Using UAV & S2 reflectance and vegetation index for calibrating realistic 3D models of maize fields with DART and simulating their radiative budget

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Abstract

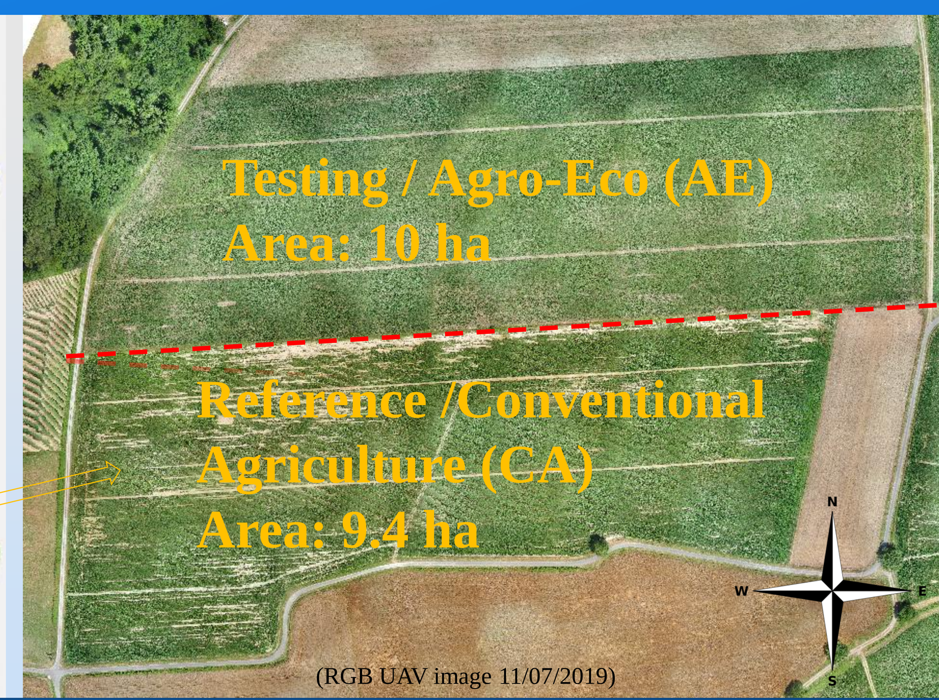
How does the type of maize cultivation (agro-ecological and conventional) influence the Radiative Budget of plants (RB_{plant}) and ground (RB_{ground}), especially in the APAR (Absorbed Photosynthetically Active Radiation) domain?

We assess this influence with the 3D radiative budget of the DART model for 2 maize fields each with specific type of cultivation, 3D architecture and optical properties. The LAI of the fields was not accurately defined by the SNAP code applied to Sentinel 2 (S2). Therefore, we derived from a new method that uses DART, and UAV (Δr=11cm) or S2 (Δr=10m) images.

Our study highlights:

- The conventional field has a larger $APAR_{ground}$ than the agro-eco field with its crop residues
- The agro-eco field has a larger albedo than the conventional field
- The plant architectures of the two fields (interplant and inter-rows) greatly influence RB_{plant}
- The soil optical property, LAI and plant architecture greatly influence the APAR of the fields

Site description



Southwest, France (43°41'N; 0°28'E)

Climate: temperate climate, 1110 mm of cumulative precipitation in 2019, average July temperature > 22 ° C.

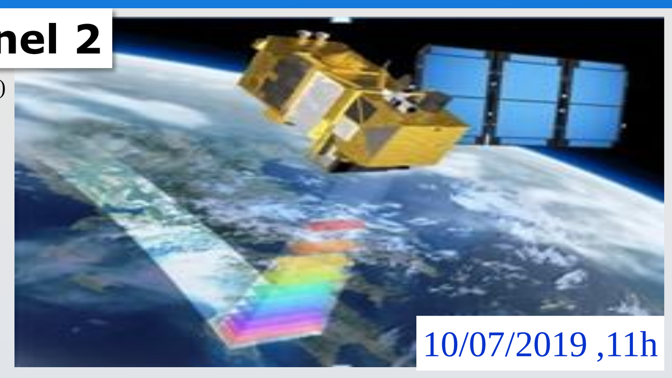
Two types of cultivation with same plant density per hectare (90 000 pl/ha):

- Agro-ecology (no-till, intermediate crops, crop residue,...)
- Conventional

This site (Estampes, Gers) participates to the TRISHNA CAL/VAL, and is part of the CESBIO's Regional Space Observatory

Data and method used

Sentinel 2



Spatial resolution	Satelite Sentinel-2B		Sensor
	Wavelength	Bandwidth	
10 m	492.1 nm	98 nm	MSI
	559 nm	46 nm	
	665 nm	39 nm	
	833 nm	133 nm	

The Sentinel Application Platform (SNAP) is a common architecture for all Sentinel Toolboxes. It is developed by Brockmann Consult, Skywatch, Sensar and C-S.

UAV

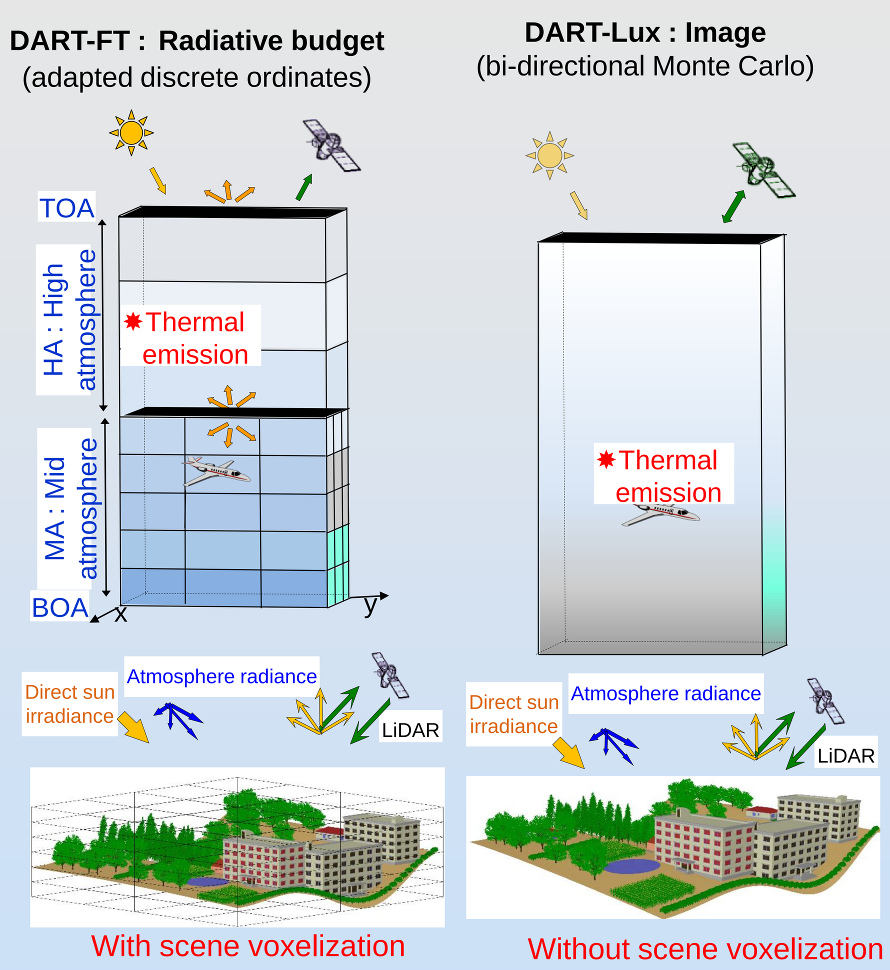
Spatial resolution	UAV Ebee		Sensor
	Wavelength	Bandwidth	
≈11 cm	550 nm	40 nm	Multi Spec 4 C
	660 nm	40 nm	
	735 nm	10 nm	
	790 nm	40 nm	

Our work is a continuation of the BAG'AGES project (2016-2021, Adour-Garonne Water Agency) to study agro-ecology (no-till, residues,..), water balance and local determinants (morphology, hydrology, soil properties …), and also to evaluate the effects of its determinants. We used:

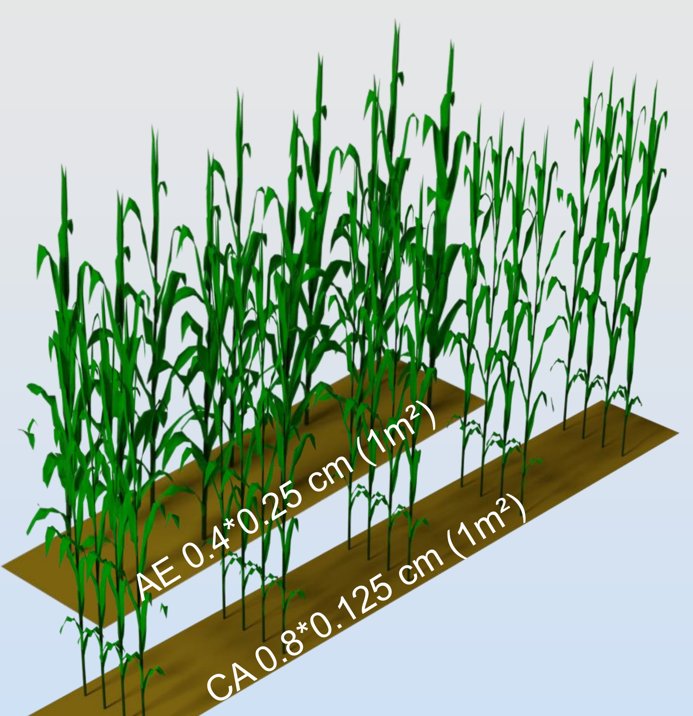
- Remote sensing images at 1 day interval: 2019/07/10 at 11am for Sentinel 2 (S2) and 2019/07/11 at 2pm for UAV (VIS NIR, TIR). UAV was used to create soil and vegetation classification masks (RGB, resolution: 3 cm)
- In situ data: 4 radiative fluxes (short and long waves, upward and downward), images of a TIR camera at 7m height, soil / plant optical properties (OP_{soil}, OP_{plant}) from ASD spectroradiometer, T°& RH micro-sensors (ibuttons inside canopy and soil surface)
- The DART model: simulation of in-situ radiative fluxes, and 3D radiative budget and images of the fields

DART (Discrete Anisotropic Radiative Transfer Model)

- Developed at CESBIO since 1992 (patented in 2003).
- One of the most complete 3D radiative transfer models to simulate the radiative budget and remote sensing observations (VIS / TIR spectro-radiometer, LiDAR, SIF) of natural and urban surfaces.
- It contains the PROSPECT/FLUSPECT plant models and MARMIT soil model.
- Landscapes and atmosphere are voxelized (DART-FT) or not (DART-Lux).
- 3D scenes (maize field,…) are made of DART-created and imported scene elements (maize plant,…).



Mock-up DART



The AE and CA maize fields are simulated as an infinite repetition of a pattern of 10 plants with specific 3D architecture (plant geometry, LAI, inter-row, inter-plant, row orientation).

The optical properties (soil, stem, plant) are derived from in-situ, UAV and satellite data.

The time variation of spectral direct $E_{BOA,dir}(t,\lambda)$ / diffuse $E_{BOA,diff}(t,\lambda)$ irradiance were derived from a DART-based inversion method applied to local BOA shortwave direct $E_{BOA,dir}(t)$ + diffuse $E_{BOA,diff}(t)$ irradiance.

DART simulated S2 and UAV images according to their observation configurations: spectral bands, and atmospheric conditions using the MidLatSum gas model and the Rural23 aerosol model

LAI adjustment strategy

Measurement: ⓪ UAV Median Reflectance: MR_{UAV} (Green, Red, Nir)

Measurement: ⓪ UAV Median Vegetation Index: MVI_{UAV} (NDVI, MTVI2)

① LAI SNAP + All measured (OP_{soil}, OP_{plant}) ⇒ MR_{DART} and MVI_{DART}

SIMULATION

② Adjusted DART LAI_1 for $MR_{DART} = MR_{UAV}$

③ Adjusted DART LAI_2 for $MVI_{DART} = MVI_{UAV}$

④ Find pair of (OP_{soil}, Op_{plant}) with $| LAI_1 – LAI_2 | = min$; $LAI = mean (LAI_1 ;LAI_2)$

⑤ Validation: comparison of UAV and DART reflectance of pure vegetation & soil (3 bands,11 cm)

⓿ Compute Median Reflectance MR_{UAV} and Median Vegetation Index MVI_{UAV} of UAV image

❶ Choice of OP_{soil} and OP_{plant} spectra (in-situ data)

❷ Find LAI_1 such that $MR_{DART}=MR_{UAV}$ (11cm)

❸ Find LAI_2 such that $MVI_{DART}=MVI_{UAV}$ (10 m).

❹ Select (OP_{soil}, OP_{plant}) from ❶, ❷ and ❸ that gives the minimal value of $|LAI_1\text{-}LAI_2|$.

❺ Validation: compare UAV & DART reflectance of pure soil and vegetation (from RGB classification masks)

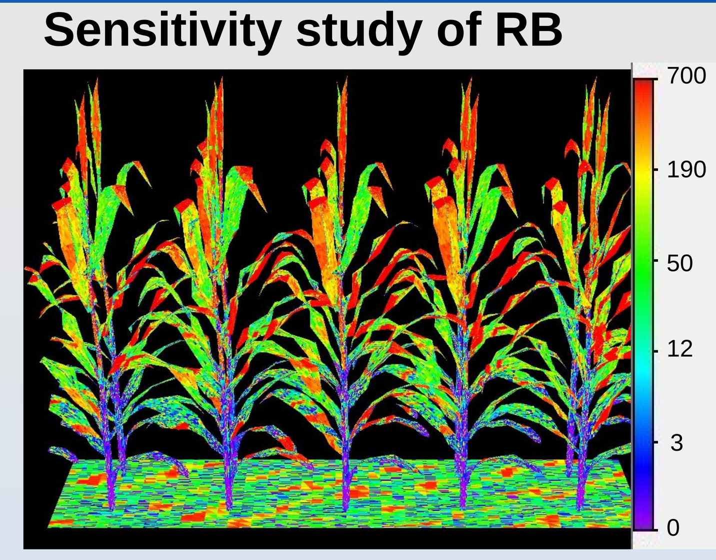
The method can also be used with S2 (without step ❺, Mock-up considerate at 10 m)

☞ Better LAI from UAV & S2 than from S2 SNAP:

- S2 SNAP: LAI_{AE}= 1.90 and LAI_{CA} = 1.70
- S2 data: LAI_{AE}= 3.17 and LAI_{CA} = 2.84
- UAV data: LAI_{AE}= 3.52 and LAI_{CA} = 3.24

LAI S2 and LAI UAV ≠ LAI SNAP and agreed with *Jiang et al., 2022*

Sensitivity study of RB



3D radiative budget PAR agro-eco field band 1 (W/m²/µm)

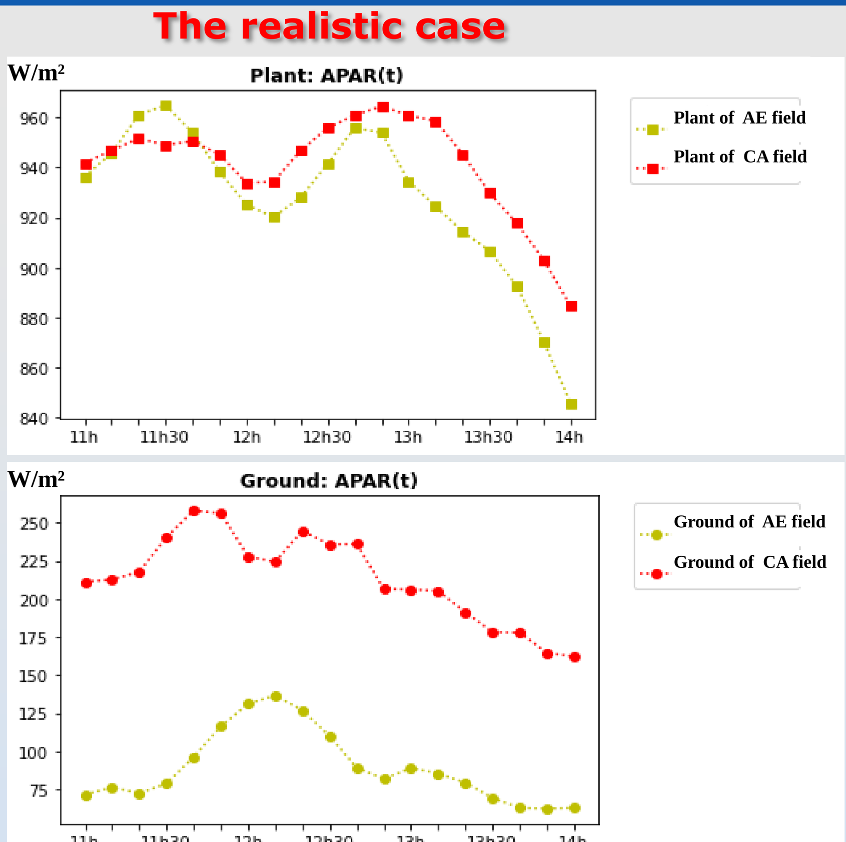
Time series {$RB_{plant}(t)$, $RB_{ground}(t)$} from 11am to 2pm (Δt=10') in PAR (8 bands) function of:

- 3D geometry: LAI, plant mock-up, plant spacing and orientation
- Optical properties (soil, plant).

This work was carried out with 3D mock-ups to take into account clumping effects (*Duthoit et al., 2008*) shading and geometry of plants.

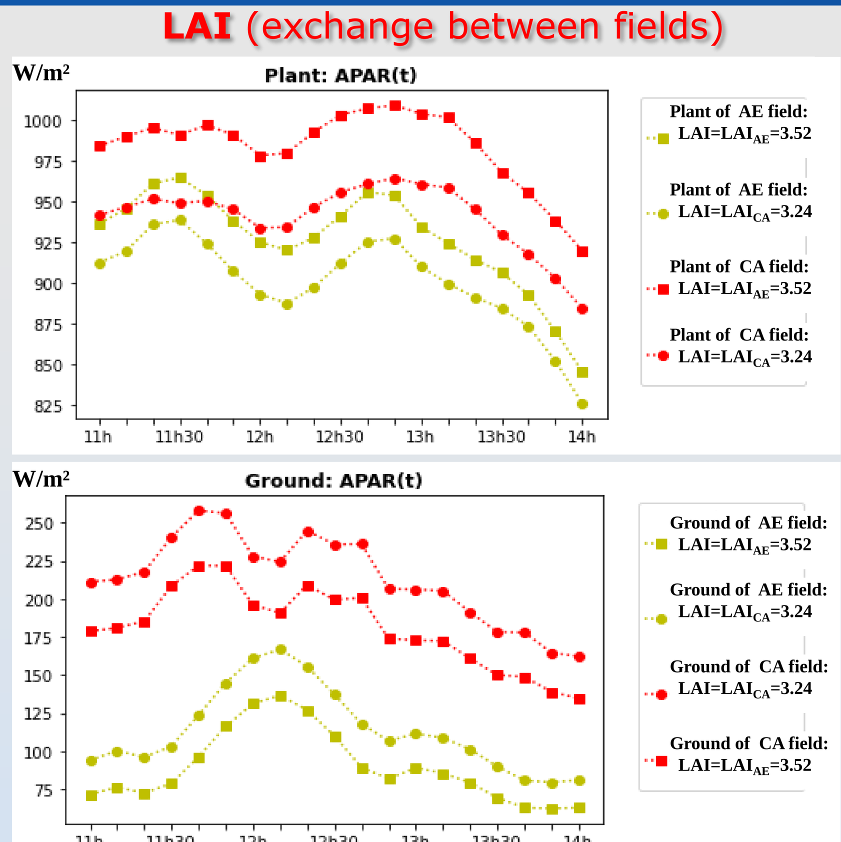
Sensitivity analysis on $APAR_{plant}$ and $APAR_{ground}$: realistic case, variable LAI, field architecture and OP_{soil}

The realistic case



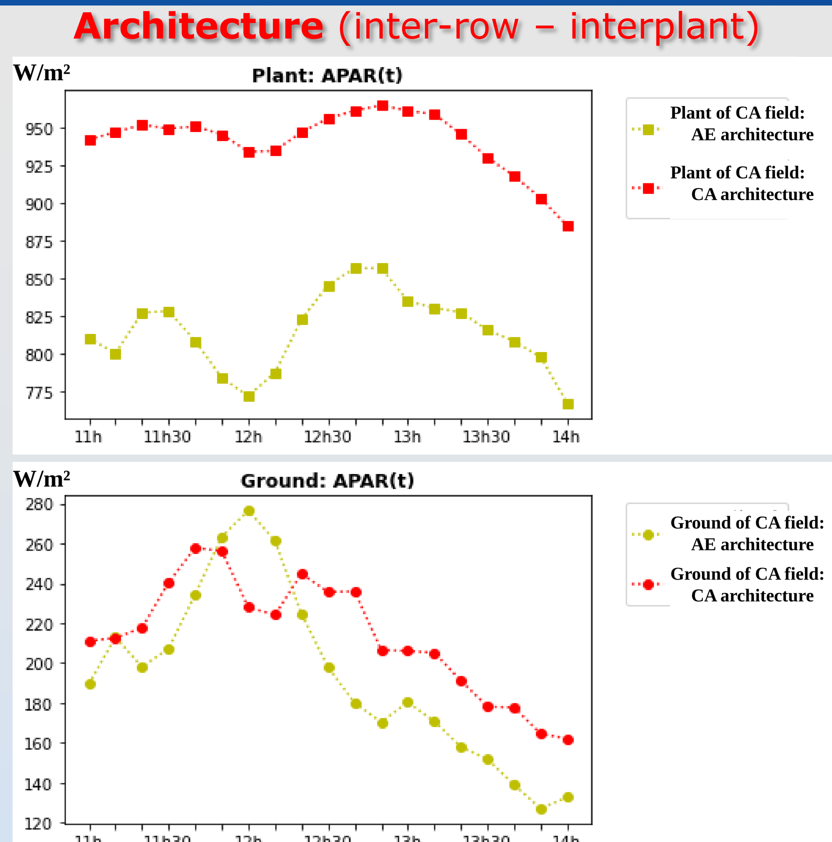
AE $APAR_{plant}$ ≈ CA $APAR_{plant}$ and Mean Difference on the three Hours (MDH) ≈ 14 W/m².
CA $APAR_{ground}$ >> AE $APAR_{ground}$ with a MDH of 124 W/m². AE scattered more to the atmosphere. This study explains the "CA-"AE" difference and quantifies the influence of each parameter.

LAI (exchange between fields)



$APAR_{plant}$ ↗ and $APAR_{ground}$ ↘ if LAI ↗.
Here: LAI_{AE} > LAI_{CA} ⇒ difference "AE - CA" smaller for $APAR_{plant}$ and larger for $APAR_{ground}$.
If LAI_{AE} = LAI_{CA}: MDH of $APAR_{ground}$ = 92 W/m² instead of 124 W/m². The difference of LAI contributes but cannot explain alone the differences on $APAR_{ground}$ for the real case.

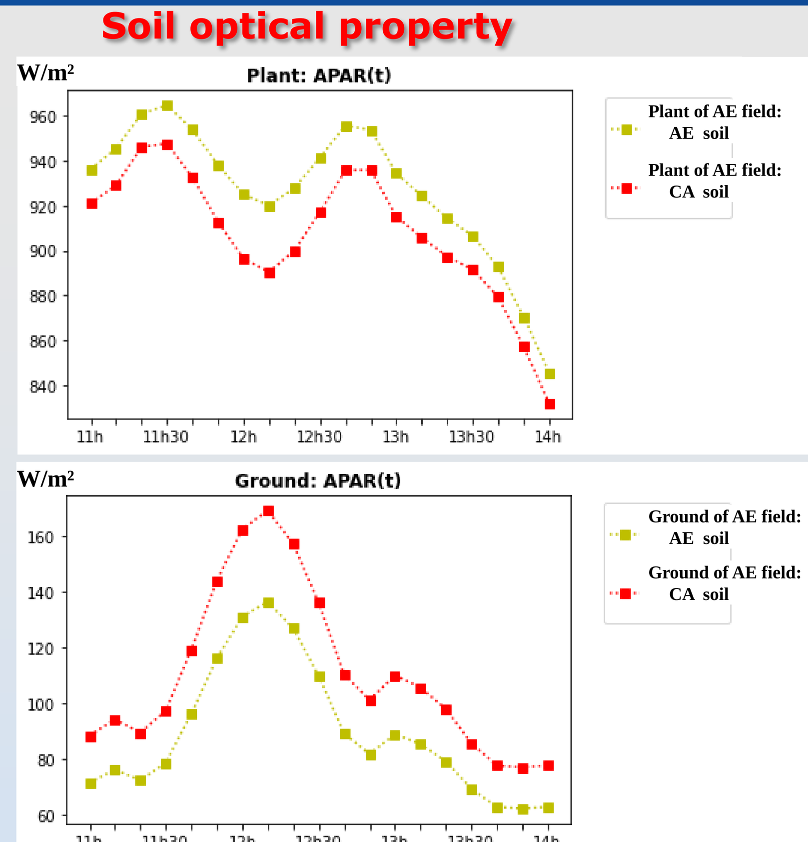
Architecture (inter-row – interplant)



The architecture of the field with CA :

- Greatly increases $APAR_{plant}$ (MDH=126-147 W/m²)
- Slightly increases $APAR_{ground}$ (MDH=20 W/m²).

Soil optical property



Tilled soil (CA) ⇒ higher $APAR_{ground}$ (MDH ∊ [20-35 W/m²])
Crop residue on soil (AE) ⇒ higher $APAR_{plant}$ (MDH ∊ [20-40 W/m²]).
OP_{soil} contributes to the difference on $APAR_{ground}$.

Conclusion: Field architecture, LAI and OP_{soil} greatly affect $APAR_{ground}$ and $APAR_{plant}$. For the CA and AE fields, $\Delta APAR_{ground}$ = 124 W/m². The only architectural difference implies $\Delta APAR_{plant}$ = 120-147 W/m². It could explain microclimatic differences in the CA and AE fields and the observed differences in local temperatures (https://backoffice.inviteo.com/upload/compte84/Base/inscriptions_projets/supplement20/2522-trishna_days_paul_boitard.pdf).