A method for plant leaf area measurement by using stereo vision

Vincent Leemans, Benjamin Dumont, Marie-France Destain, Françoise Vancutsem, Bernard Bodson

gembloux agro bio tech

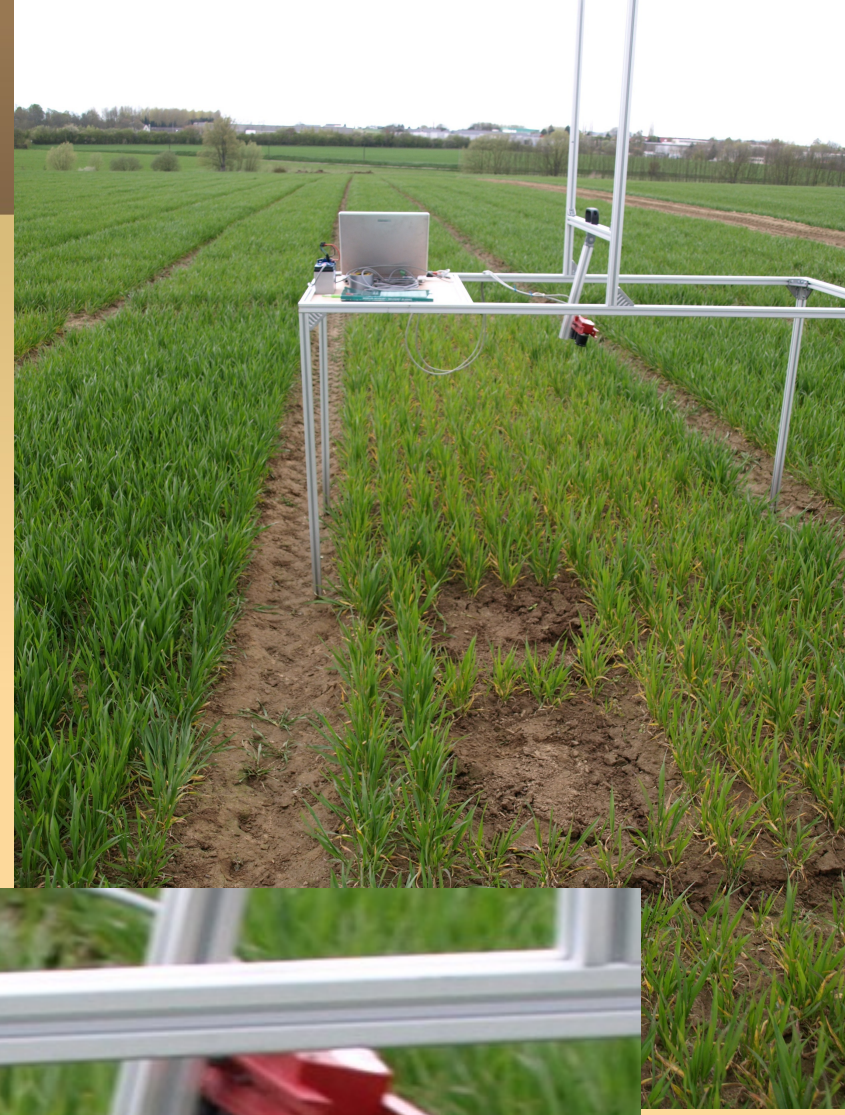
Université de Liège

Introduction

- Leaf Area Index (LAI) is an important measurement for agronomist and modellers
- Its measure is destructive, tedious and expensive

Material

- Stereo images acquisition :
  - Two cameras 1280 * 960 pix
  - Base distance : 120 mm
  - Distance camera-crop :+/- 700 mm
  - Focal length : 6 mm
  - Vergence : 8°
  - Disparity of 1 pixel ≈ Δz 2.5 mm

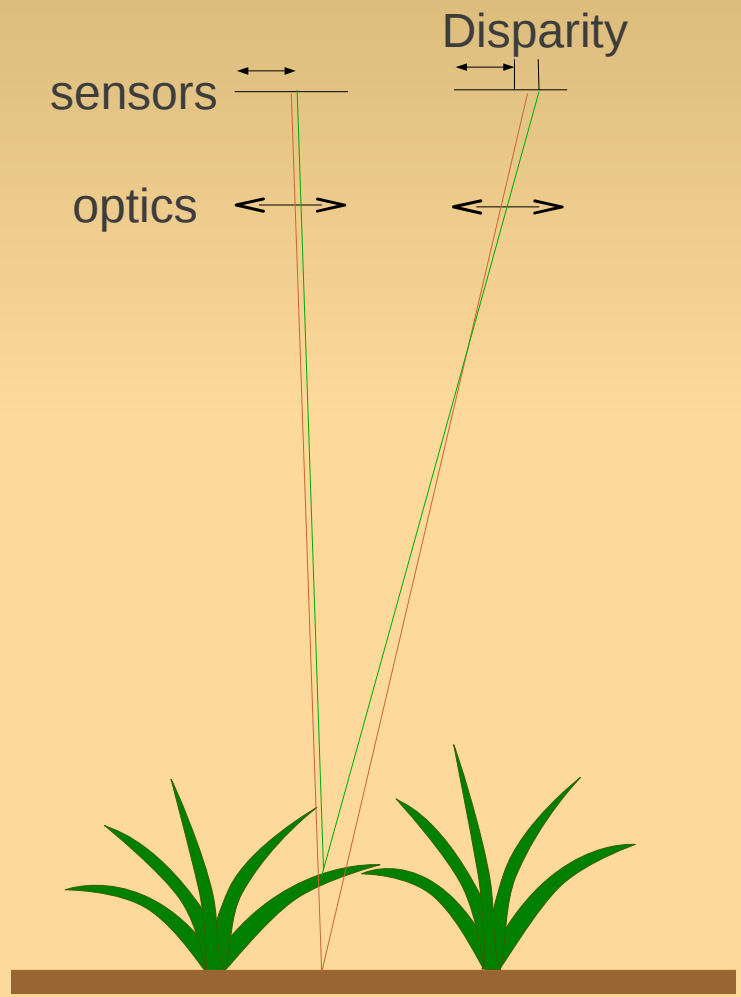


Experimental set-up

- Measurements were made on 16 plots
  - 2 N applications
  - 2 soils
  - 4 repetitions
- 3 dates (27th March, 23th April, 5th June)
- 5 stereo image couples per plots
- Destructive reference measures on 50 cm for each plot

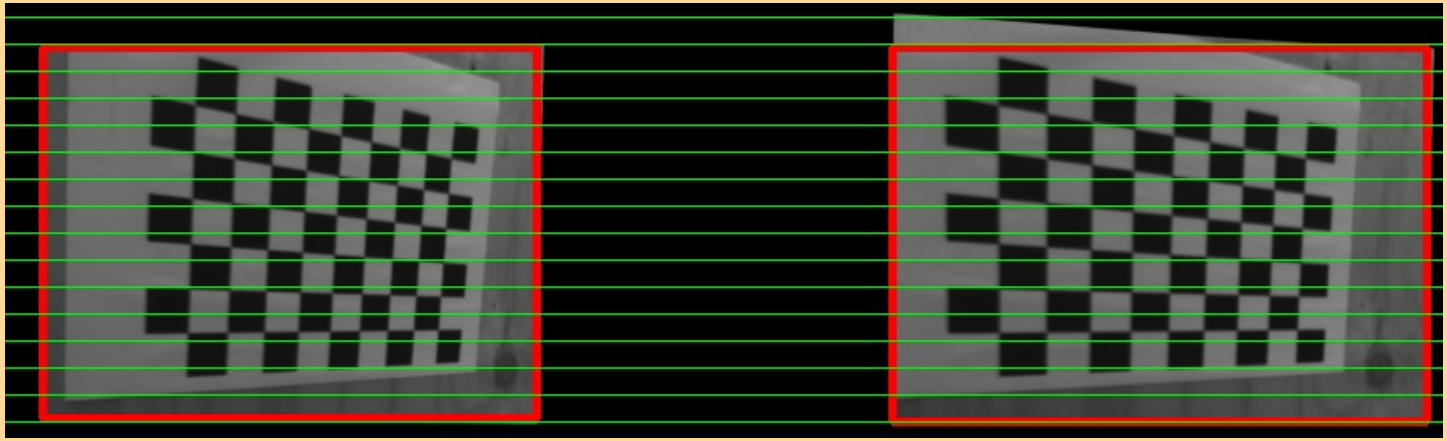
Method

- Principle



Method

- Algorithm
  - Image rectification *
    - To have the same points on the same lines on both images



* : OpenCV Libraries

Method

- Algorithm
  - Image rectification *
  - Estimate disparities *
    - “modified H. Hirschmuller algorithm”
    - For each pixel of the left image, research in the right image the best match of a block centred on the pixel
      → Block size, MinDisparity, DisparityRange

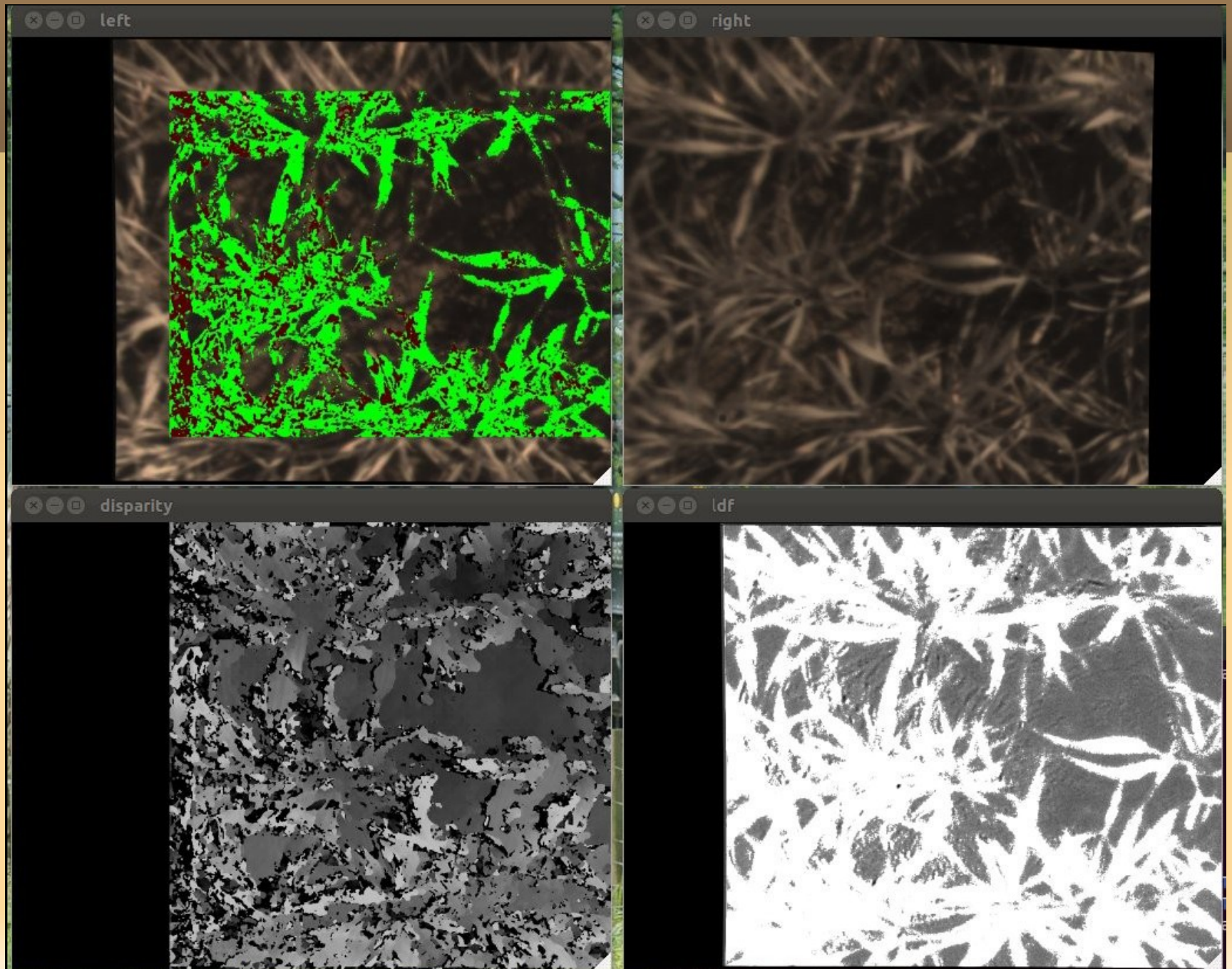
* : OpenCV Libraries

Method

- Algorithm
  - Image rectification *
  - Estimate disparities *
  - Post treatments *
    - Eliminate doubtful data and hidden pixels
    - Minimal values

    } Parameters
  - Compute xyz in ”human” coordinates *
    - $(xyd)_{pixels} \rightarrow (xyz)_{m}$
    - By using calibration (indoor, checkboard)

* : OpenCV Libraries


left
right
disparity
ldf

Method

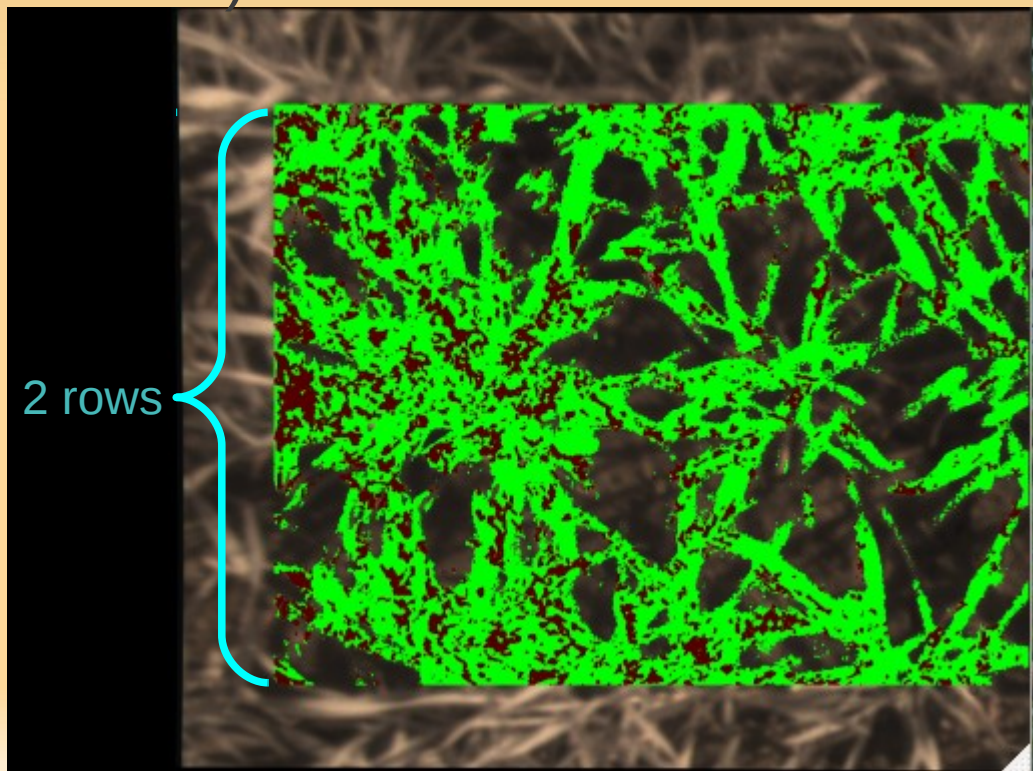
- Algorithm
  - Image rectification *
  - Estimate disparities *
  - Post treatments *
  - Compute xyz in ”human” coordinates *
  - Image segmentation (Leaves/Soil)
    - LDA on RGB

Threshold

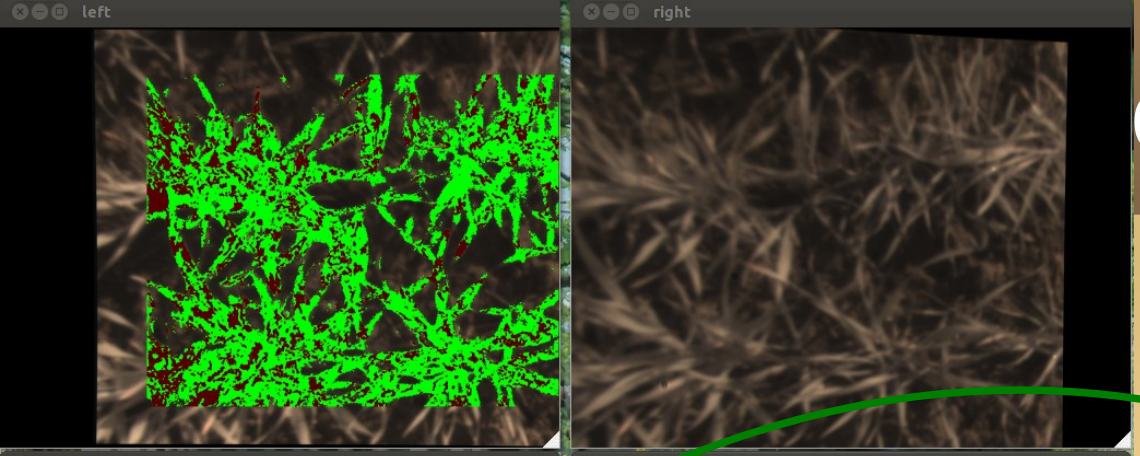
* : OpenCV Libraries

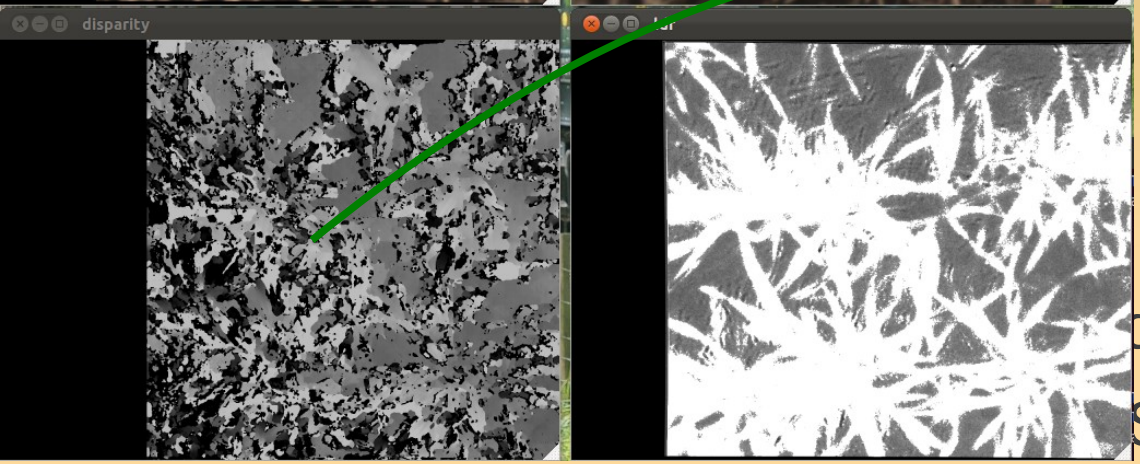
Method

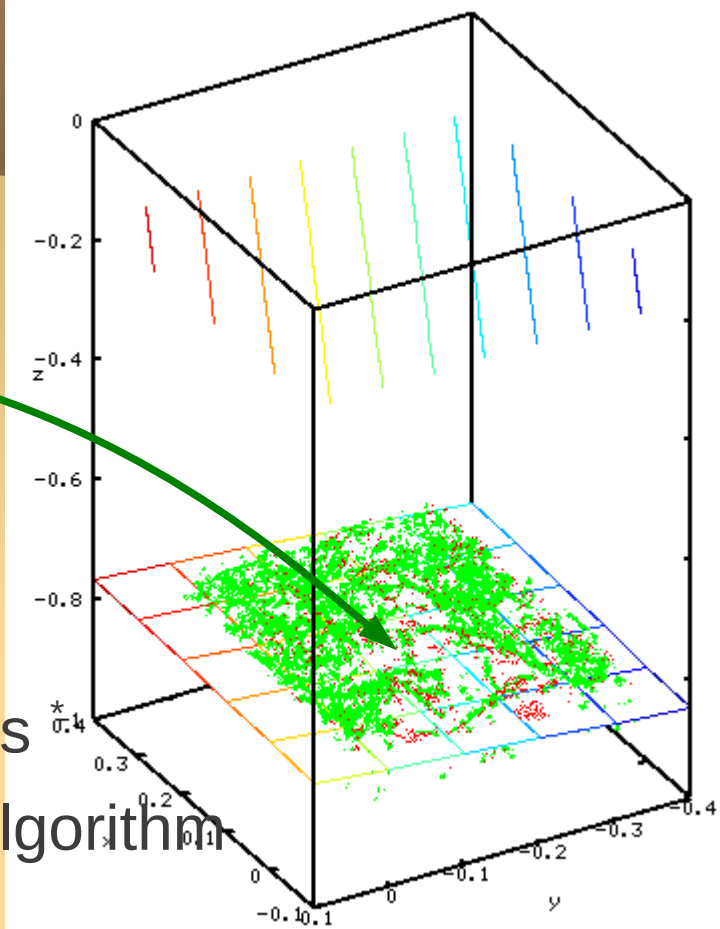
- Algorithm
  - ...
  - Image segmentation (Leaves/Soil)
  - Definition of the ROI



d



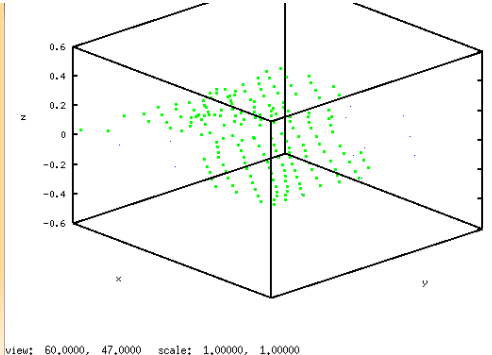




dinates

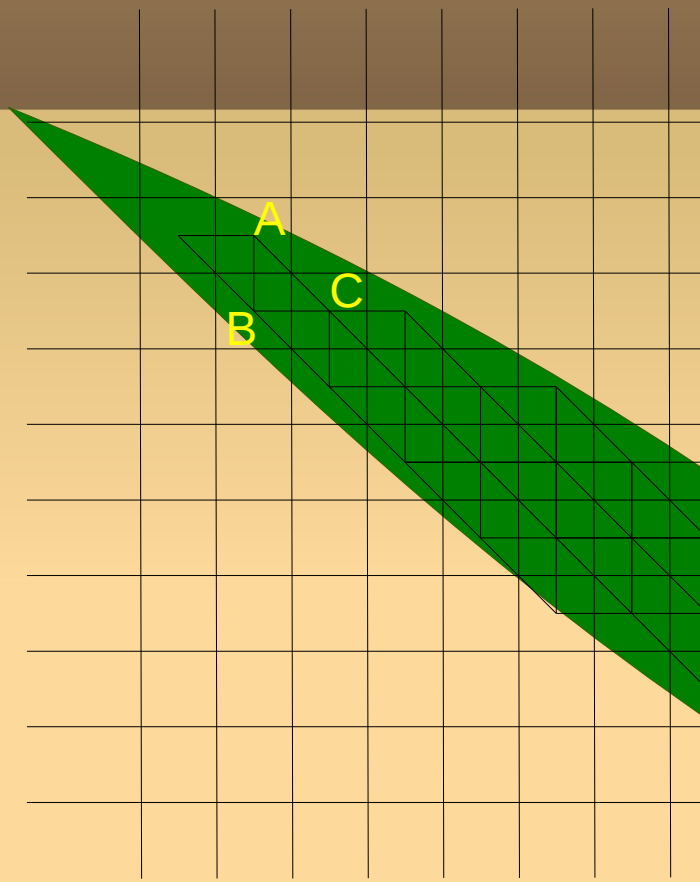
Soil)Algorithm

- Definition of the ROI



Method

- Algorithm
  - ...
  - Image segmentation (Leaves/Soil)
  - Definition of the ROI
  - Computation of the areas
    - Leaves $\sum_{Triangles} \left| \vec{AB} \times \vec{AC} \right| / 2$
    - Total : based on the mean leave z plane and on the ROI dimensions
  - LAI = Leave Area / Total Area

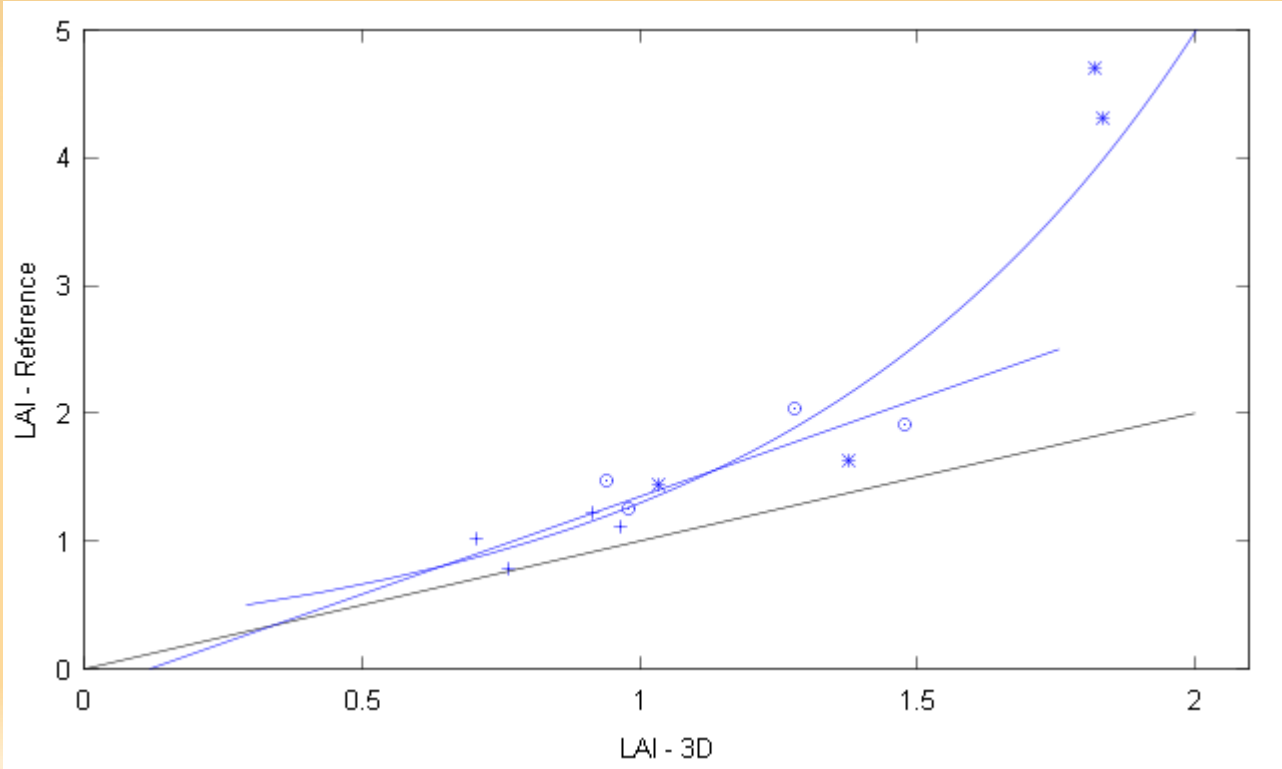


Results

- Sensitivity analysis of LAI *vs* parameters
  - Not sensible to the 3D algorithm parameters
  - Sensible to the threshold
    - Determined based on visual inspection

Results

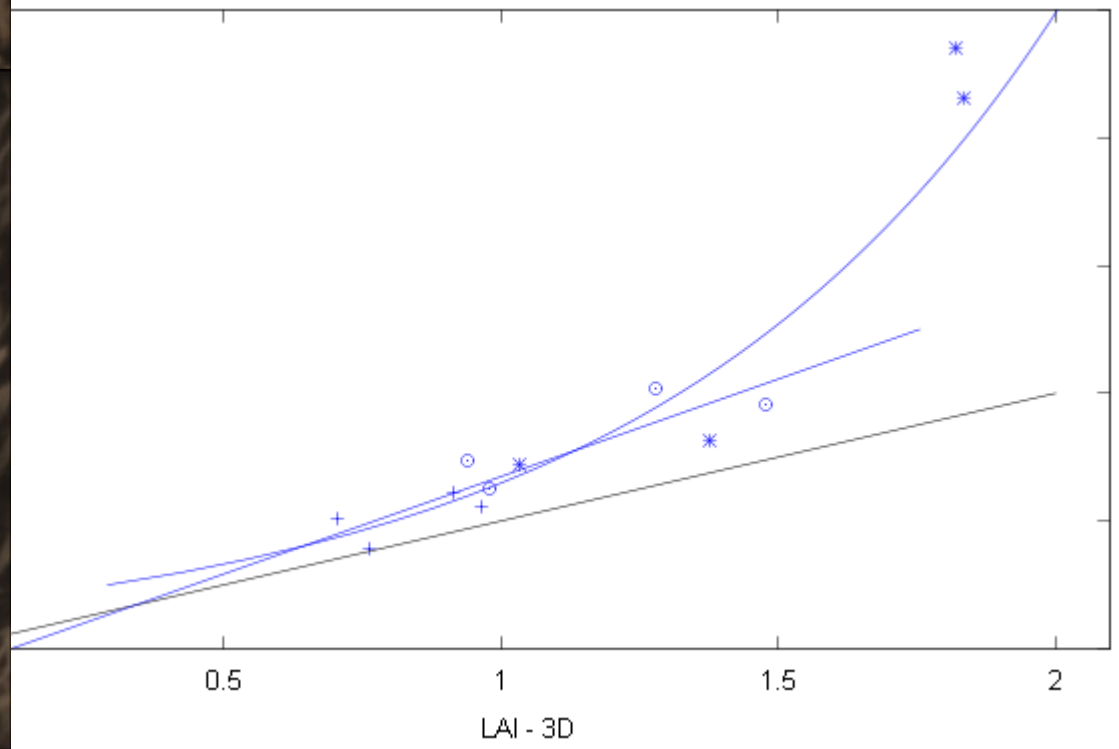
- LAI-3D < LAI Ref $\rightarrow$ reference LAI under estimated
- Linear relation between LAI-3D and LAI Ref for LAI Ref < 2 $\rightarrow$ ”saturation” afterwards



esults

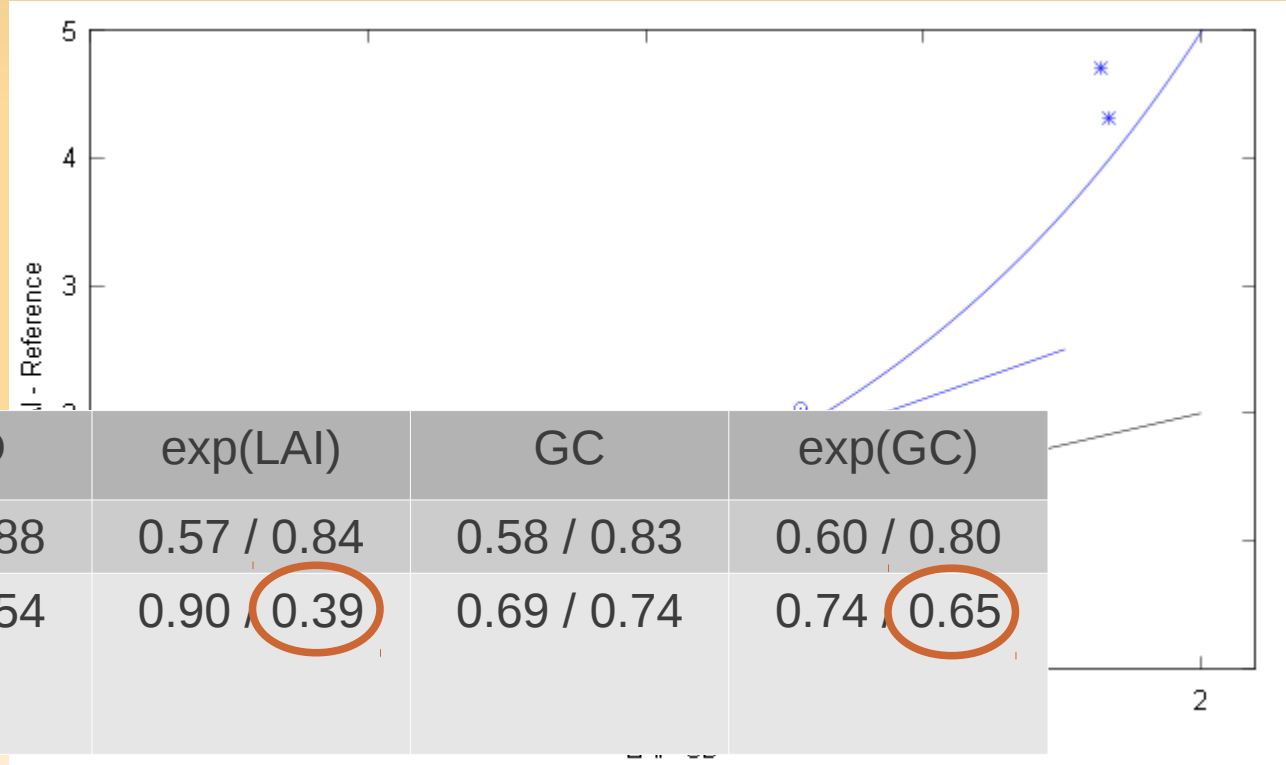
estimated

n LAI-3D and LAI Ref for LAI
n" afterwards



Results

- Reference LAI under estimated
- Linear relation between LAI-3D and LAI Ref for LAI Ref < 2 → ”saturation” afterwards
- LAI-3D < LAI Ref
- At plot level
  $\sigma_{\text{LAI Ref}} = 0.31$



R^2 / $s_{y.x}$	LAI 3D	exp(LAI)	GC	exp(GC)
Raw data	0.53 / 0.88	0.57 / 0.84	0.58 / 0.83	0.60 / 0.80
Mean on 5 images and 4 repetitions	0.83 / 0.54	0.90 / 0.39	0.69 / 0.74	0.74 / 0.65

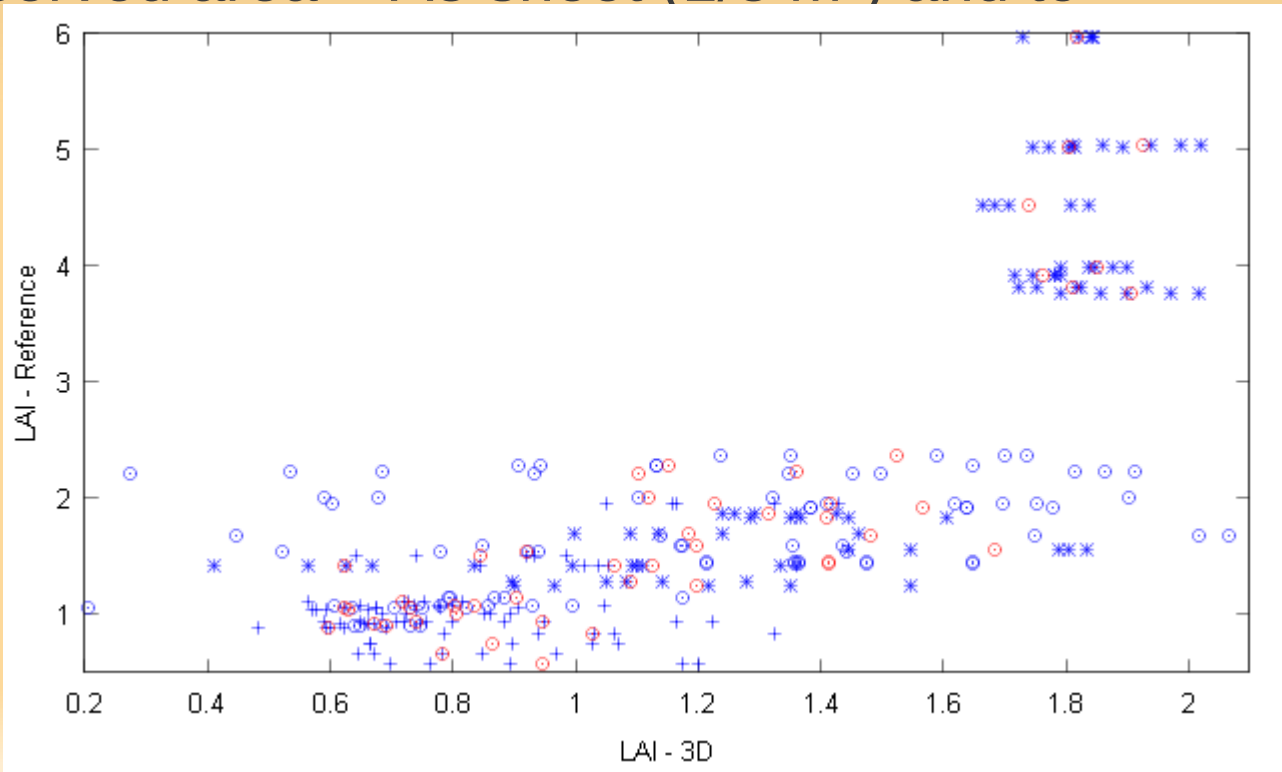
Conclusion

- It was possible to evaluate the reference LAI with a standard deviation of 0.4
- The standard deviation on the predicted LAI was not much higher than the standard deviation of the reference LAI
- No difference was observed linked to the origin of the LAI variation
- There was a ”saturation” phenomenon, but it was less important than with the ground cover method

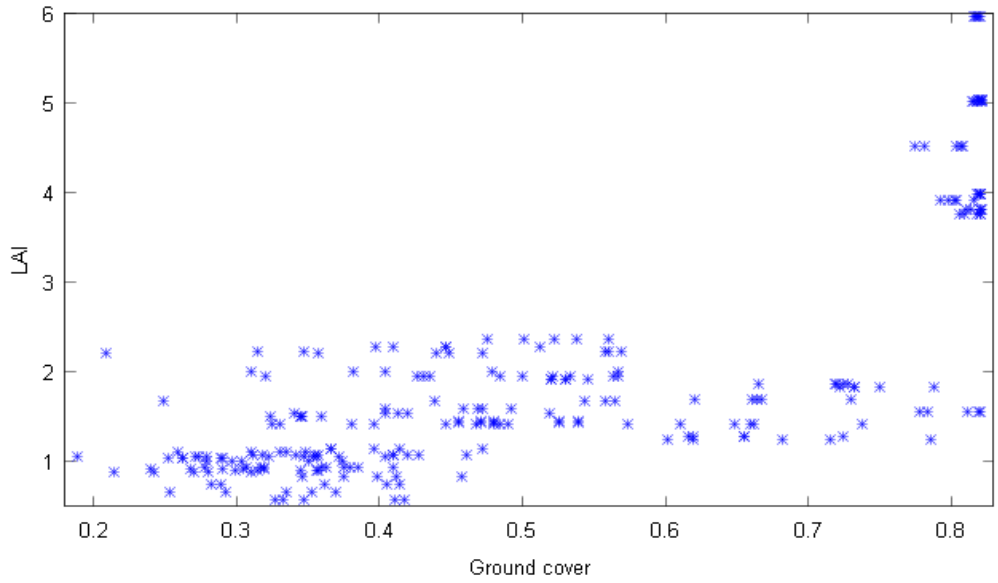
Thank you for your attention ...

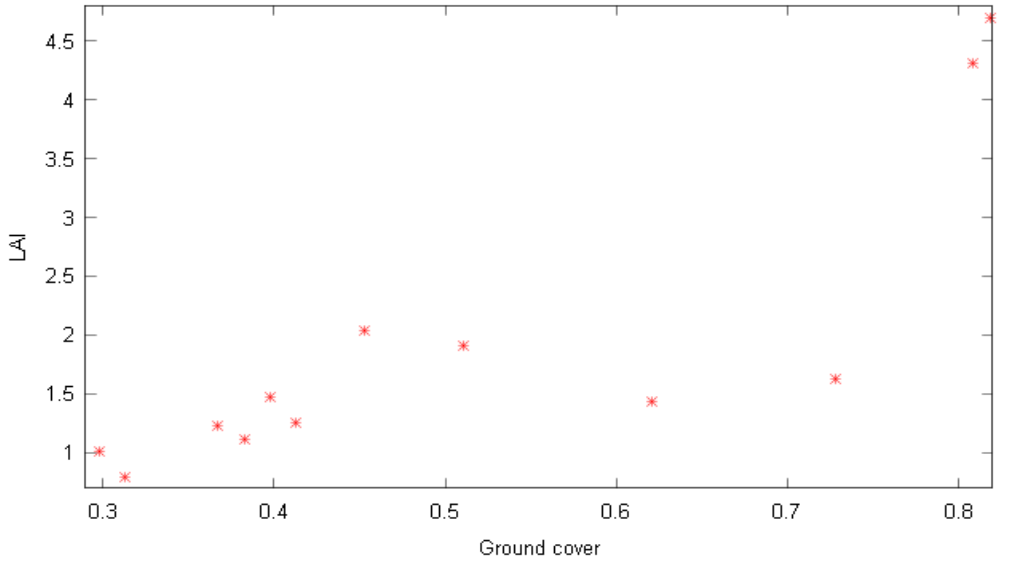
Results

- Variability of the results :
  - Wide ”in plot” variability
  - Linked to the observed area ≈ A3 sheet (1/8 m²) and to the length of picking (0.5m)



LAI Ref - Ground cover





Results

- Analysis of the variability
  - Standard deviation (variance)
  - Between plot (3D) + in plot (3D) < Between plot (Ref)
  - But 5*4 images / 4* 0.5 m

March and April data

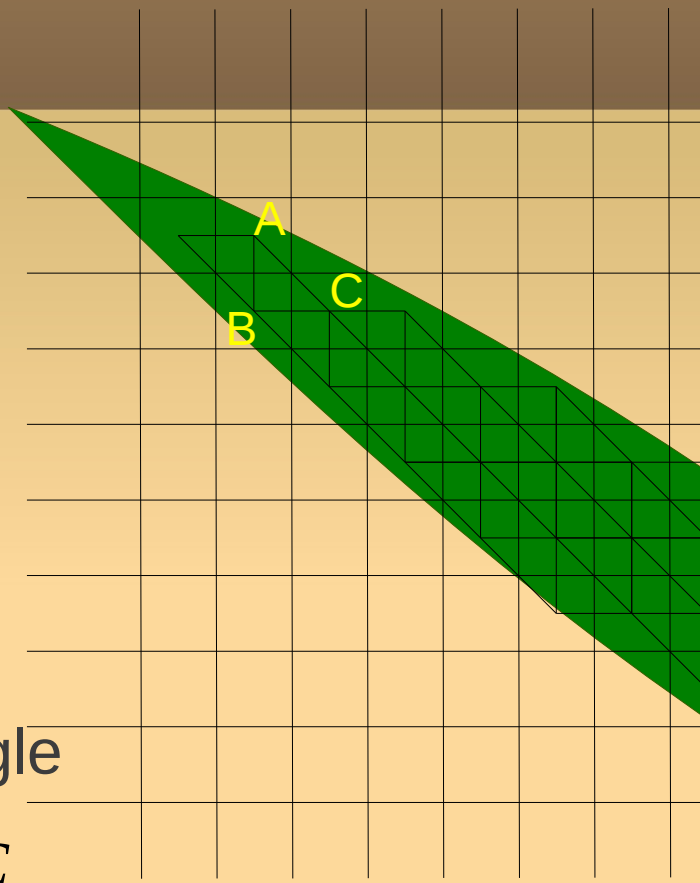
Source of variations	Reference	3D estimate
General averages	1.35	1.14
Treatments and dates	0.39 (0.155)	0.36 (0.131)
Plot	0.36 (0.13)	0.13 (0.017)
Between images		0.27 (0.074)
Total	0.52 (0.27)	0.45 (0.21)

March, April and June data

Source of variations	Reference	3D estimate
General averages	1.91	1.17
Treatments and dates	1.24 (1.5)	0.33 (0.11)
Plot	0.56 (0.31)	0.26 (0.07)
Between images		0.30 (0.09)
Total	1.29 (1.66)	0.46 (0.21)

Method

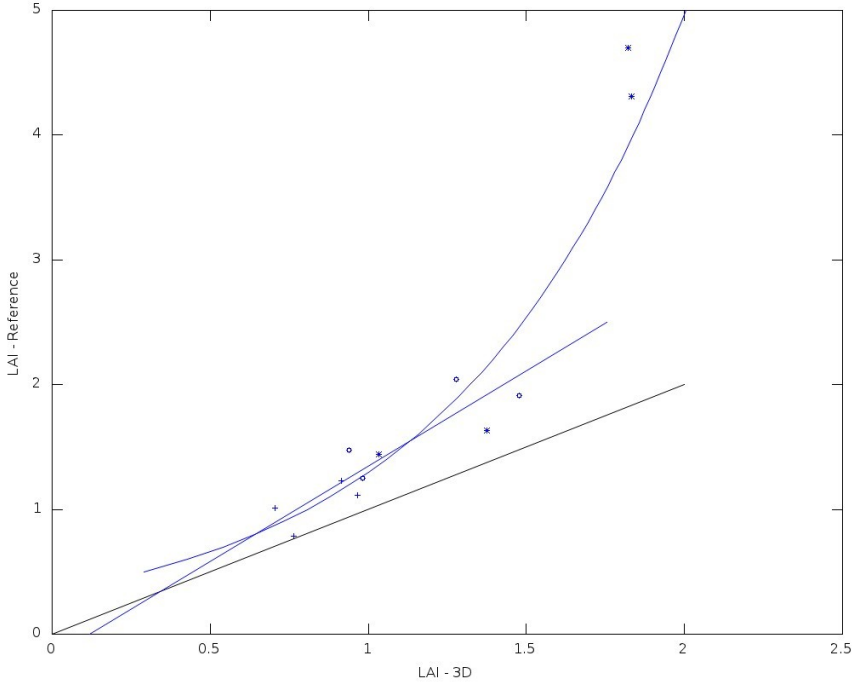
- Algorithm
  - ...
  - Image segmentation (Leaves/Soil)
  - Definition of the ROI
  - Computation of the LAI
  - Computation of the Average Leaf Angle

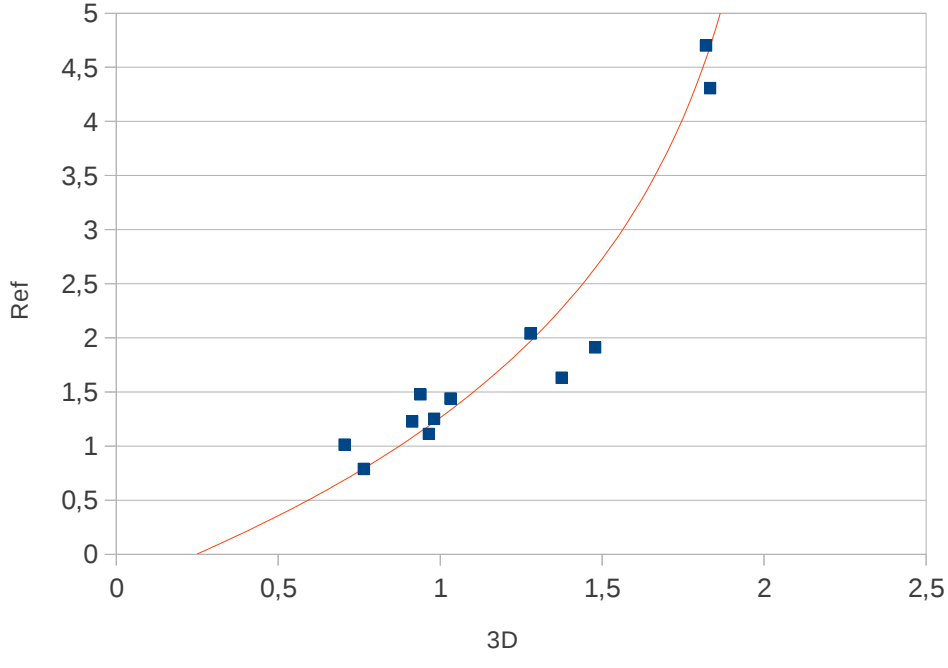


$$\vec{CP} = \vec{AB} \times \vec{AC}$$

$$ALA = mean\left(acos\left(\frac{\vec{CP}}{\left|\vec{CP}\right|} \right) \right)$$

* : OpenCV Libraries


LAI - Reference
LAI - 3D
0
0.5
1
1.5
2
2.5
3
4
5


Ref
3D
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5

- sgbm.P1 = 4*cn*sgbm.SADWindowSize*sgbm.SADWindowSize;
- sgbm.P2 = 16*cn*sgbm.SADWindowSize*sgbm.SADWindowSize;
- sgbm.minDisparity = minDisparity;
- sgbm.numberOfDisparities = numberOfDisparities;
- sgbm.uniquenessRatio = 0;//10;
- sgbm.speckleWindowSize = 0;
- sgbm.speckleRange = 32;
- sgbm.disp12MaxDiff = 2;//1;
- sgbm.fullDP = true;