Simulating UAV sampling using high-density Lidar data to characterize the structure of short canopies

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Aircraft for Environmental and Forest Science
AIRFORS

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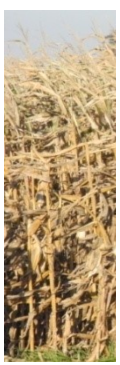
Research and Innovation Centre-FEM & Airborne Technologies



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RS of crops damaged by extreme weather events…

Why?

- AT interested in business towards the **RS & Precision Agriculture market** (in Europe and beyond)
- **Scale issue**: European market is limited because of low avg field/property size
- Research together with HV Insurance: **on possible extensive monitoring the effects extreme weather events (hail) on corn**

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RS of crops damaged by extreme weather events…

- Frequency of extreme weather events (drought, hailstorms, icestorms) increased in Central Europe
- Number of claims significantly increased: management issues
- Bottom-up research questions from HV Insurance:

a) can we use RS to monitor the effects (canopy height, defoliation, damage) of extreme weather events (drought, hailstorms) on crops?

b) can we integrate such tools into an efficient & cost-effective, monitoring system using aircraft or UAV monitoring?

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HV

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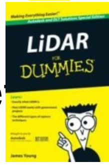
LiDAR for dummies: point density and vertical resolution



LiDAR is a RS technology that measures distance (height) by illuminating a targe with a laser light. For each pulse there are many returns.

Point densities for airborne observations:

0.5-1 points/m^2 -> DEM applications

5-12 points/m^2 --> forest inventories

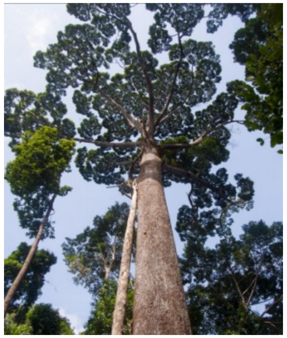
> 20 points/m^2 -up to 100- increasingly available for urban areas and for archeology (multiple flights)

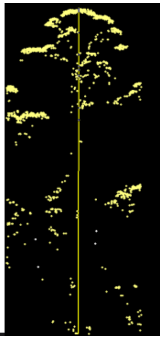
New generation lidar: > 20 points/m^2 with a single flight

UAV lidar: hundreds of points m^2

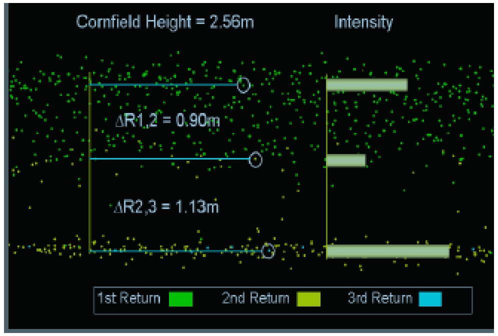
Our study: 40 points/m^2, resampled to 20, 10, 5 and 2 points/m^2

Vertical resolution (vert. distance between adjacent returns at a given distance): up to 10 (15) cm !!!





Ussyshkin and Theriault. (2011)



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Objectives of this study

·to test the use of in-situ biophysical measurements (based on canopy height and canopy denseness) as a **quantitative proxy for corn canopy defoliation** (which is generally assessed by visual estimation)

·to test the ability of LiDAR data **to map canopy height of corn crops**

·to analyze the canopy denseness profile and the **LiDAR return patterns** in different corn canopies with various hail defoliation rates;

·to investigate the ability of LiDAR models based on both *traditional* and *new metrics* introduced in this study **to retrieve canopy denseness and canopy defoliation**;

·to highlight the **effect of adopting different LiDAR sampling point densities** on the ability of ALS metrics to retrieve canopy height and canopy defoliation.

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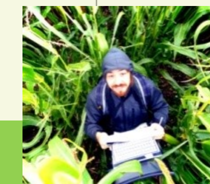
Remote Sensing upscaling based on ground-truth observations

EVENT
(Hail)

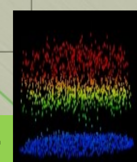
(Preliminary ispection)

Flight campaign
All area

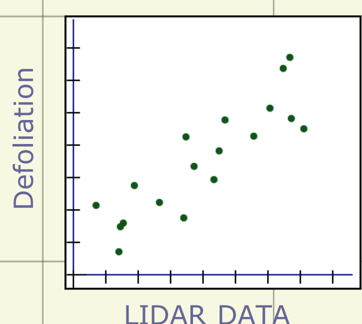
Ground measurements
In a few selected rapresentative plots (no damage → max damage)



RS Dataset
LIDAR



Ground dataset
Canopy height
Photos panels
Defoliation, damage
(FEM, HV)



Modeling
Empirical, complex

Mapping
All area

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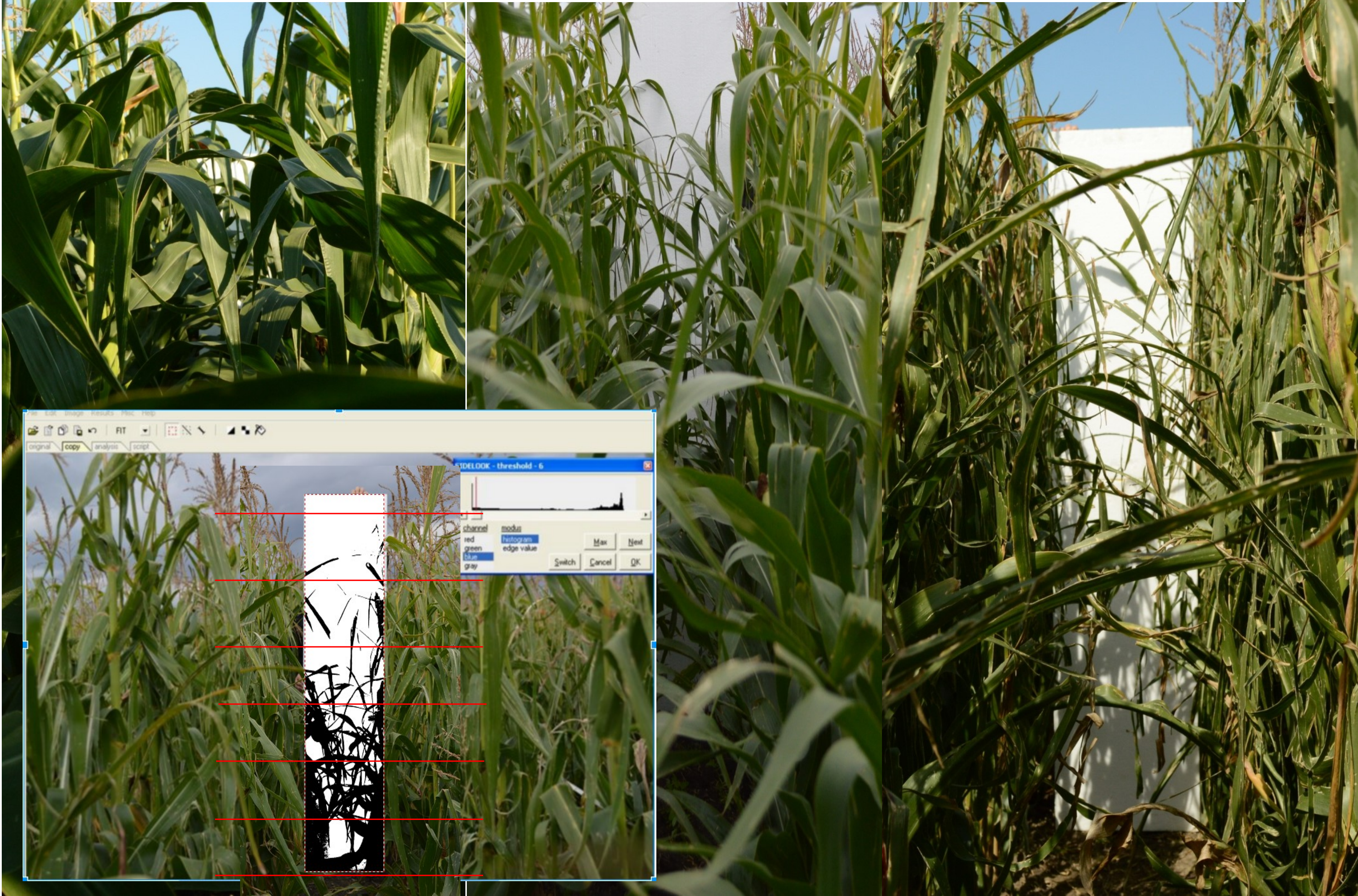
Defoliation-damage: beyond visual estimation

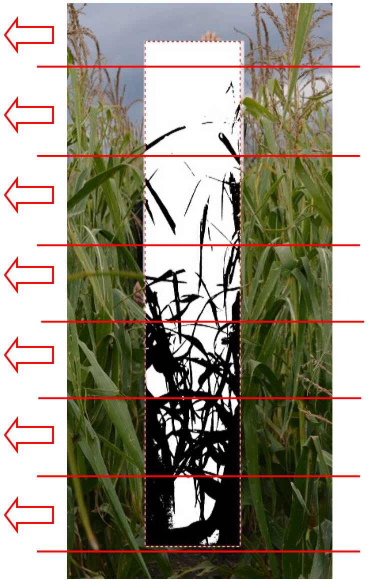


Defoliation-damage: beyond visual estimation

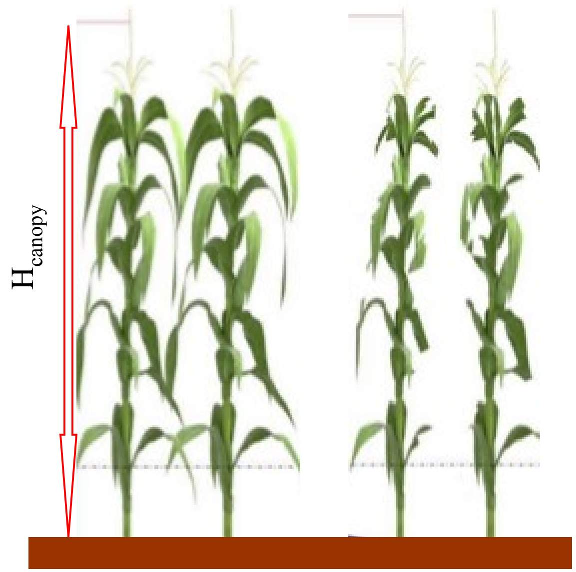
- Defoliation: visual estimation (FEM, HV)
- Can we use a biophysical index to "measure" defoliation, based on our biophysical observations (canopy height, denseness profiles)?

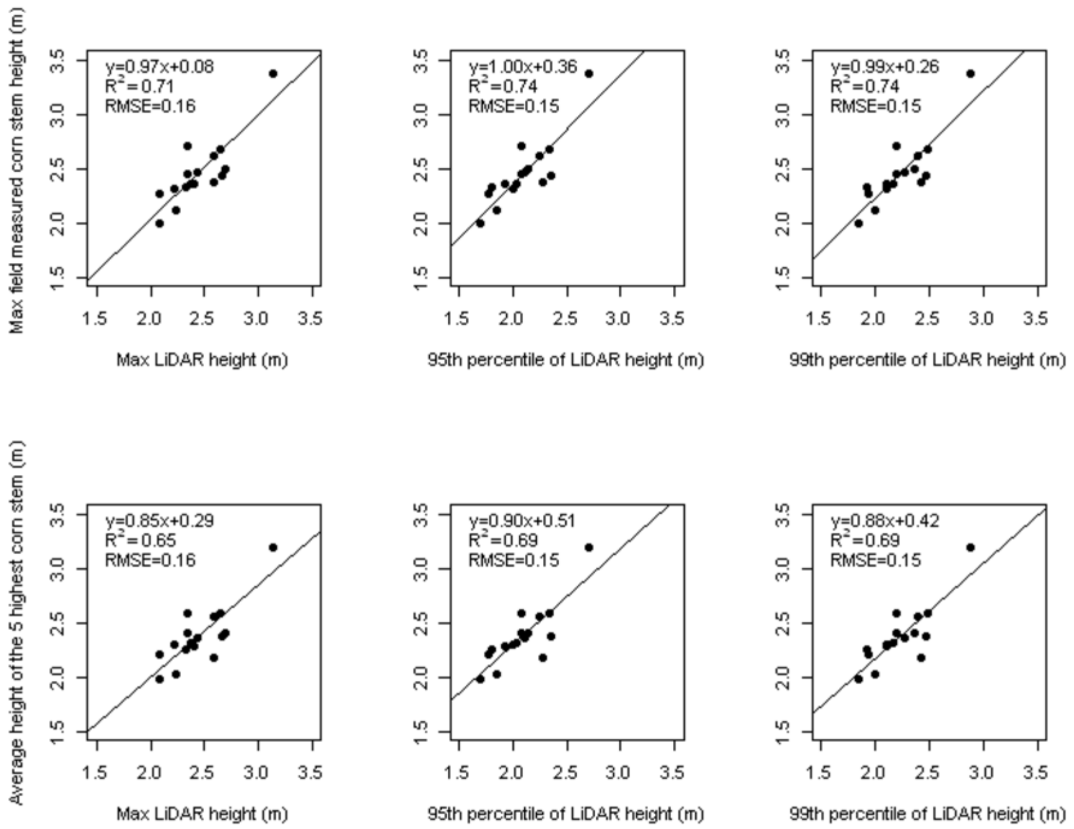
CANOPY DEFOLIATION INDEX $CDI = H_{canopy}/D_{panel}$

R^2 (RMSE)	Canopy denseness	Canopy Defoliation Index (CDI)	Defoliation assessed by FEM (%)	Defoliation assessed by HV (%)
Canopy denseness	1			
Canopy Defoliation Index (CDI)	0.8191 (0.8360)	1		
Defoliation assessed by FEM (%)	0.5599 (10.6635)	0.7007 (0.5636)	1	
Defoliation assessed by HV (%)	0.6008 (10.1566)	0.7585 (0.5062)	0.9211 (3.7805)	1



Corn canopy height estimation

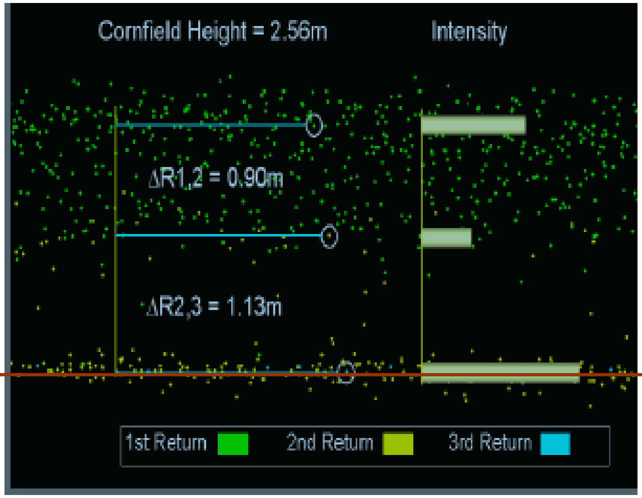




Height estimation:

-Input in productivity models for crops
-Mapping drought effects (e.g. corn)
-Mapping the effects of (severe) storms (e.g.corn, barley, wheat)

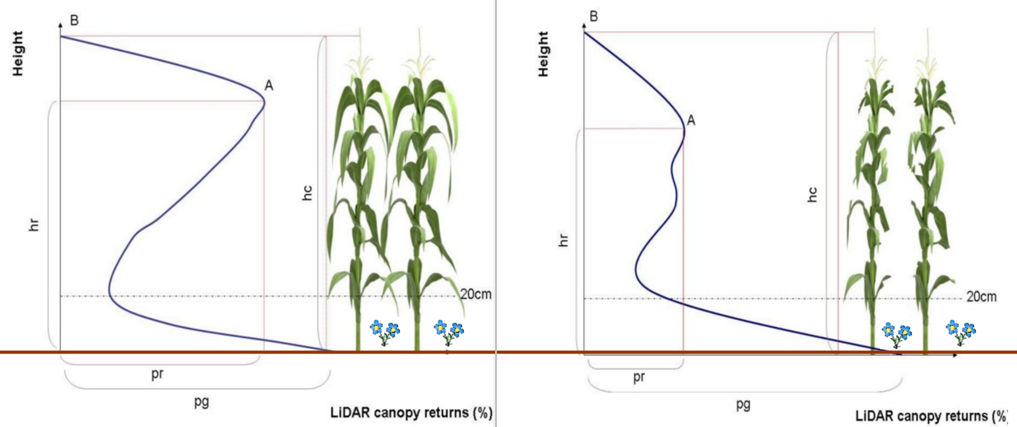
LiDAR return profile: what we were expecting & what we found

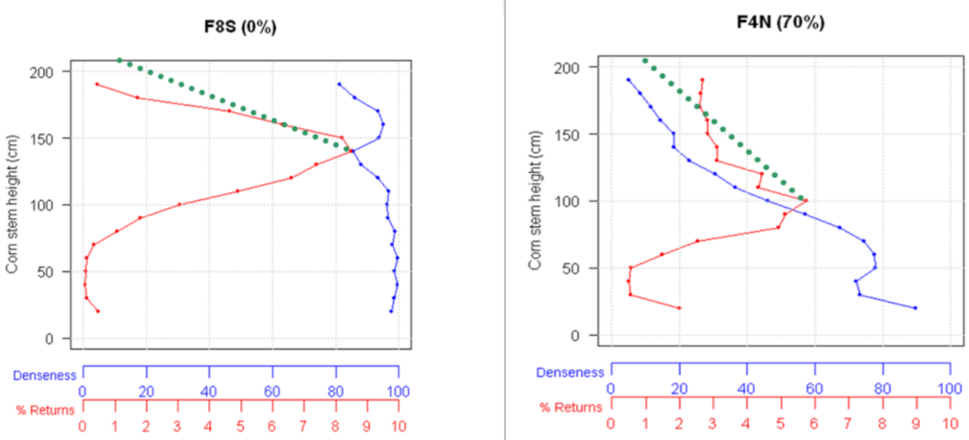


Ussyshkin and Theriault. (2011)

NORMAL CANOPY

DEFOLIATED CANOPY





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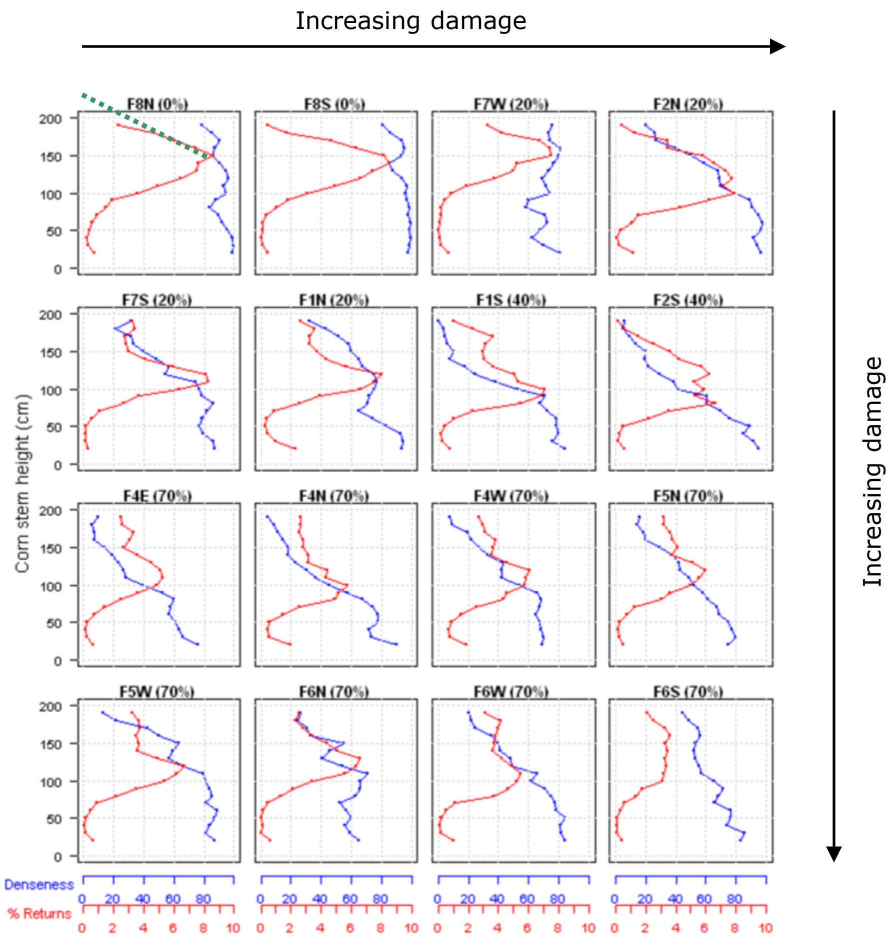
LiDAR return profile: what we found within the 16 corn plots

We can retrieve the slope information and use a LiDAR metric to estimate damage



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Two metrics for corn defoliation assessment in this study

1) CANOPY METRIC

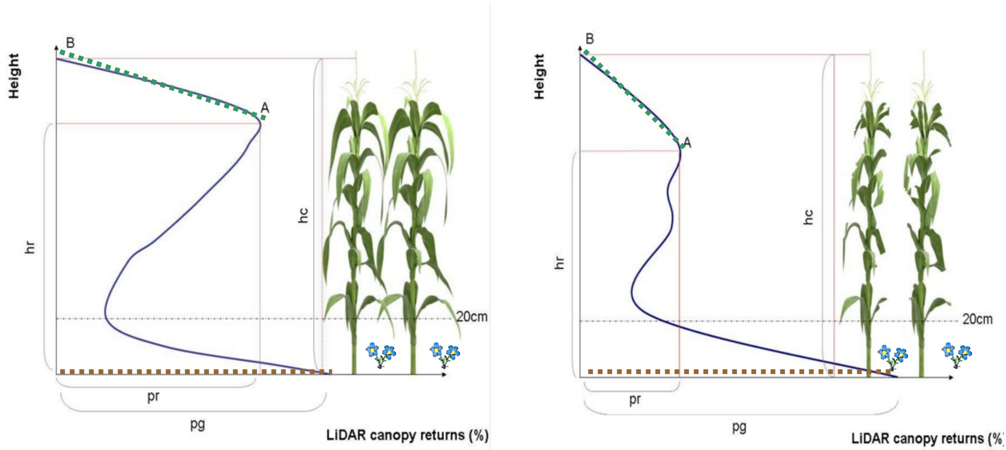
$$CM = [(hc-hr)/hr]*100/pr$$

-Slope of the upper part of the canopy lidar profile

hc = maximum height value of all LiDAR returns intersecting the plot;
hr = the height corresponding to the maximum percentage value of all LiDAR returns (excluding the 0 - 10 and the 10 - 20 cm layers);
pr = the maximum percentage value of all LiDAR returns for the various 10 cm layers (excluding the 0 - 10 and the 10 - 20 cm layers).

NORMAL CANOPY

DEFOLIATED CANOPY



2) GROUND METRIC

$$GM = pg * (hc /350)*100$$

-Percentage of the returns reaching the ground (normalised by height)

hc = maximum height value of all LiDAR returns intersecting the plot
pg = the percentage value of all LiDAR returns at the ground level (0 - 20 cm).

Canopy Defoliation Index estimated by the Canopy Metric and the Ground Metric: coefficients and statistics of the linear regression model. Sampling point density equal to 42 points/m^2.

	Estimate	Standard error	t value	Pr(>|t|)
CDI = 0.21 CM + 2.00 R^2 = 0.63				
Intercept	2.0005	0.4815	4.155	0.0010
CM	0.2111	0.4369	4.834	0.0003
CDI = 0.00 GM + 2.78 R^2 = 0.15				
Intercept	2.7799	0.9191	3.025	0.0091
GM	0.0003	0.0002	1.585	0.1352

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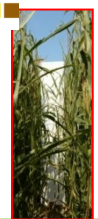
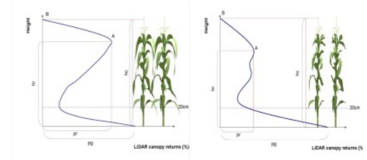
Model validation and next steps

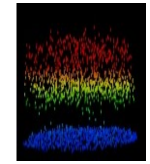


Defoliation FEM

Biophysical measurements

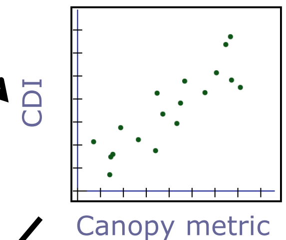
Canopy Defoliation Index (CDI)



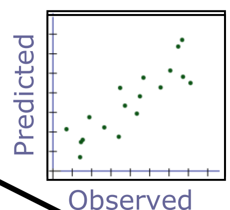


ALS data

LiDAR Canopy Metric



Defoliation HV



Model Validation

Corn defoliation maps of the area

Impact of different Lidar densities on estimations

Impact of LAS point density on the models performance

Canopy height
Using 3 different metrics
(Values of R^2 and RMSE over 100 repetitions)

	Average height of the 5 highest corn stem vs Max LiDAR height		Average height of the 5 highest corn stem vs 95th percentile LiDAR height		Average height of the 5 highest corn stem vs 99th percentile LiDAR height	
Point density (points/m²)	R^2	RMSE	R^2	RMSE	R^2	RMSE
40	0.65	0.16	0.69	0.15	0.69	0.15
20	0.67	0.15	0.69	0.15	0.69	0.15
10	0.64	0.16	0.68	0.15	0.67	0.16
5	0.67	0.16	0.69	0.15	0.68	0.15
2	0.63	0.16	0.66	0.16	0.65	0.16

Canopy defoliation
Using the Canopy Metric (CM)

	Defoliation observed by HV vs Defoliation predicted by CM	
Point density (points/m²)	R^2	RMSE
40	0.69	14.49
20	0.61	16.23
10	0.59	16.43
5	0.47	18.81
2	0.41	19.98

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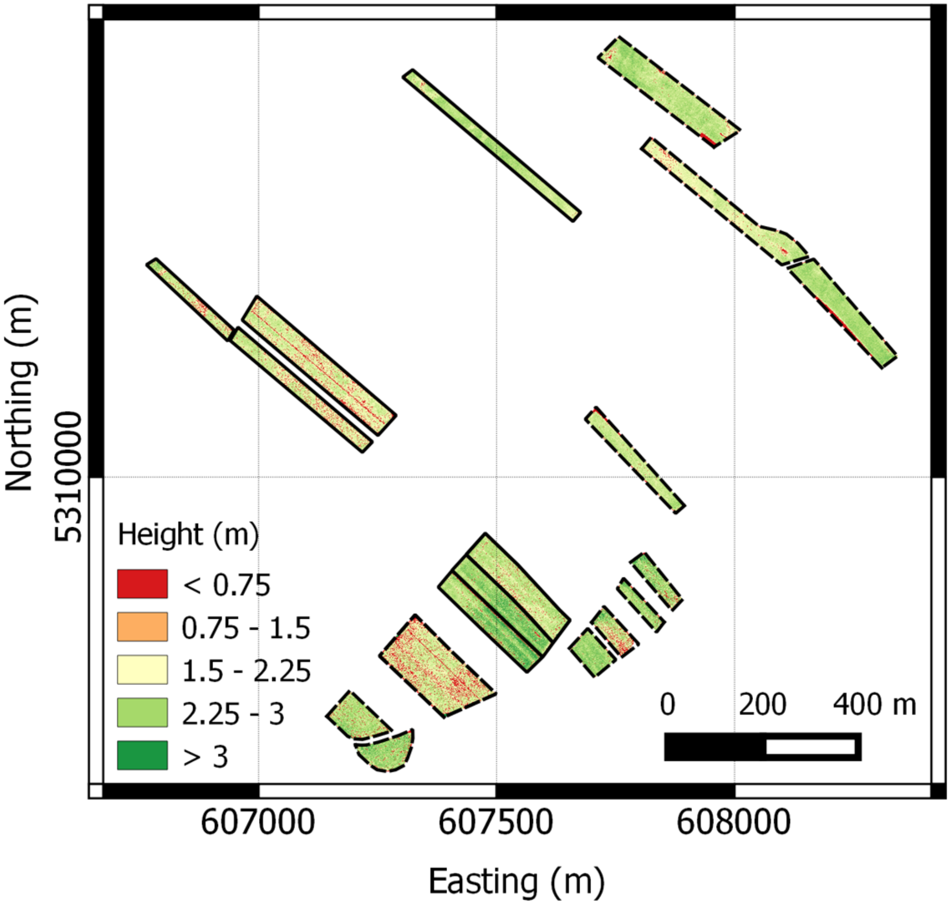
Corn canopy height map

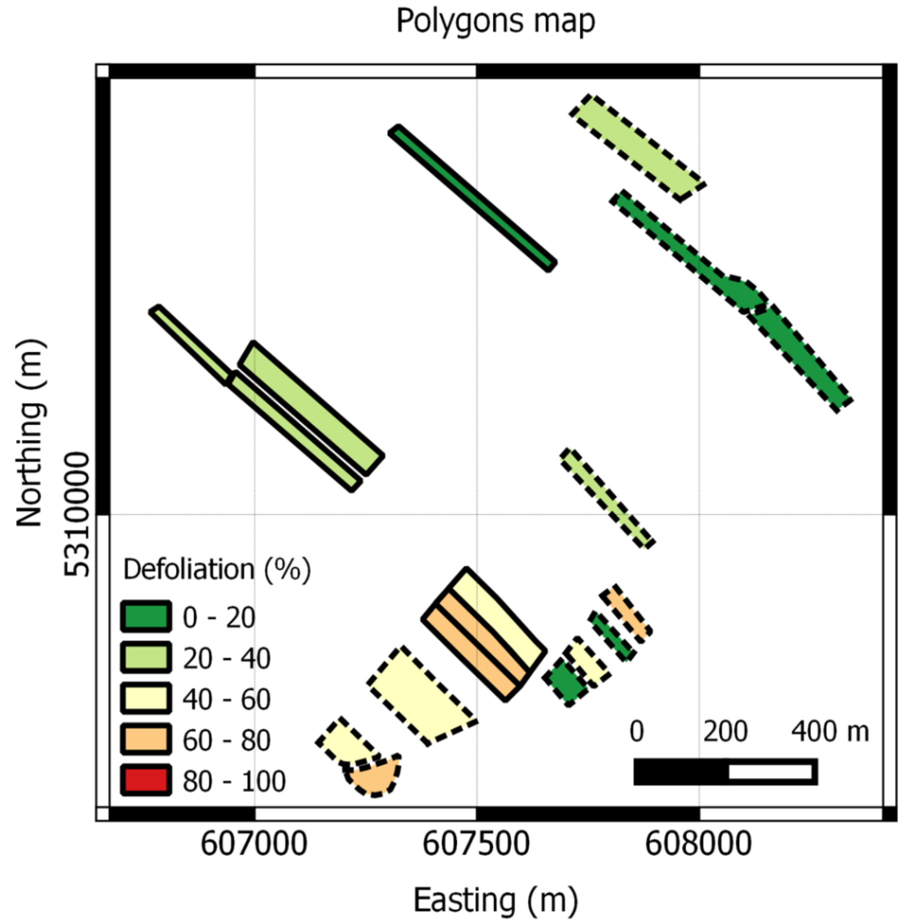
Wampersdorf, 2014 campaign



Height is a very good proxy for above-ground biomass (*Yin et al, 2011*)
Height can be used to detect severe drought damage
Height can be used to normalise canopy density observations e.g. for hail defoliation

Corn canopy defoliation map

Wampersdorf, 2014 campaign



No imagery acquisition before the event is needed, as the reference observations can be carried out simultaneously in adjacent areas not affected by the hailstorm.

Air-borne LiDAR observations are characterized by comparatively low requirements for illumination conditions (compared to optical)

Quick acquisitions are able to provide important near real-time information to optimize the field inspection procedures.

Conclusions

·Canopy Defoliation Index demonstrated to be a reliable **quantitative proxy for corn canopy defoliation**

·Traditional metrics using low density LiDAR data (2 pt./m^2) allow **to map canopy height of corn crops (for productivity models, storm damage monitoring, drought)**

·There are distinctive **LiDAR return patterns** in corn canopies with various hail defoliation rates.

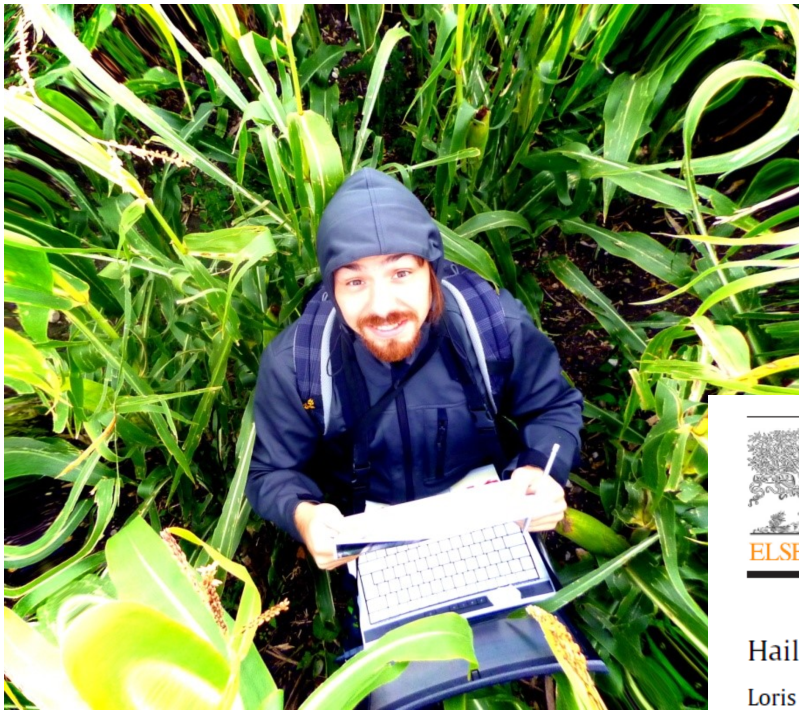
·The Canopy Metric (CM) is based on such patterns and showed a good performance for **retrieving canopy defoliation**;

·Strong **effect of adopting different LiDAR sampling point densities** on the ability of CM to retrieve canopy defoliation (20–40 pt./m^2 needed).

·**Lidar** can be efficiently used **to monitor crop density and defoliation with new generation airborne and UAV Lidar.**

·High potential for **ecosystem studies to detect canopy structure in detail**

Thanks for your attention!



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Hail defoliation assessment in corn (*Zea mays* L.) using airborne LiDAR

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A B S T R A C T

The insurance industry reports a pronounced intensification, at the global level, of weather-related events such as droughts, windstorms and hailstorms. As an efficient quantification tool, improved capacities can be built adopting innovative remote sensing methods to map vegetation damage spatial distribution, to quantify its intensity and impact. New airborne LiDAR (Light Detection and Ranging) sensors provide high vertical resolution data, which are potentially suitable not only for forest canopies but also for monitoring shorter crop canopies (e.g. corn – *Zea mays* L.) for crop injury and lodging assessment.

To evaluate the potential of LiDAR metrics to map corn canopy height and hail defoliation, a flight campaign was organized in 2014 in Wampersdorf (Austria) in a cropland area affected by a hailstorm. Ground-truth observations were carried out in 16 plots, where defoliation was assessed both visually (observed range from 0% to 70%) and using a biophysical parameter-based method. The performance of both traditional and newly-introduced metrics (i.e. Canopy Metric, Ground Metric) was assessed at different sampling point densities. The results showed the ability of LiDAR data to map both corn canopy