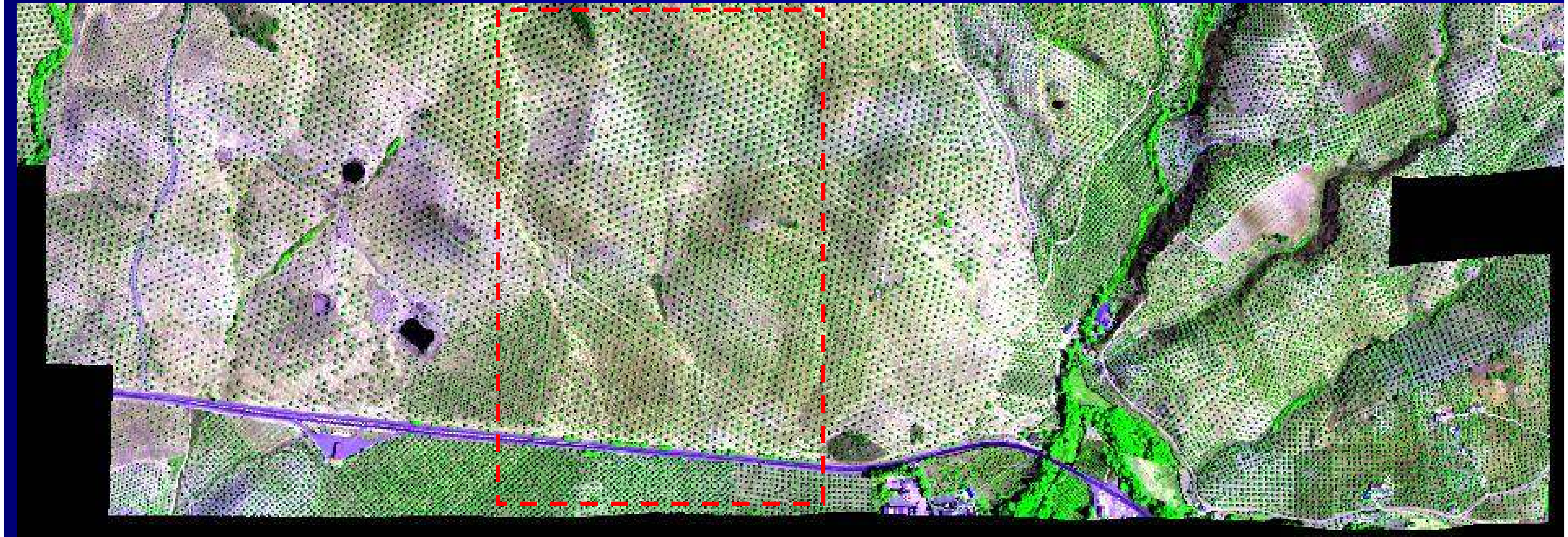
Study Areas Vineyards (IV)



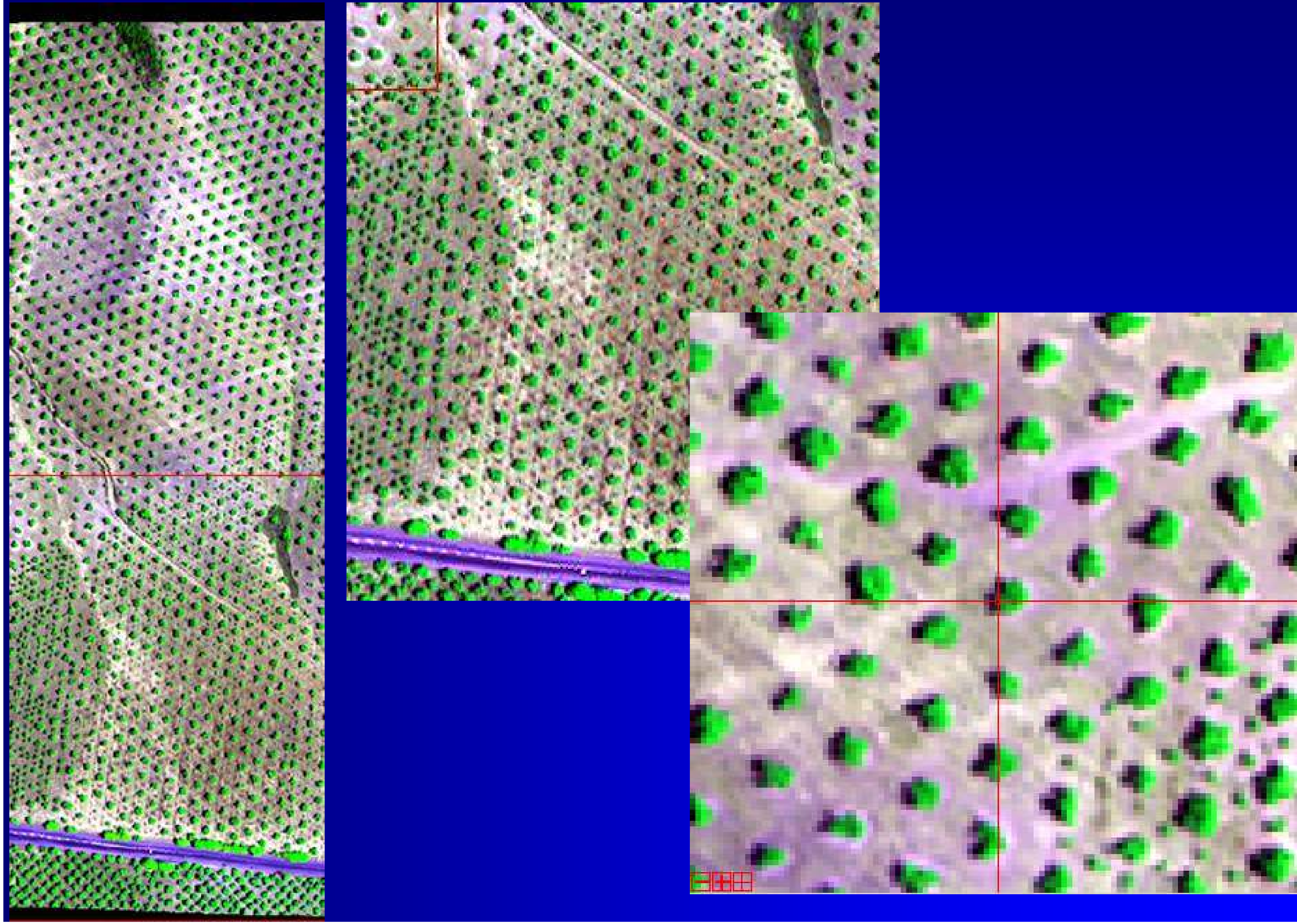
VH1, VC1, VH2

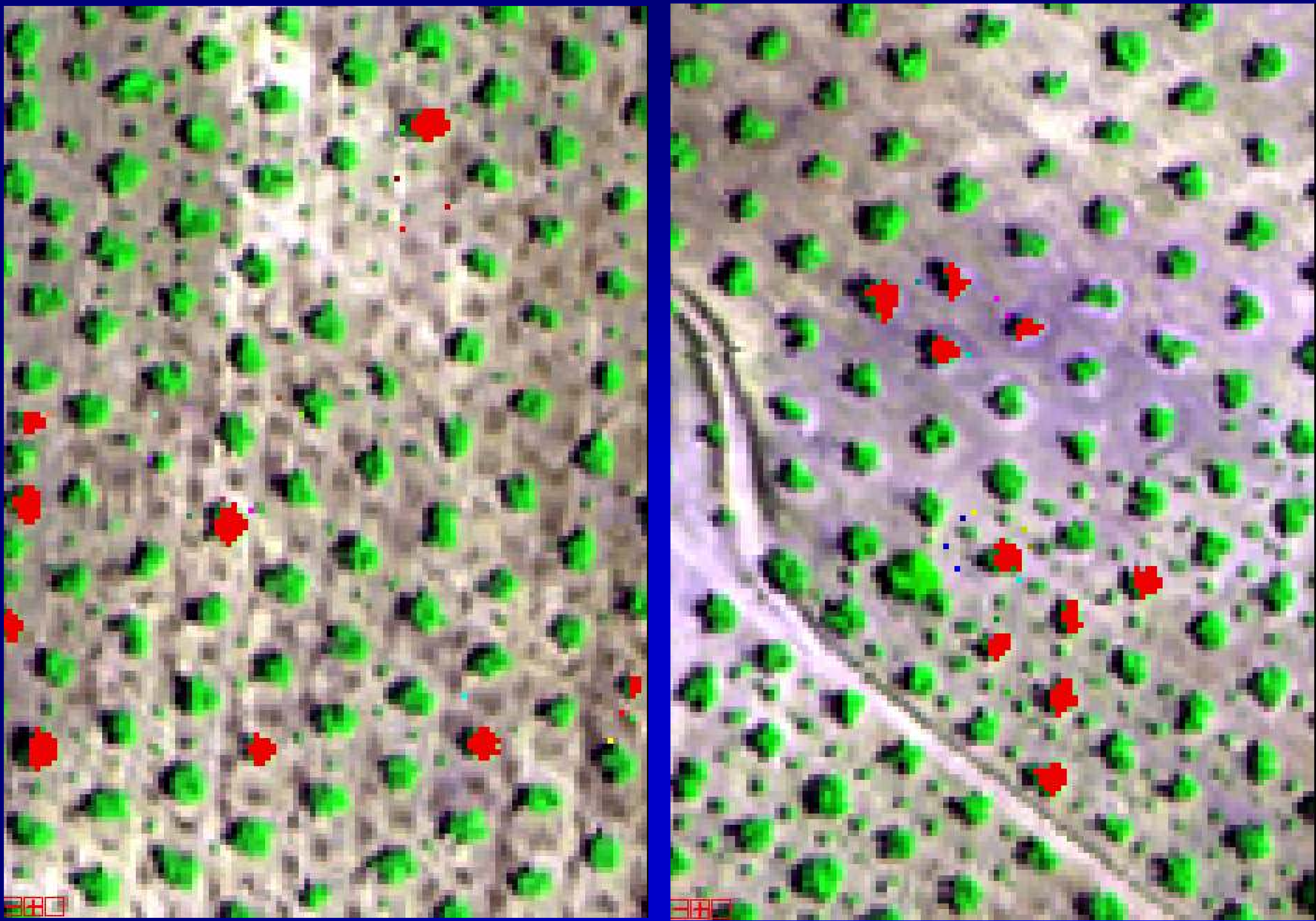

381800
381900
382000
382100
382200
382300
4609700
4609600
4609500

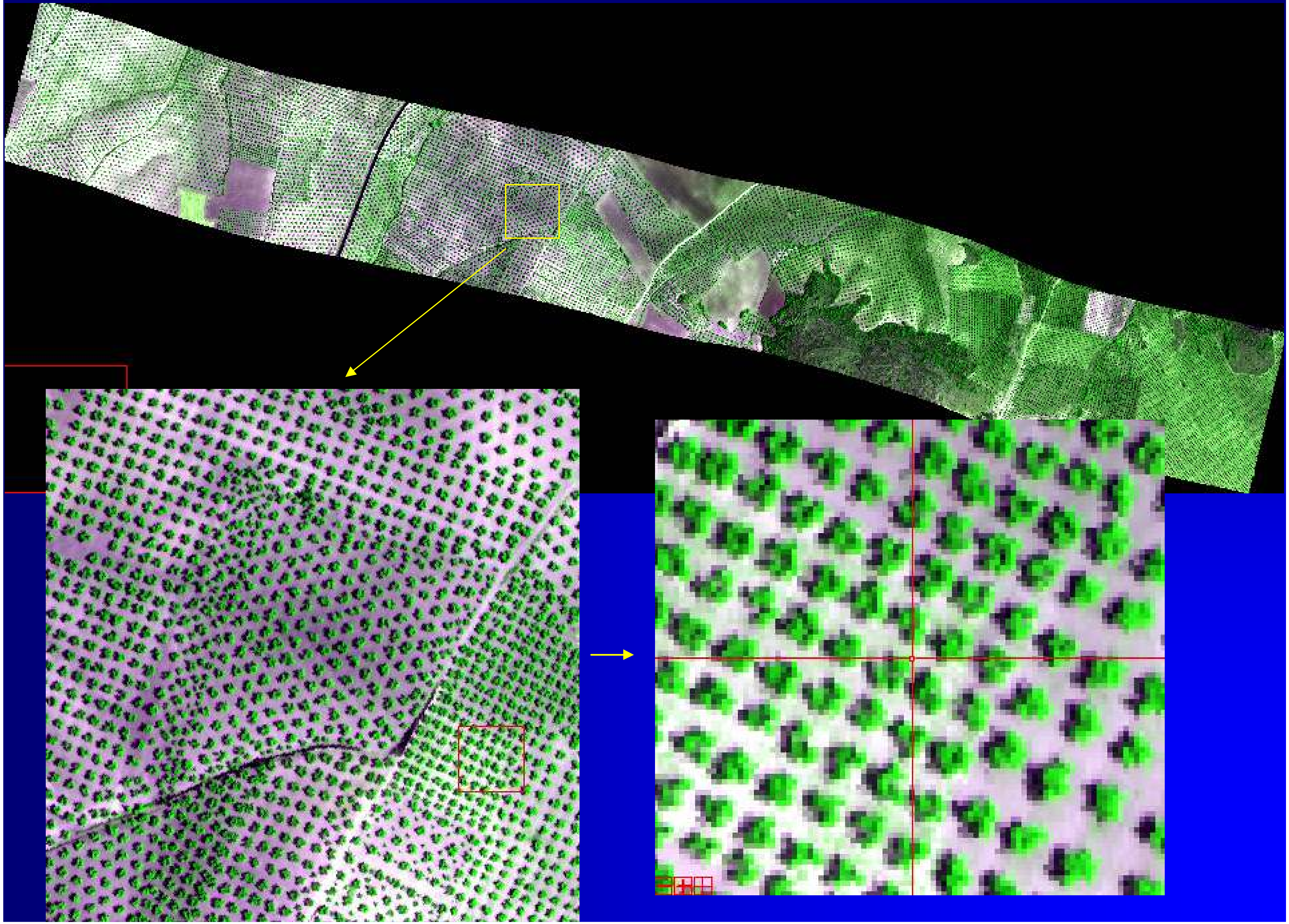
Study Areas Olive Fields

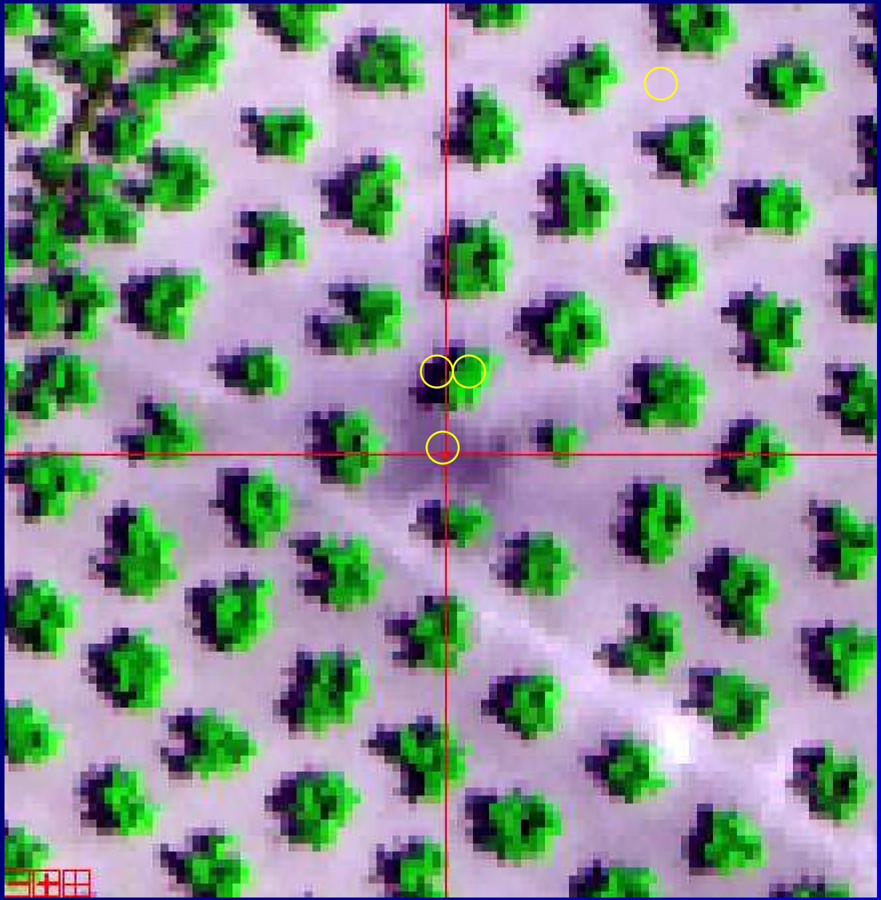


Study Areas Olive Fields



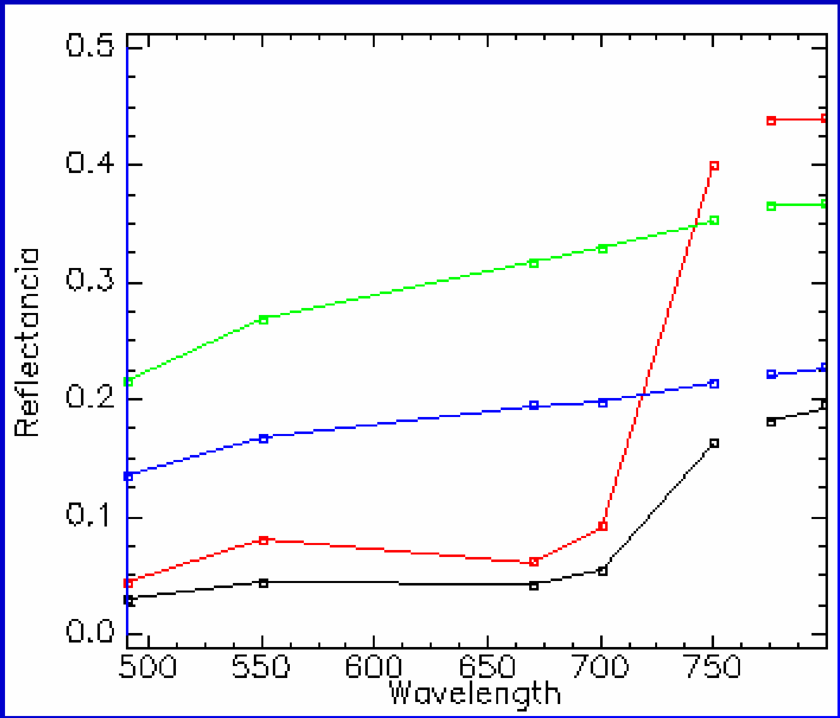


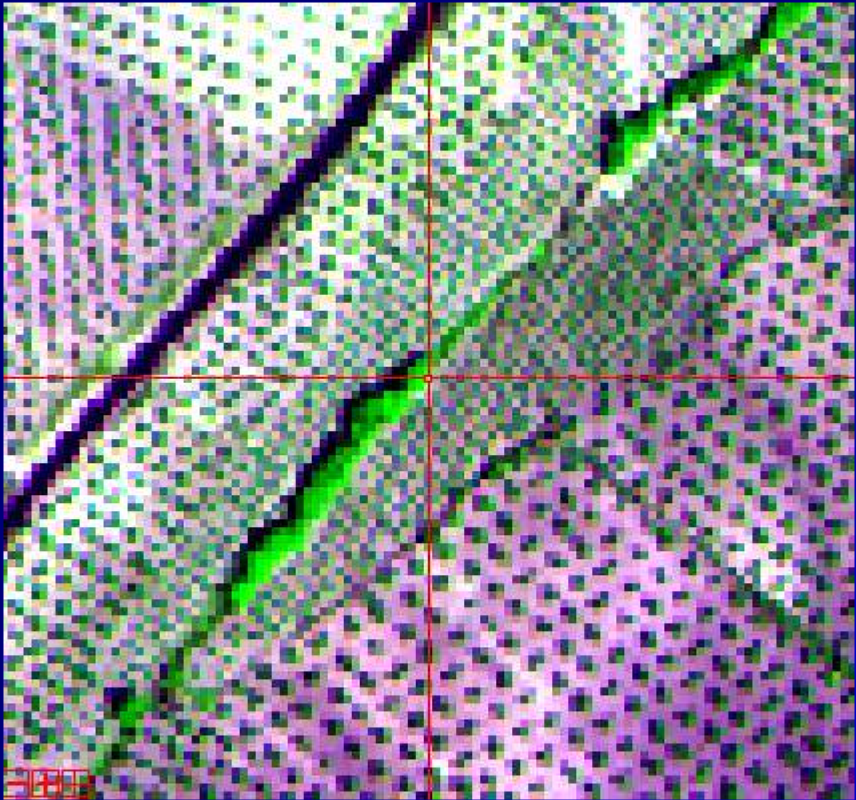




8 bands, 4-12 nm FWHM

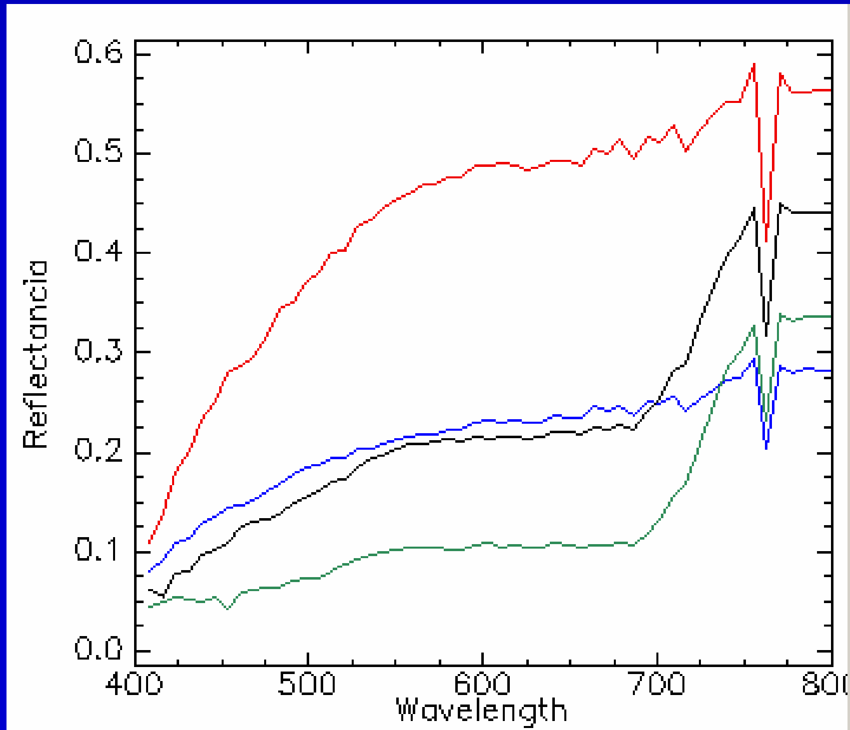
1 m spatial resolution



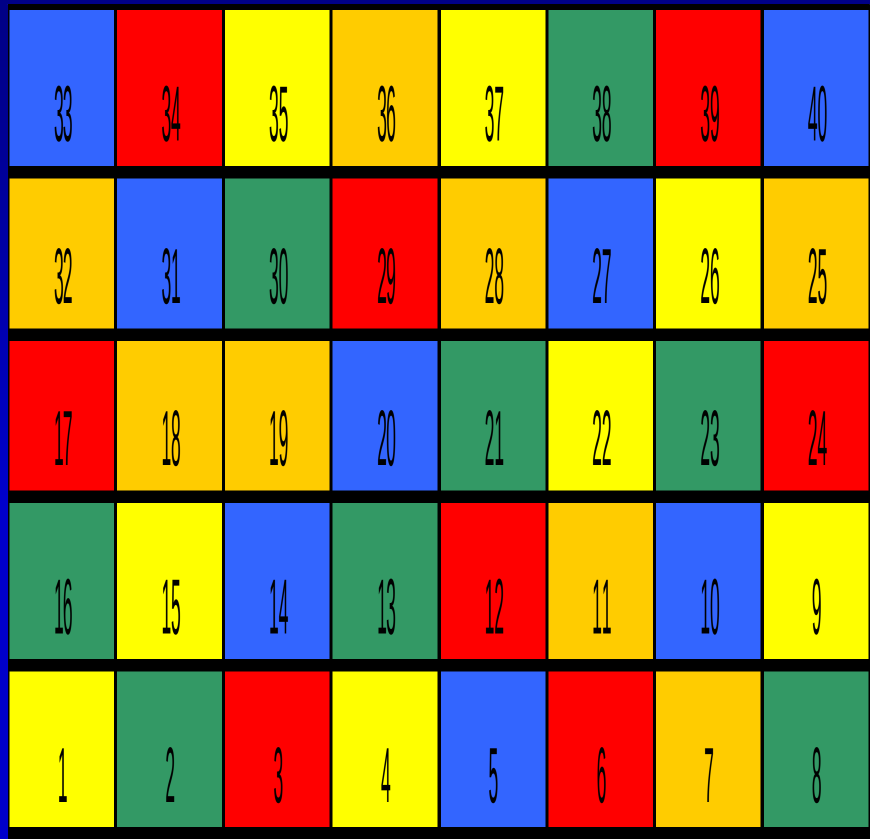


72 bands, 7.5 nm FWHM

4 m spatial resolution



Study Areas Olive Fields



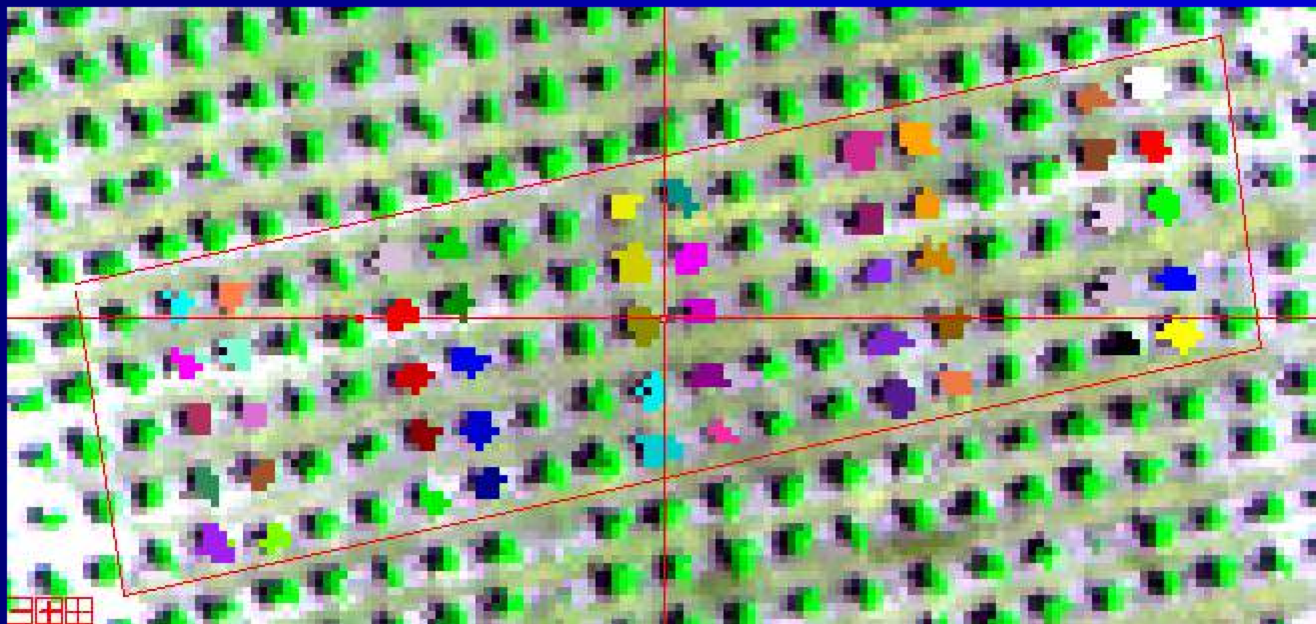
- Q_0 (Testigo)
- Q_1 (Q Fe 4.8 o-o)
- Q_2 (+33% Q_1)
- Q_3 ($2Q_1$)
- Q_1^*(Q Fe 2.3 o-o)

Study Areas Olive Fields

81	121	111	101	91
82	122	112	102	92
93	83	123	113	103
94	84	124	114	104
105	95	85	125	115
106	96	86	126	116
117	107	97	87	127
118	108	98	88	128
129	119	109	99	89
130	120	110	100	90

Q_0 (Testigo)
Q_1 (Q Fe 4.8 o-o)
Q_2 (+33% Q_1)
Q_3 ($2Q_1$)
Q_1^*(Q Fe 2.3 o-o)

Study Areas Olive Fields



Q_0 (Testigo)

Q_1 (Q Fe 4.8 o-o)

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Combined Indices for C_{ab} Estimation with PROSPECT+SAILH

- **CARI** → minimize effects of non-photosynthetic materials
- **MCARI** → depth of chlorophyll absorption at 670 nm relative to the reflectance at 550 nm and 700 nm
  still sensitive to non-photosynthetic element effects

$$MCARI = [(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550})] \cdot \left(\frac{R_{700}}{R_{670}}\right)$$

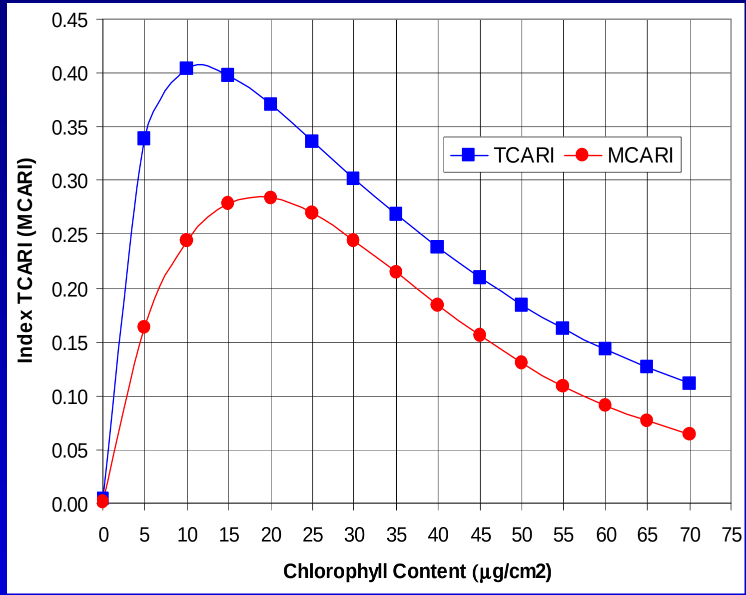
- **TCARI** → improving its sensitivity at low chlorophyll values

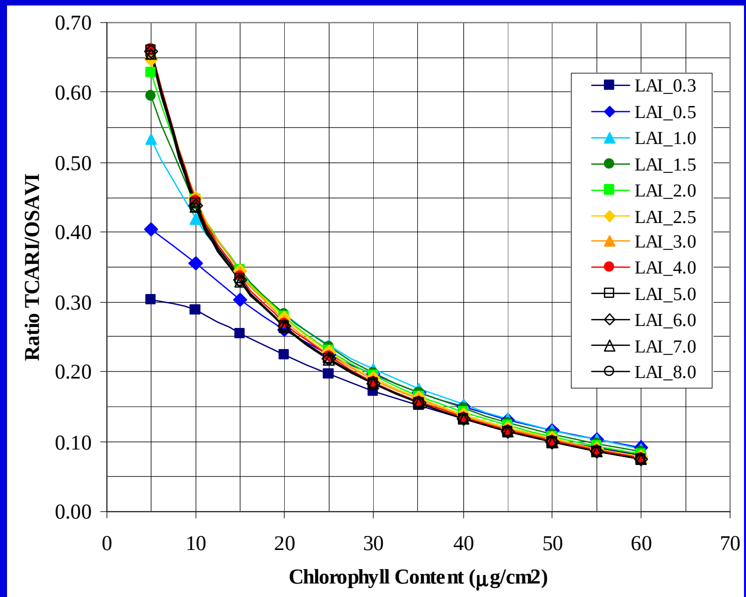
$$TCARI = 3 \cdot \left[(R_{700} - R_{670}) - 0.2 \cdot (R_{700} - R_{550}) \cdot \left(\frac{R_{700}}{R_{670}}\right)\right]$$

- Influence by soil reflectance for low values of LAI
  → **OSAVI** minimizes soil effects with MCARI

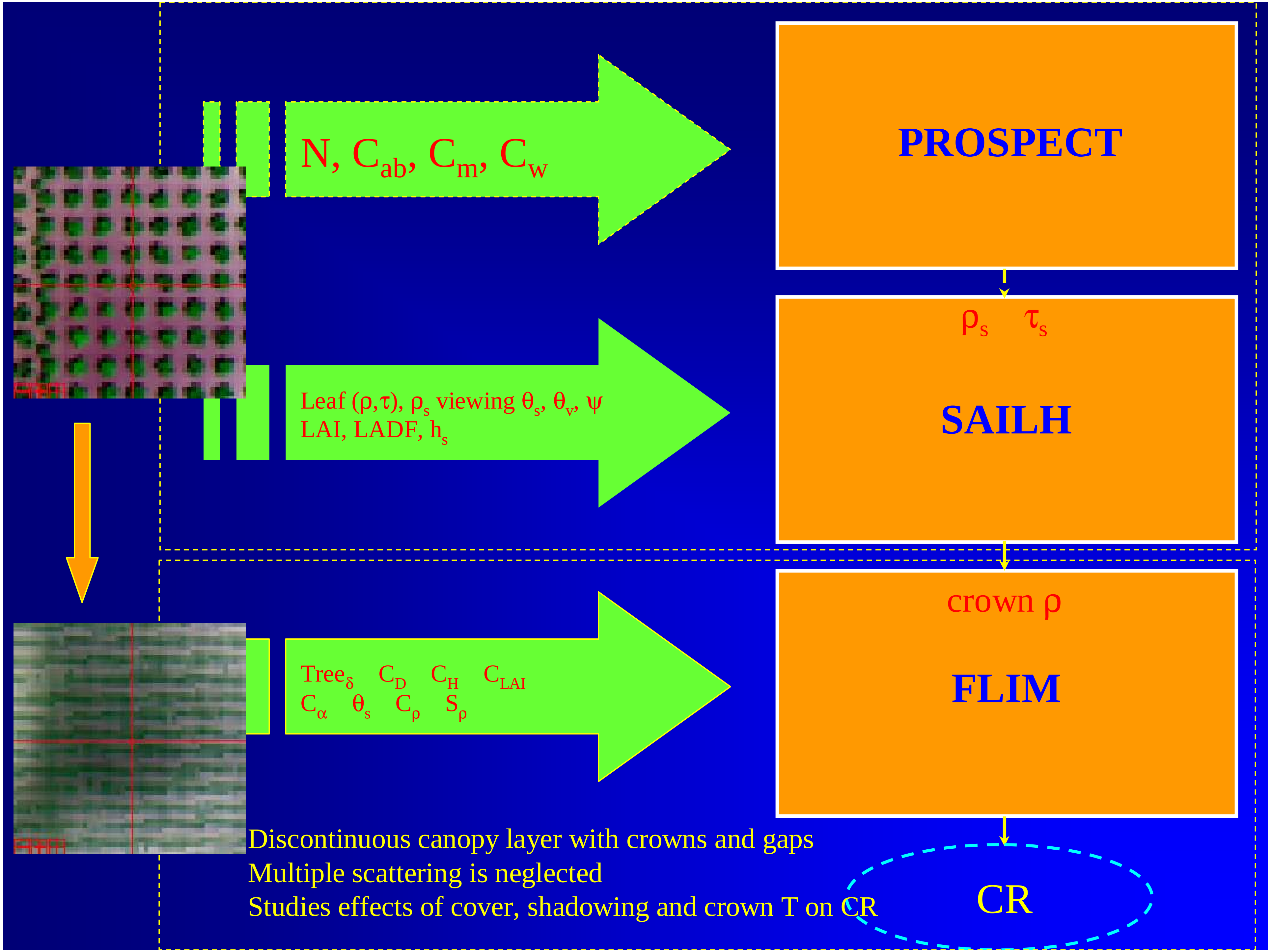
$$OSAVI = (1 + 0.16) \cdot \left[\frac{R_{800} - R_{670}}{R_{800} + R_{670} + 0.16}\right]$$

TCARI/OSAVI

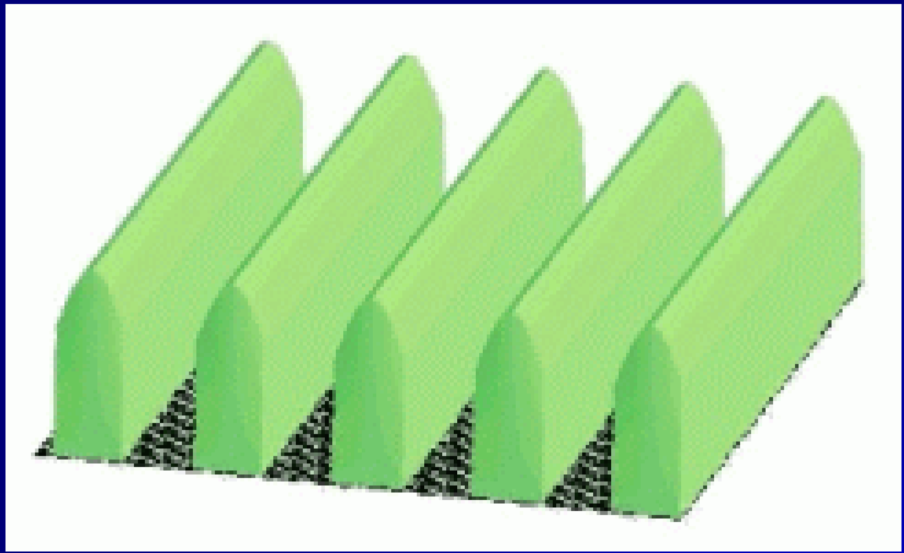


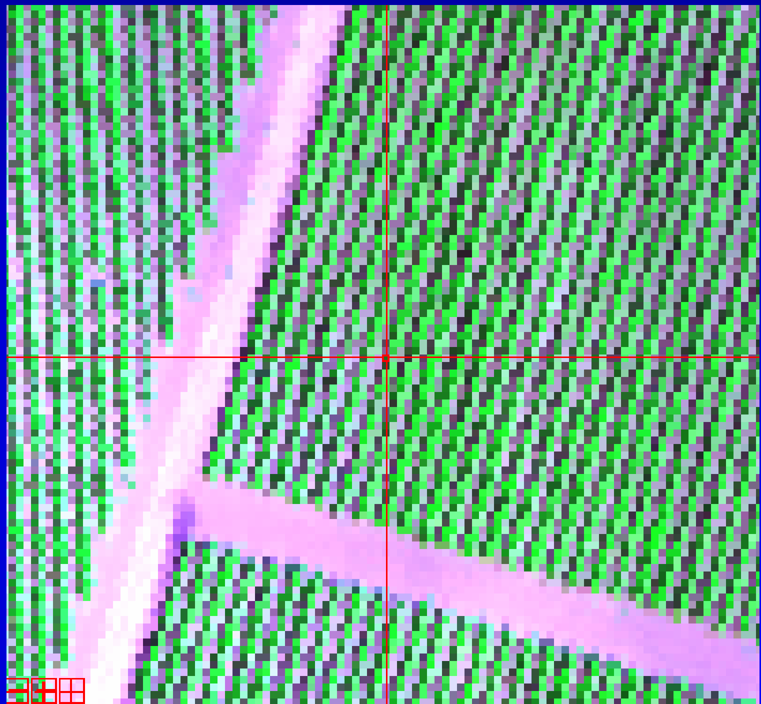


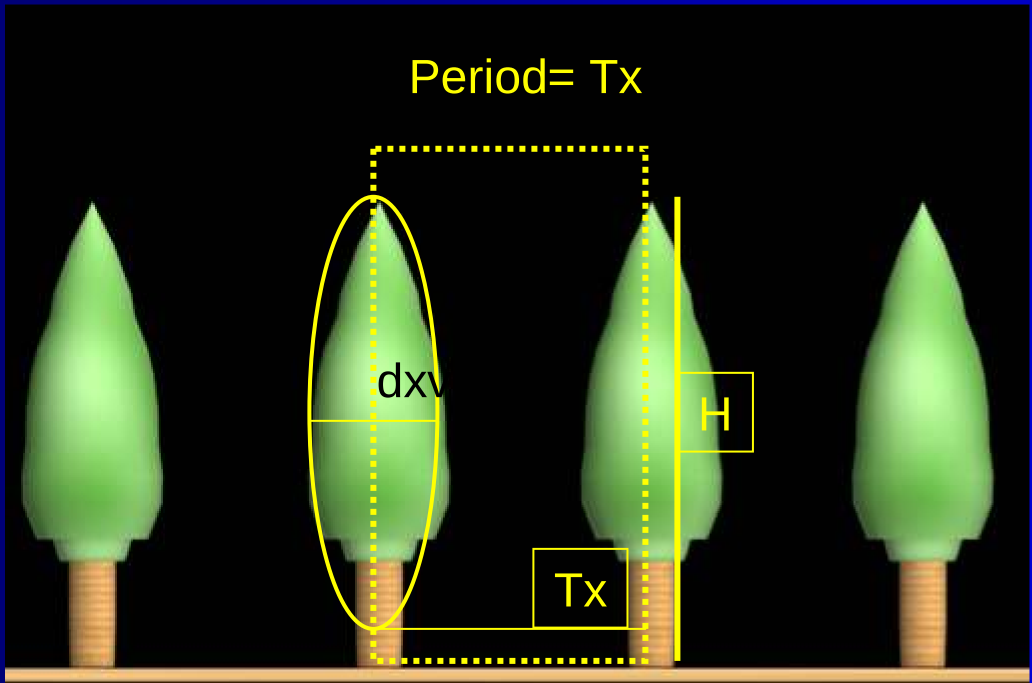
(Haboudane *et al.*, 2002)

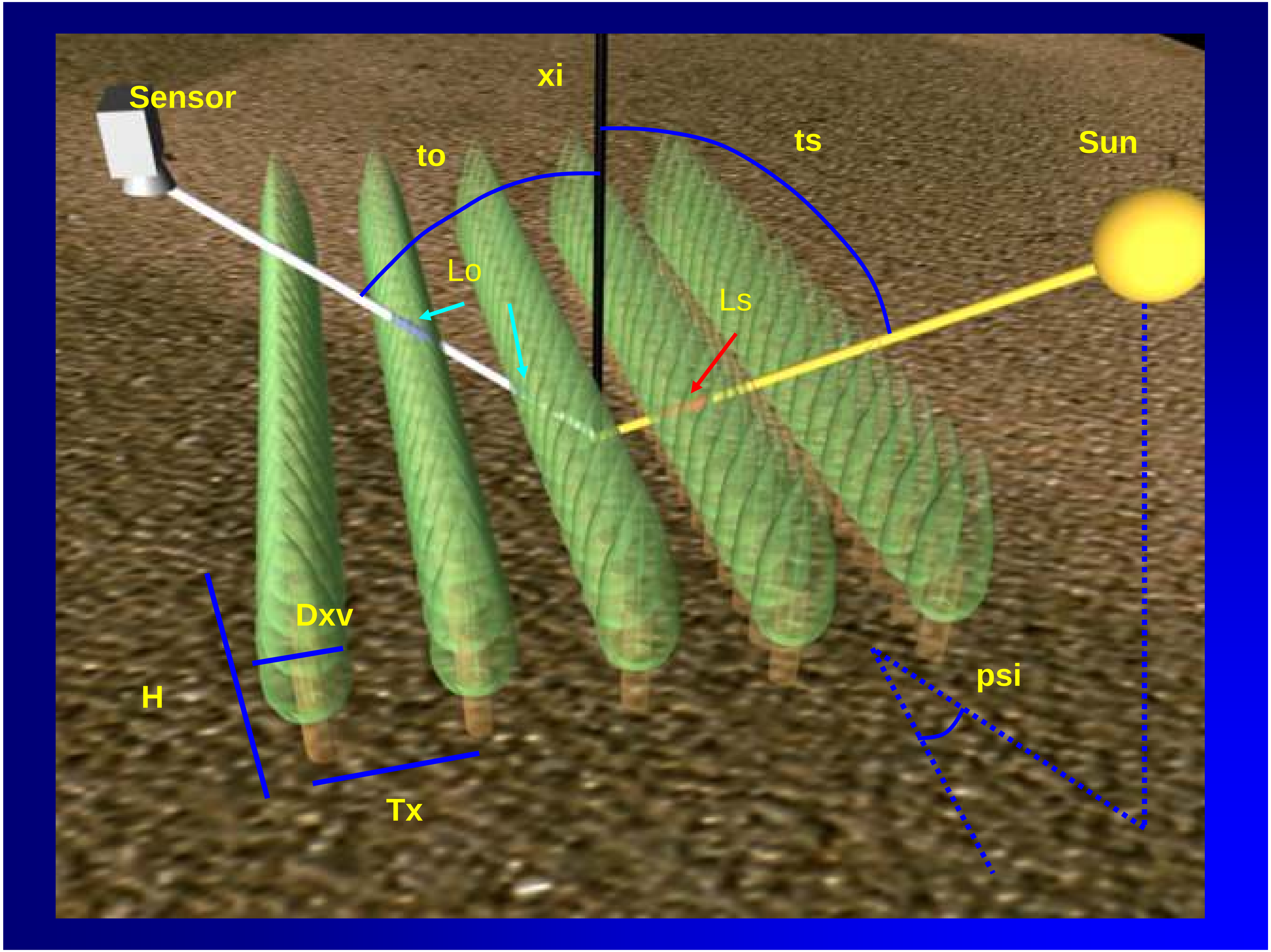

N, C_{ab}, C_m, C_w
PROSPECT
ρ_s τ_s
Leaf (ρ,τ), ρ_s viewing θ_s, θ_v, ψ
LAI, LADF, h_s
SAILH
crown ρ
$Tree_\delta$ C_D C_H C_{LAI}
C_α θ_s C_ρ S_ρ
FLIM
Discontinuous canopy layer with crowns and gaps
Multiple scattering is neglected
Studies effects of cover, shadowing and crown T on CR
CR

rowMCRM → addition of row structure to MCRM model








Sensor
xi
to
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Sun
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Ls
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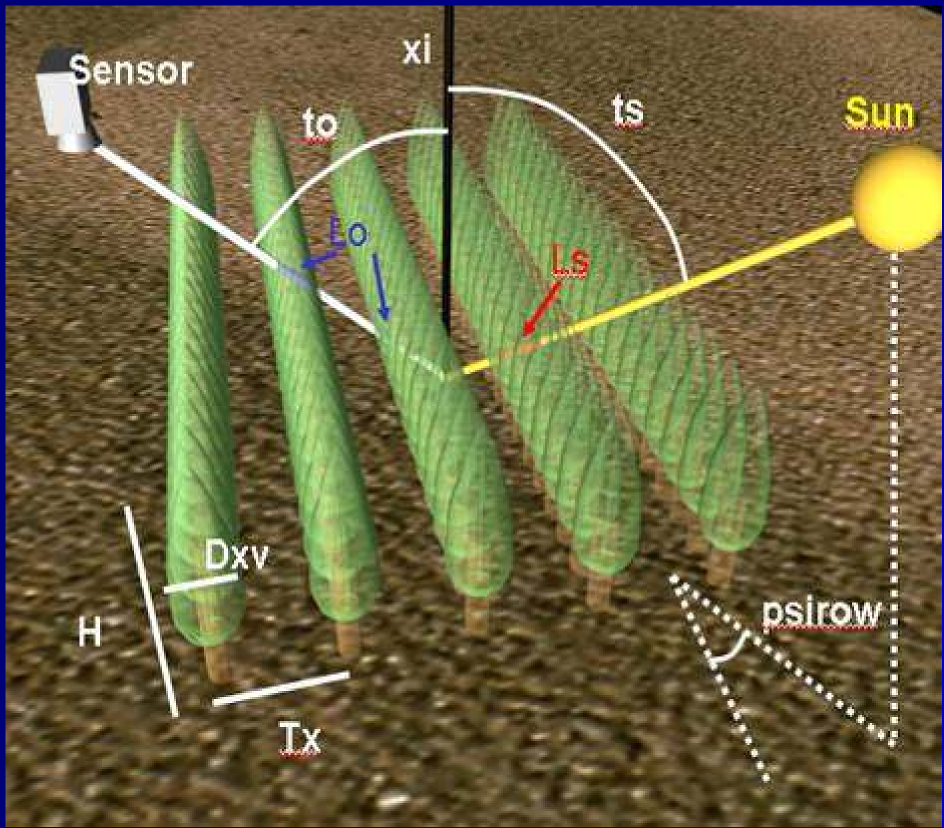
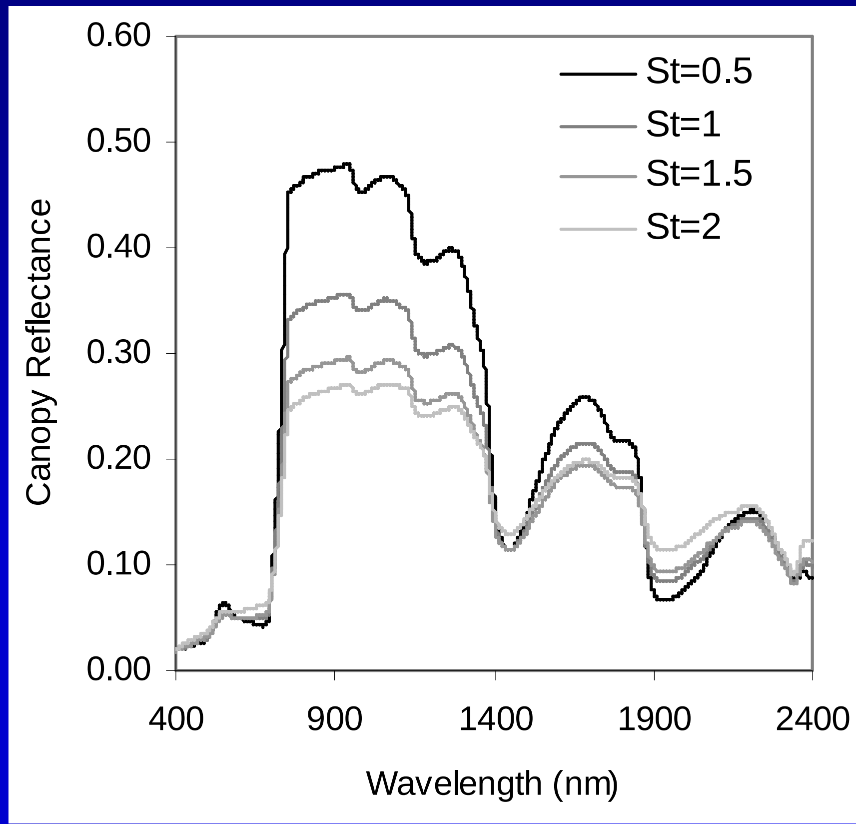
H
psi
Tx





Model simulation of row-structured discontinuous canopies with rowMCRM radiative transfer model (left). Vineyard canopy reflectance simulation as function of the visible strip length in the row crop (St=0.5, 1m, 1.5m and 2m) (right).

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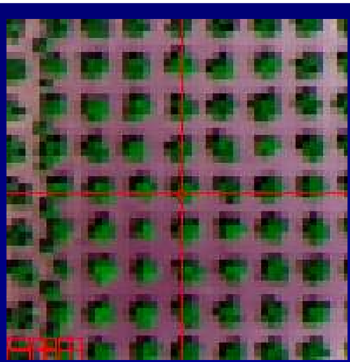
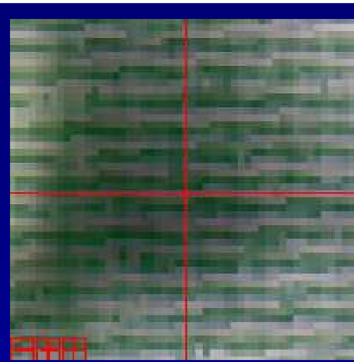
4. Results

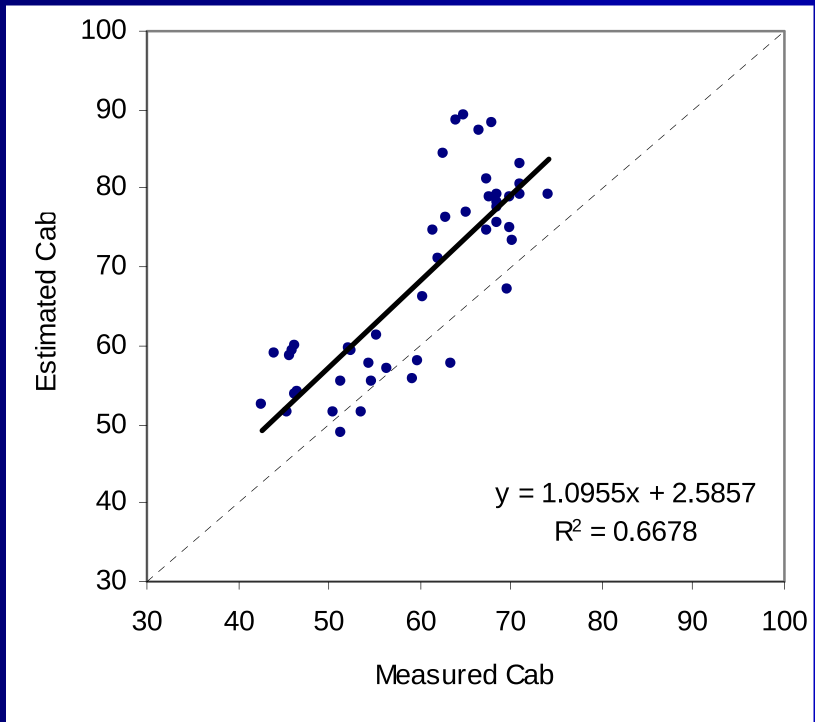
5. Conclusions



Olive Canopies

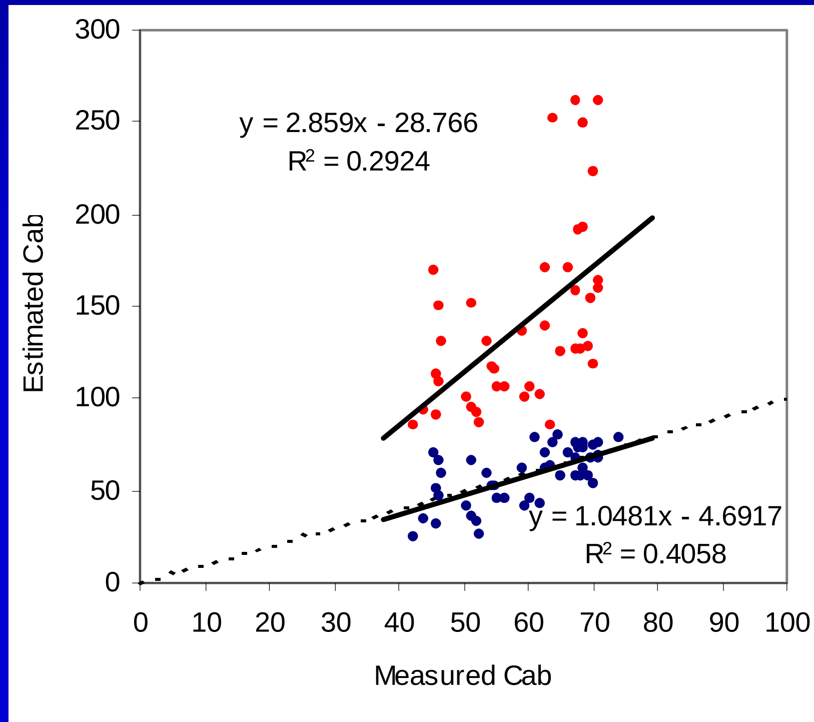


C_{ab} estimation from ROSIS crowns using MCARI/OSAVI prediction



Crowns
PROSPECT-SAILH

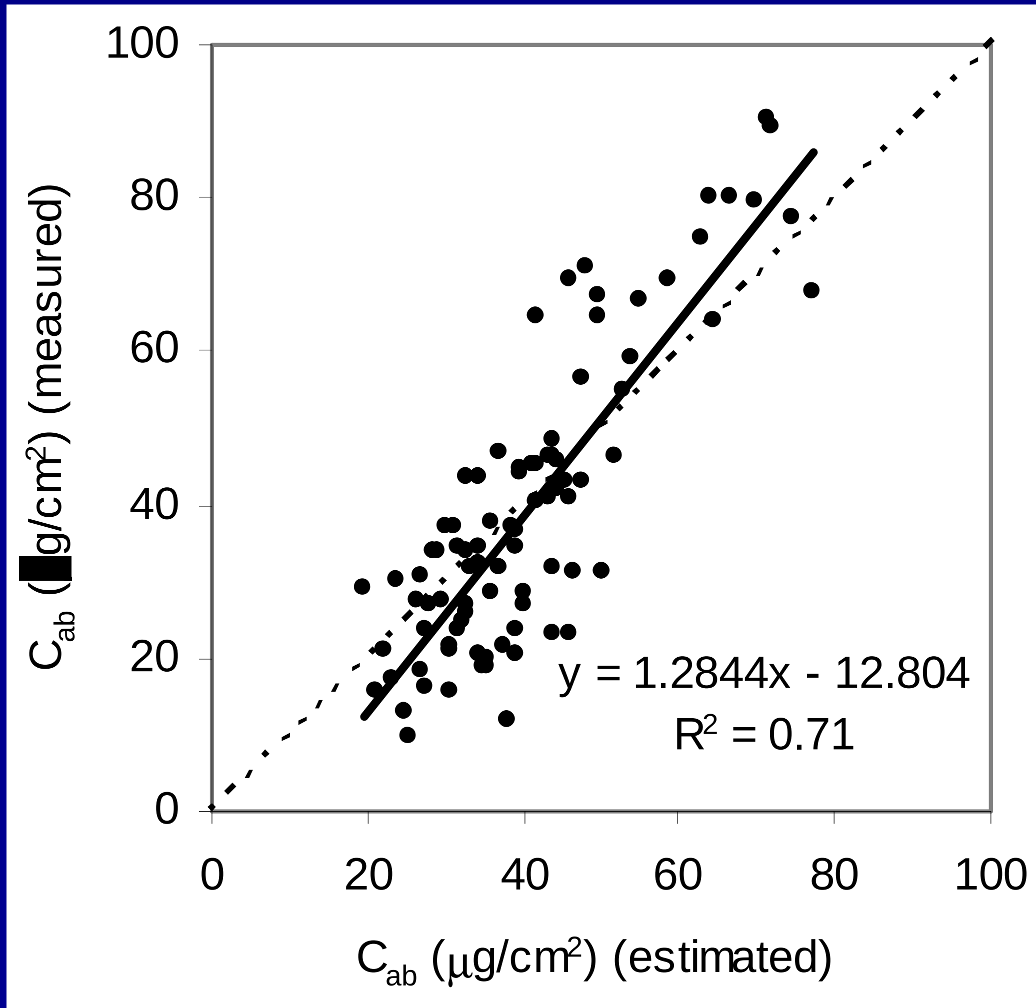
C_{ab} estimation from aggregated pixels (C+Sh+So) using MCARI/OSAVI



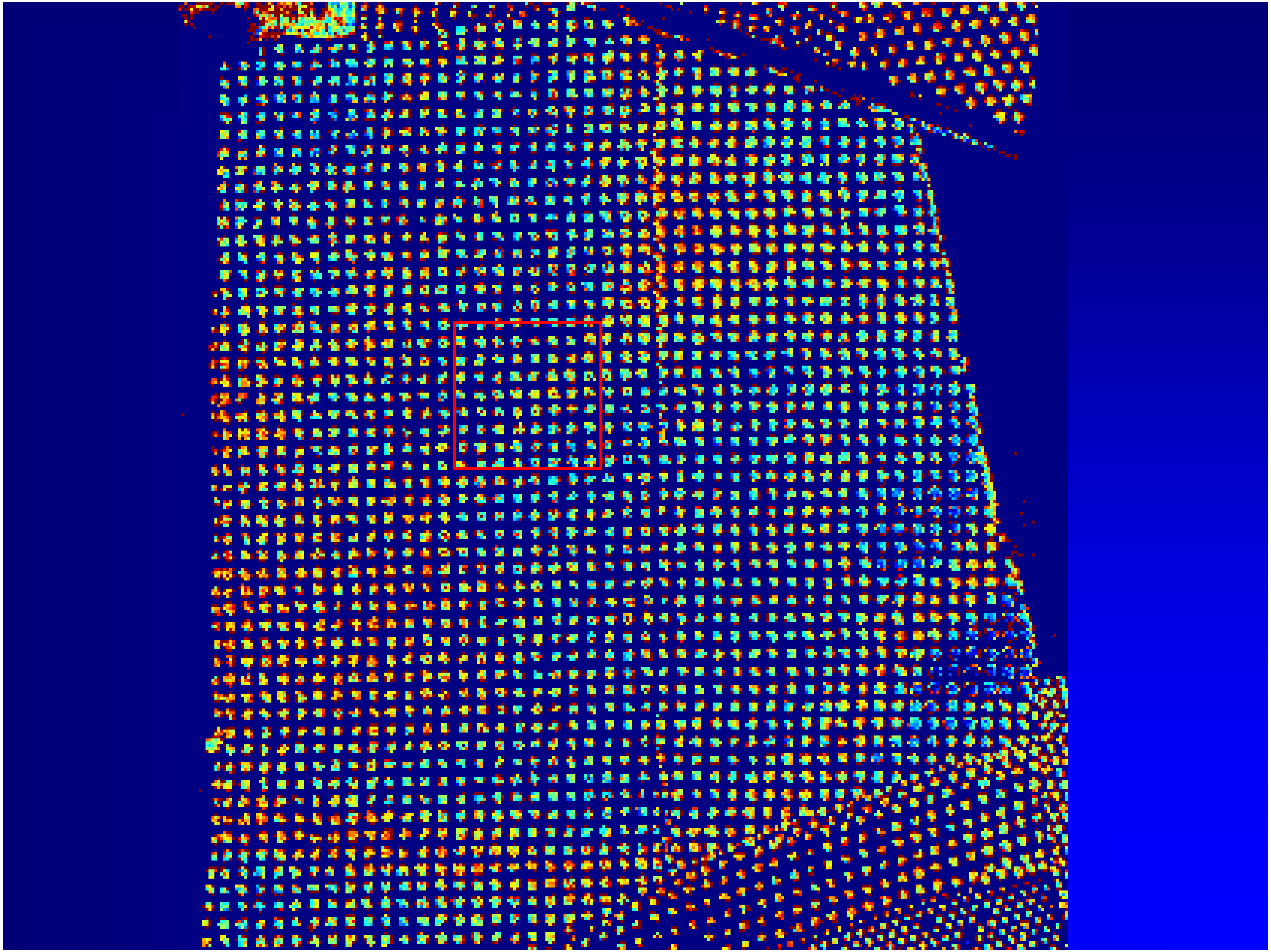
Crown+Shadow+Soil
PROSPECT-SAILH &
PROSPECT-SAILH-FLIM

Zarco-Tejada et al., 2004

Vineyard Canopies



C_{ab} estimation at canopy level by scaling up TCARI/OSAVI through PROSPECT + rowMCRM model



5. Conclusions

1. Leaf-level studies are required to identify indices related to variable of interest. Protocols for measuring leaf ρ & τ are developed

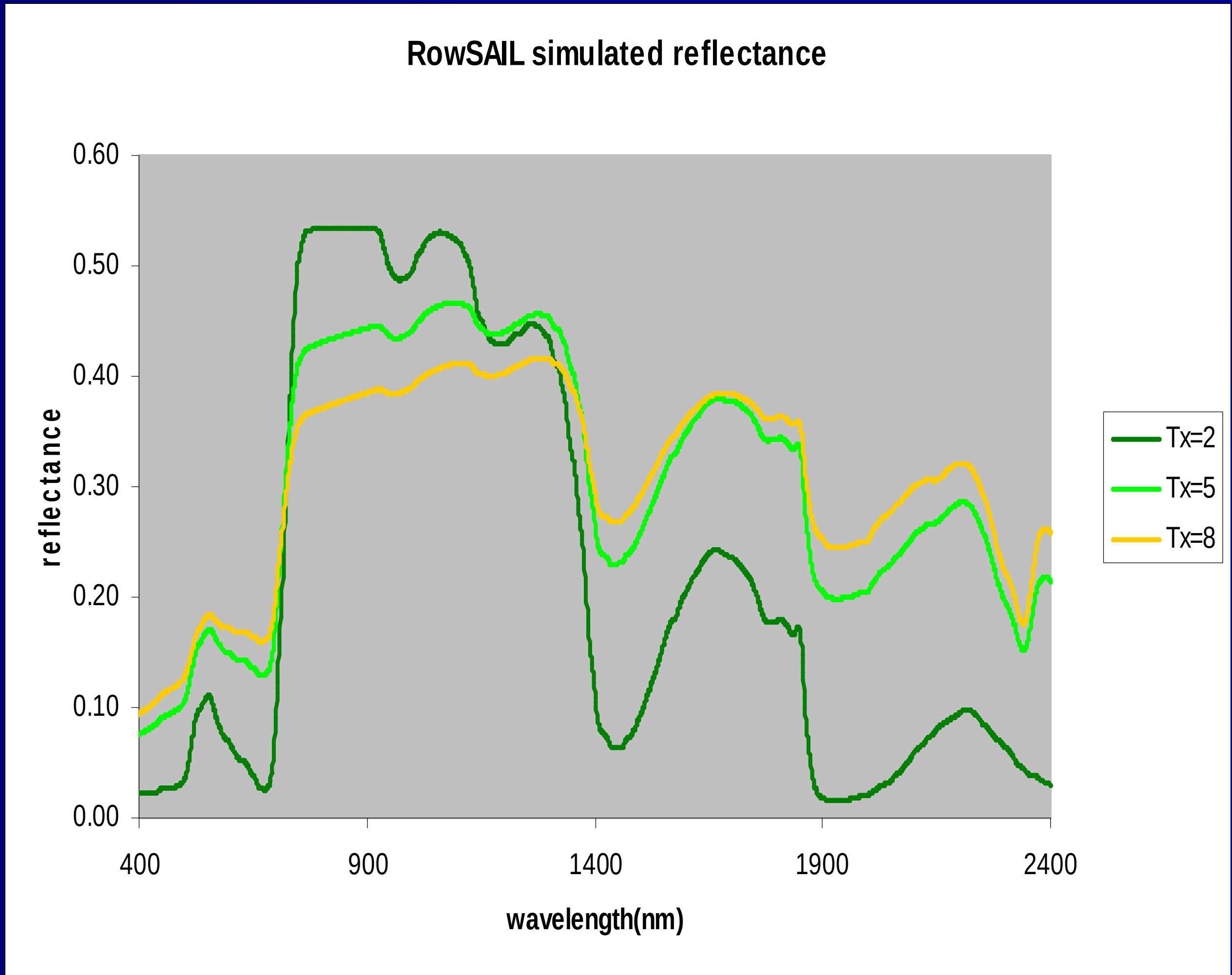
2. Successful *scaling up* of indices from leaf to canopy requires physical methods to account for the canopy structure

3. We present a simulation method for *scaling up* combined indices MCARI/OSAVI for orchard and row-structured canopies:
   - PROSPECT-SAILH when targeting crowns
   - PROSPECT-SAILH-FLIM in aggregated pixels
   - PROSPECT-rowMCRM in row-structured crops

4. Successful estimation of C_{ab} in open canopies and row structured crops (olive groves and vineyards)

   ⇒ RMSE ~ 10 $\mu g/cm^2$

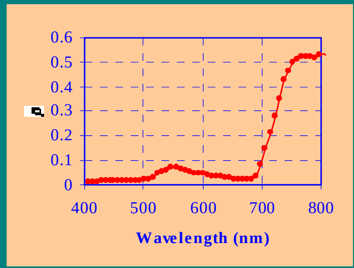
Ejemplo de simulación RowSAIL de la reflectancia en vid para distintos marcos



LAI=2.5; H=2.7m ; dxv= 2 m; Ts=45º ; To=0º; psi=90º

Tx=2
Tx=5
Tx=8

Imagen



Reflectancia de Cubierta

Imagen del Sensor

I

Relaciones Stadísticas

- Variables medidas
- Reflectancia de cubierta

(Johnson *et al*., 1994; Matson *et al*., 1994)

II

Relaciones Stadísticas

- Índices ópticos y var.
- Reflectancia de cubierta

(Peterson *et al*., 1988; Yoder *et al*., 1995); Zagolsky *et al*., 1996)

III

Relaciones Físicas de *Scaling up* RT

- Indices calculados a partir de modelos físicos CR

(Zarco-Tejada *et al*., 1999a, 2000a, 2000b;2003;2004)

IV

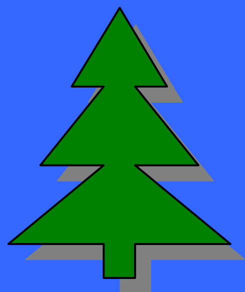
Inversiones de Modelos Físicos

- Modelos RT
- Funciones de mérito

(Jacquemoud *et al*., Kuusk; Demarez, Weiss, Zarco-Tejada *et al*.)

Datos de Campo

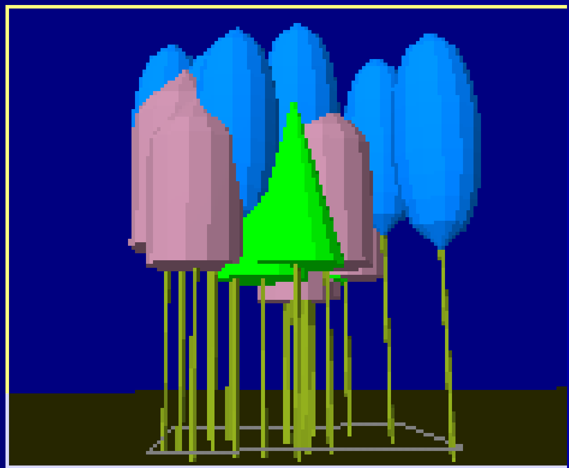
C_{ab}



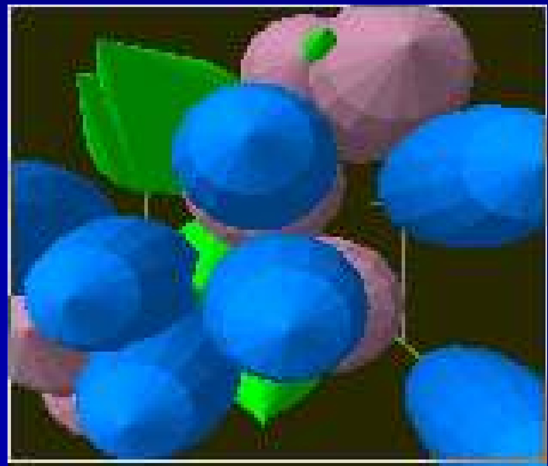
PLAI

Cab
PLAI
% Cob

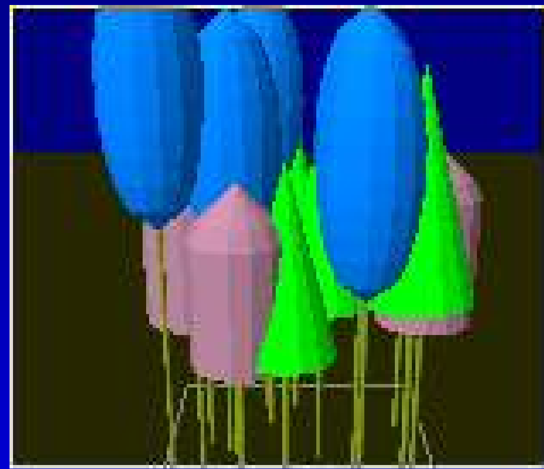
3-D Canopy Model Simulation with SPRINT



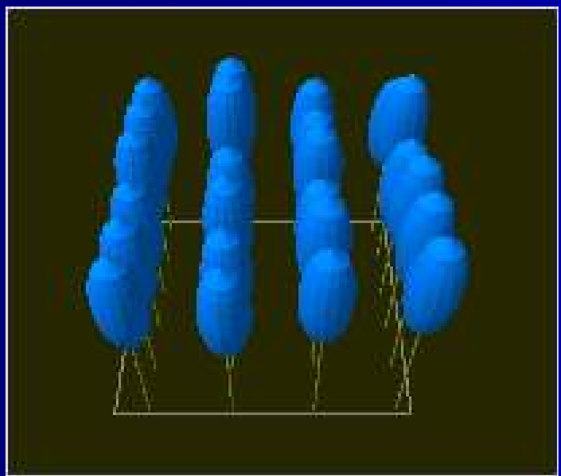
(a)



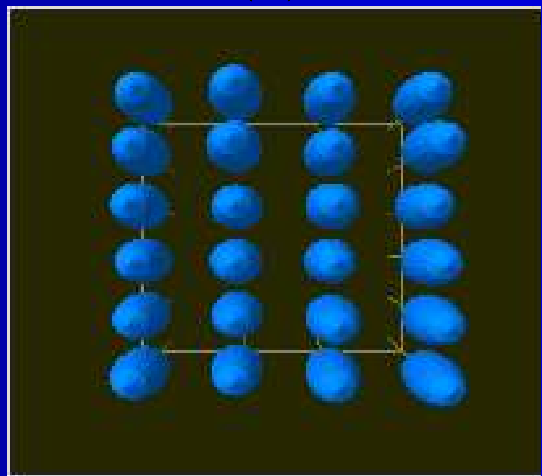
(b)



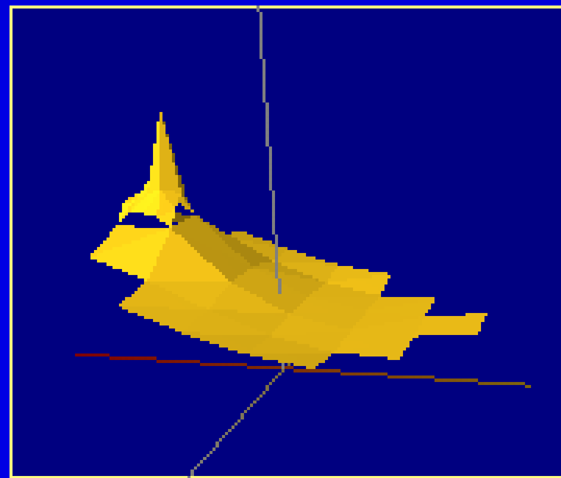
(c)



(d)

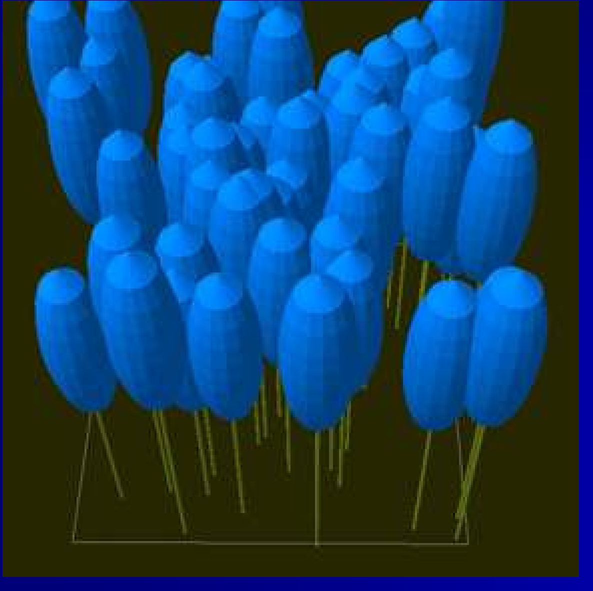


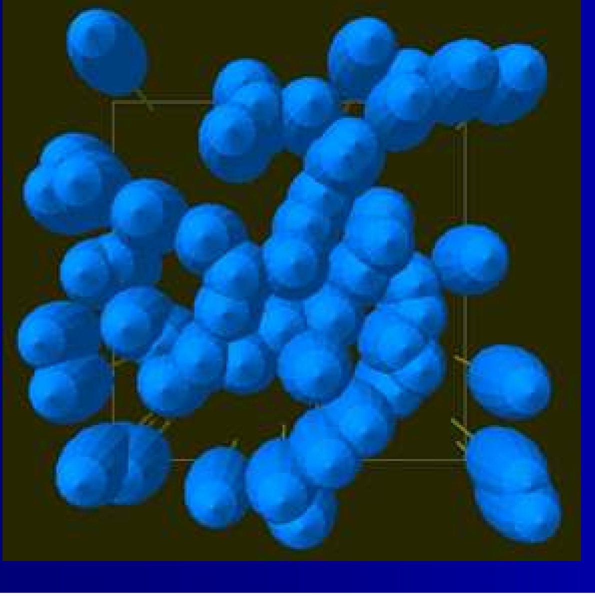
(e)



(f)

Canopy Simulation using SPRINT RT model (Goel & Thompson, 2000)

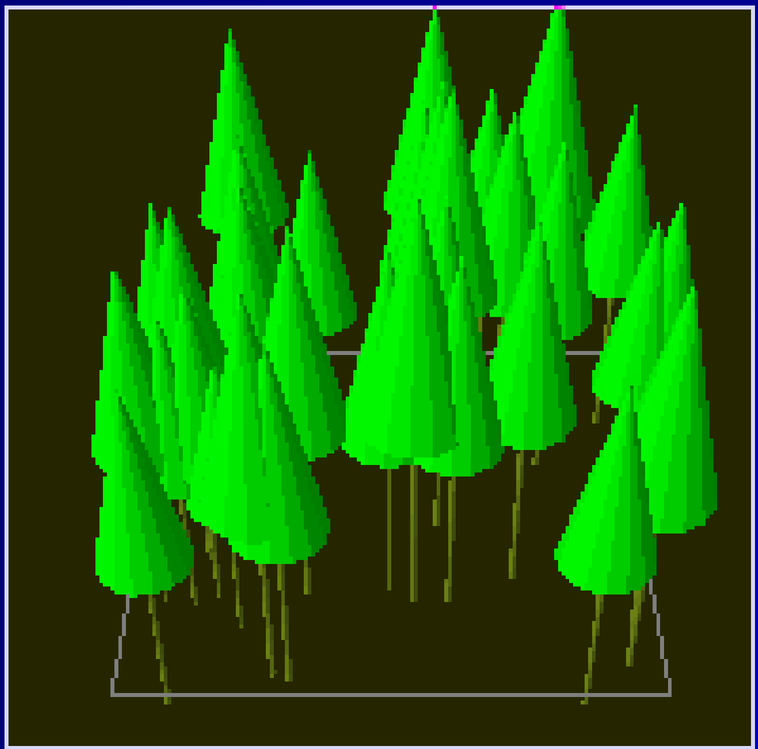
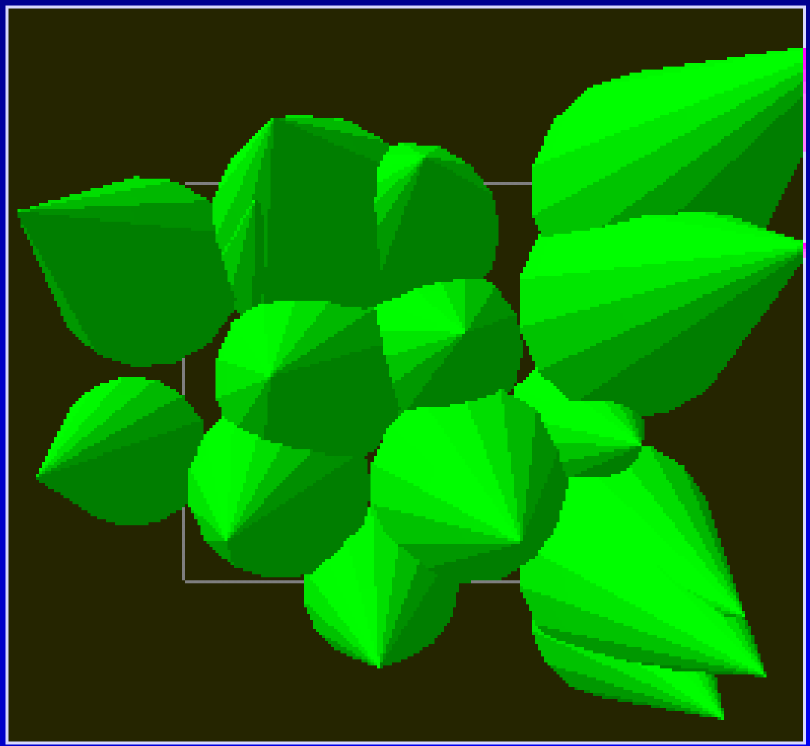




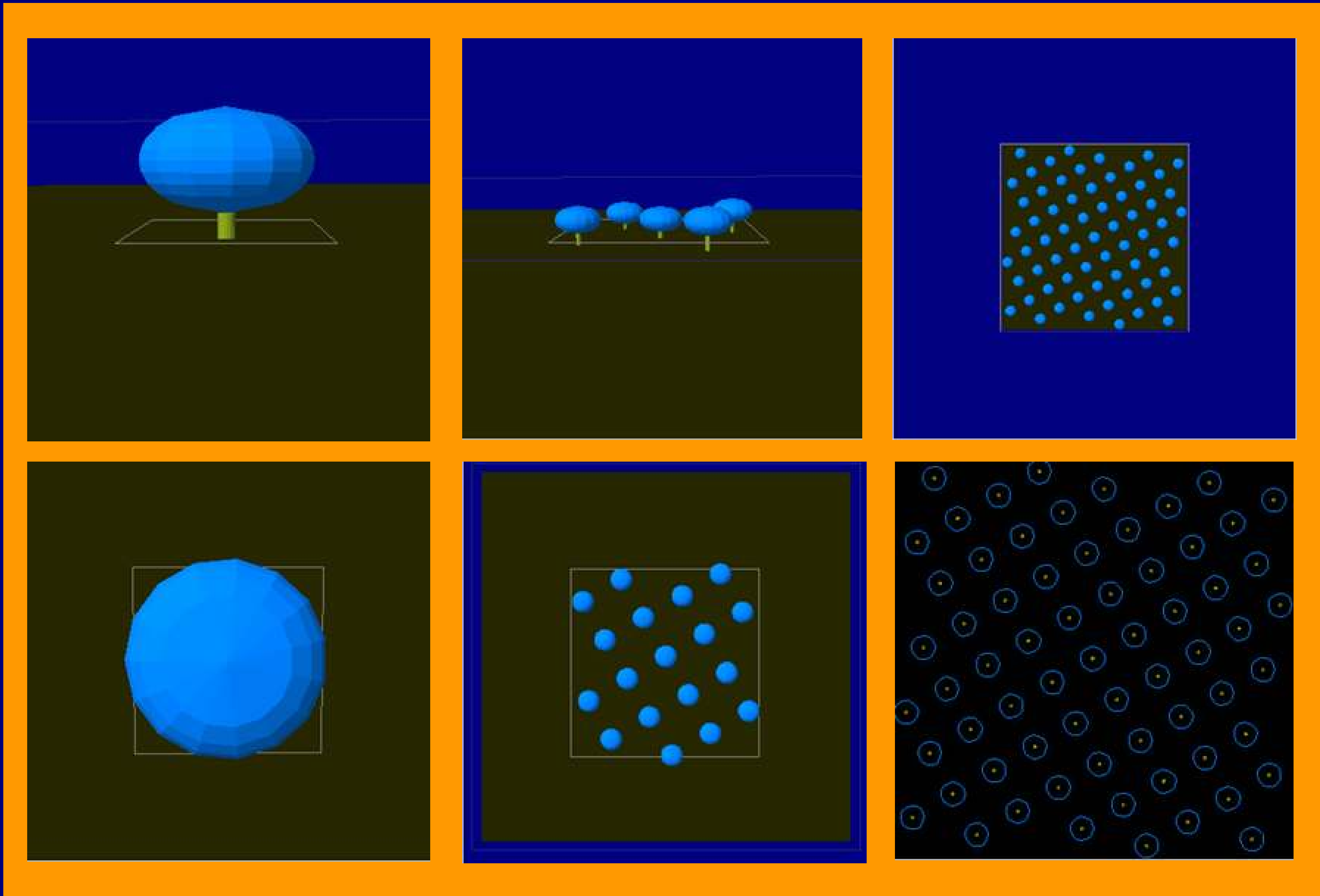
Canopy structural parameters	Nominal Values
Tree density	1100 /ha
Distribution of trees	Poisson distribution
Crown shape	Irregular conical (assumed ellipsoidal)
Height of trunk	8.5 m
Height of tree	15.0 m
Trunk radius	8.3 cm
Crown radius	2.0 m
Leaf angle distribution	Assumed spherical
Shoot area	0.0008 m^2
Canopy effective LAI	2.5
Leaf area density	0.4171 /m

Leaf and shoot structural parameters	Nominal values and range
Leaf thickness	0.062 cm (0.057 – 0.076)
Specific Leaf Area (fresh leaves)	20.9 cm^2/g (17.9 – 23.7)
Specific Leaf Area (dry weight) SLA	48.1 cm^2/g (37.7 – 58.6)

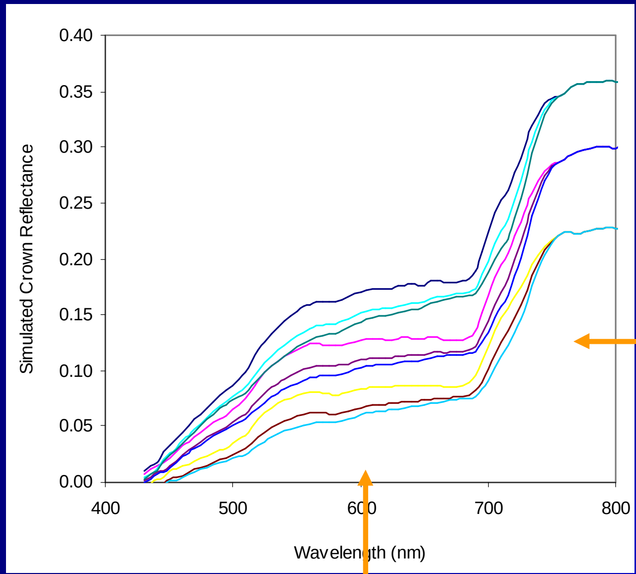
Leaf biochemical parameters	Range of values
Chlorophyll *a*	1,037 to 2,715 $\mu g.g^{-1}$
Chlorophyll *b*	274 to 997 $\mu g.g^{-1}$
Chlorophyll *a* + *b*	1,286 to 3,588 $\mu g.g^{-1}$
Carotenoids	243 to 611 $\mu g.g^{-1}$
Water (% of dry mass)	97.3 to 179.3 (values expressed per DW, usually expressed per total Fresh weight)

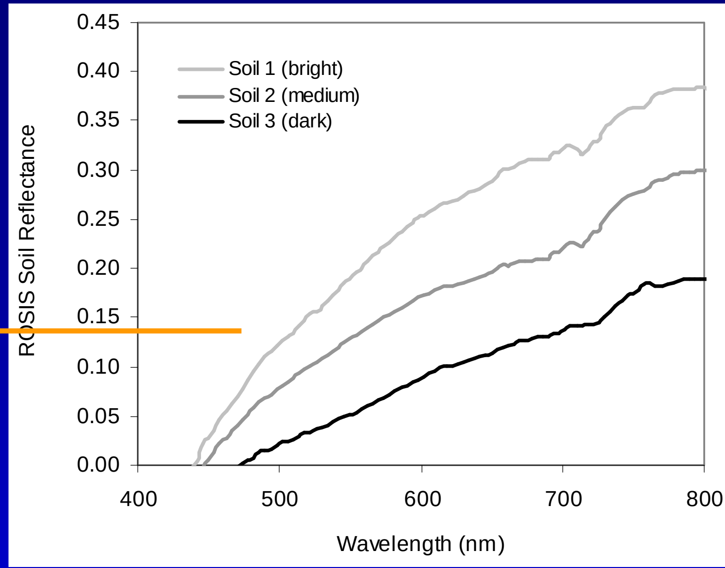
3-D Canopy Simulation using the SPRINT Radiative Transfer model for Olive Tree canopies



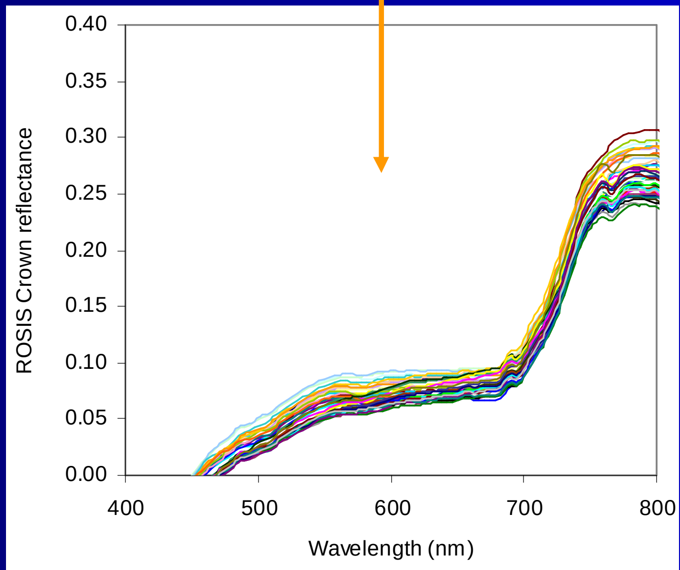
Simulated Crown Reflectance (PROSPECT-SAILH) with 3 soil spectra



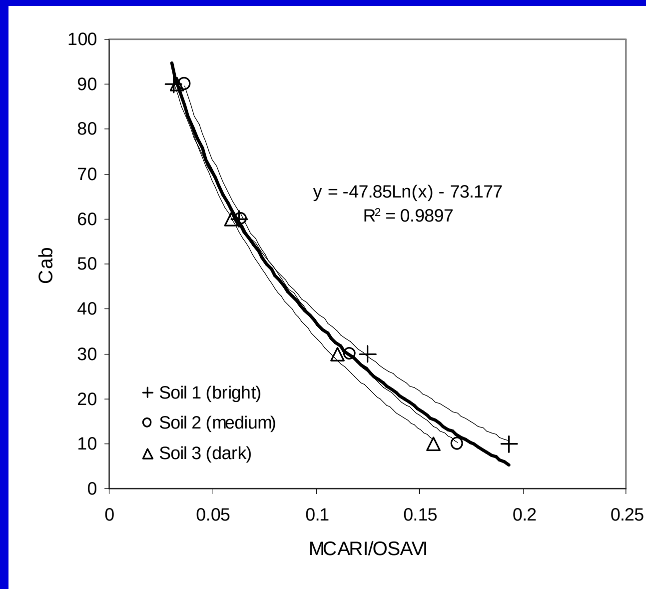
ROSIS Extreme Soil Reflectance from sites



ROSIS Crown Reflectance for all trees



Predicting relationship for MCARI/OSAVI for all soils and LAI=0.5



Relationships between crown LAI and indices for Olive trees