Exploring the Light Environment within Complex Crop Canopies using 3D Reconstruction and Ray Tracing

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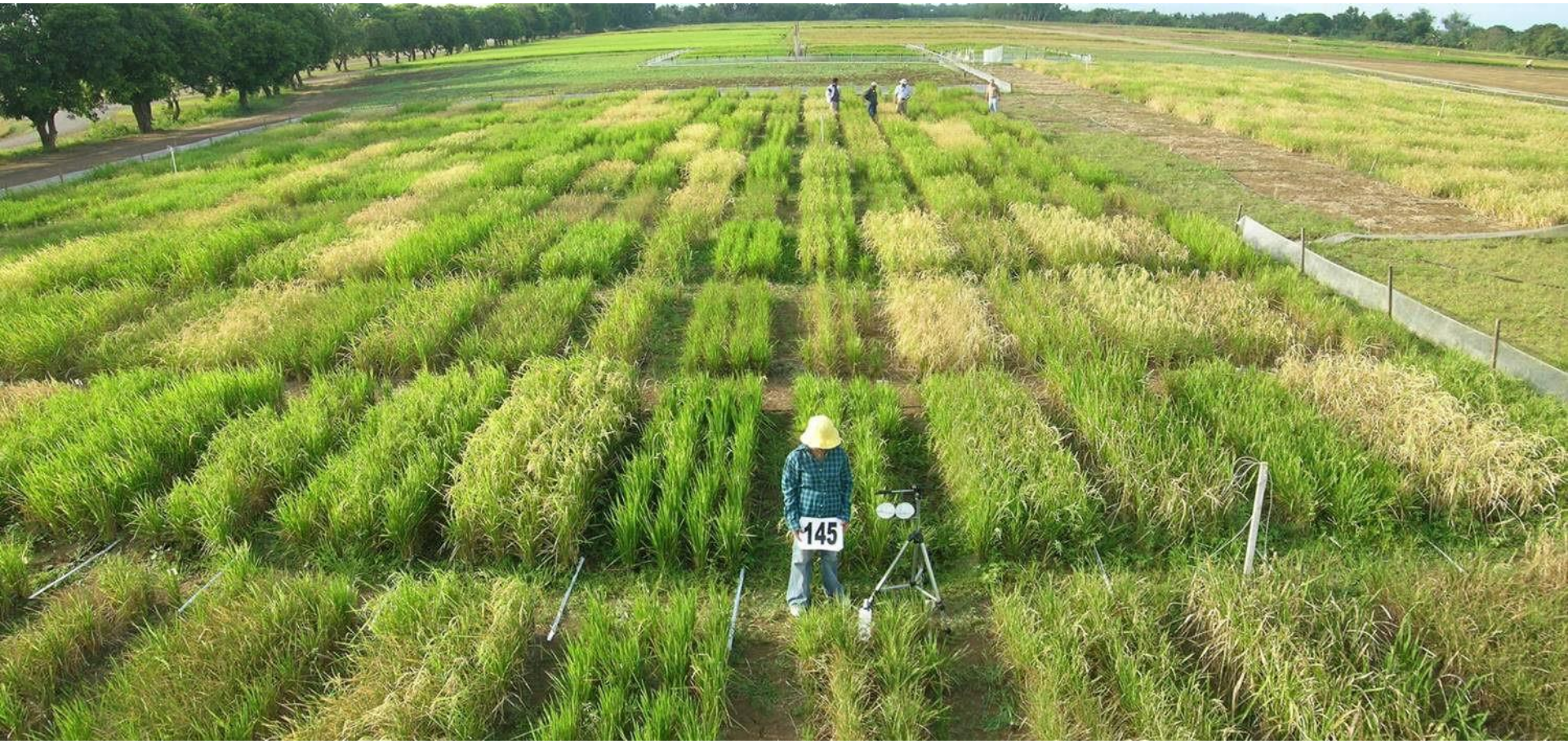
Tato akce se koná v rámci projektu:
Vybudování vědeckého týmu environmentální metabolomiky a ekofyziologie a jeho zapojení do mezinárodních sítí (ENVIMET; r.č. **CZ.1.07/2.3.00/20.0246**)
realizovaného v rámci Operačního programu Vzdělávání pro konkurenceschopnost.

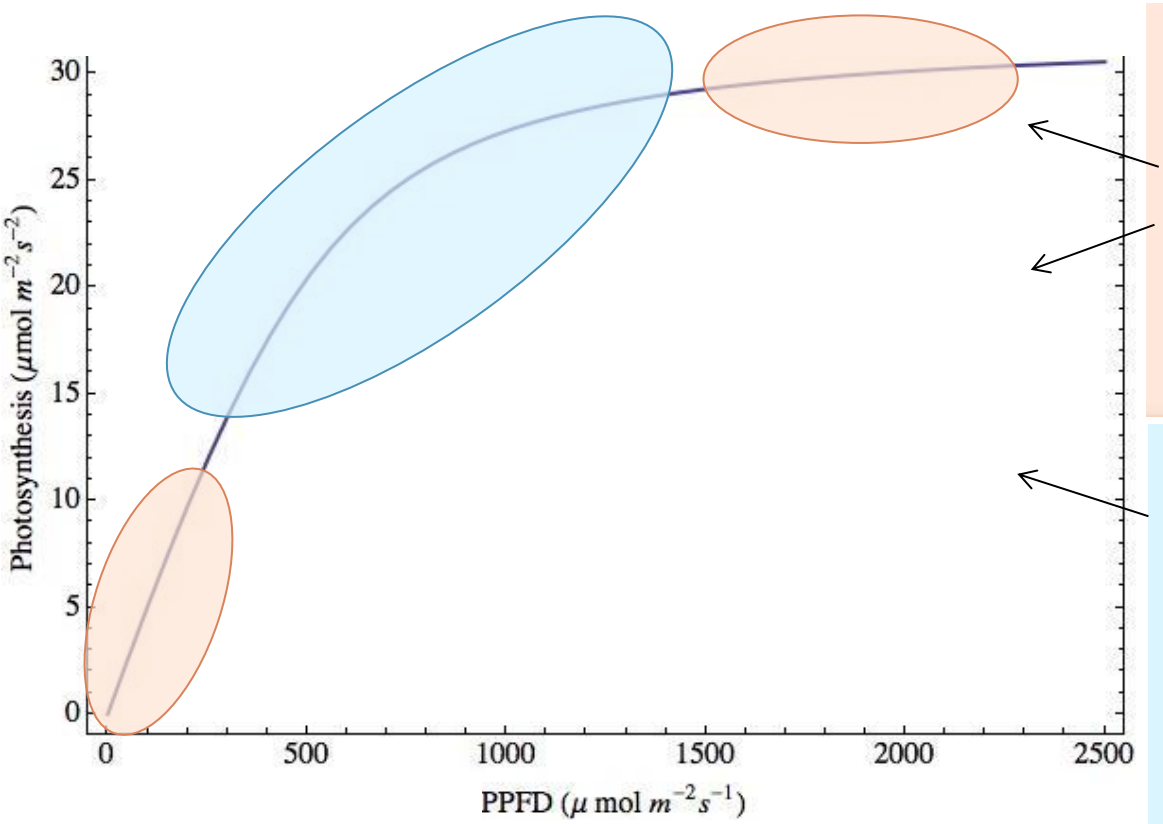
Overview

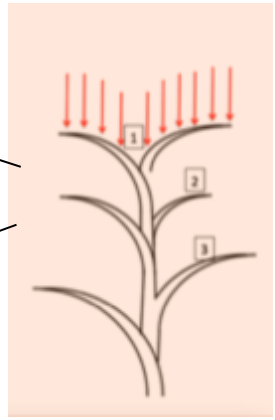
- Introduction
  - Canopy Architecture
  - Photosynthesis
- 3D Reconstructions
  - Methods
    - Imaging and Reconstruction
    - Ray Tracing
  - Applications
    - Phenotyping
    - Acclimation Model
- Future Work

Architecture, Photosynthesis and Biomass Production



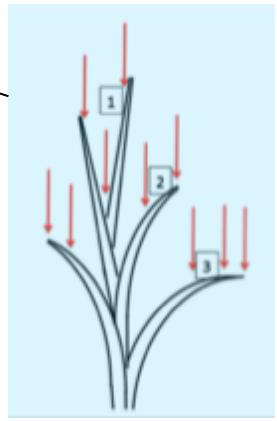
Architecture, Photosynthesis and Biomass Production





Flatter canopy

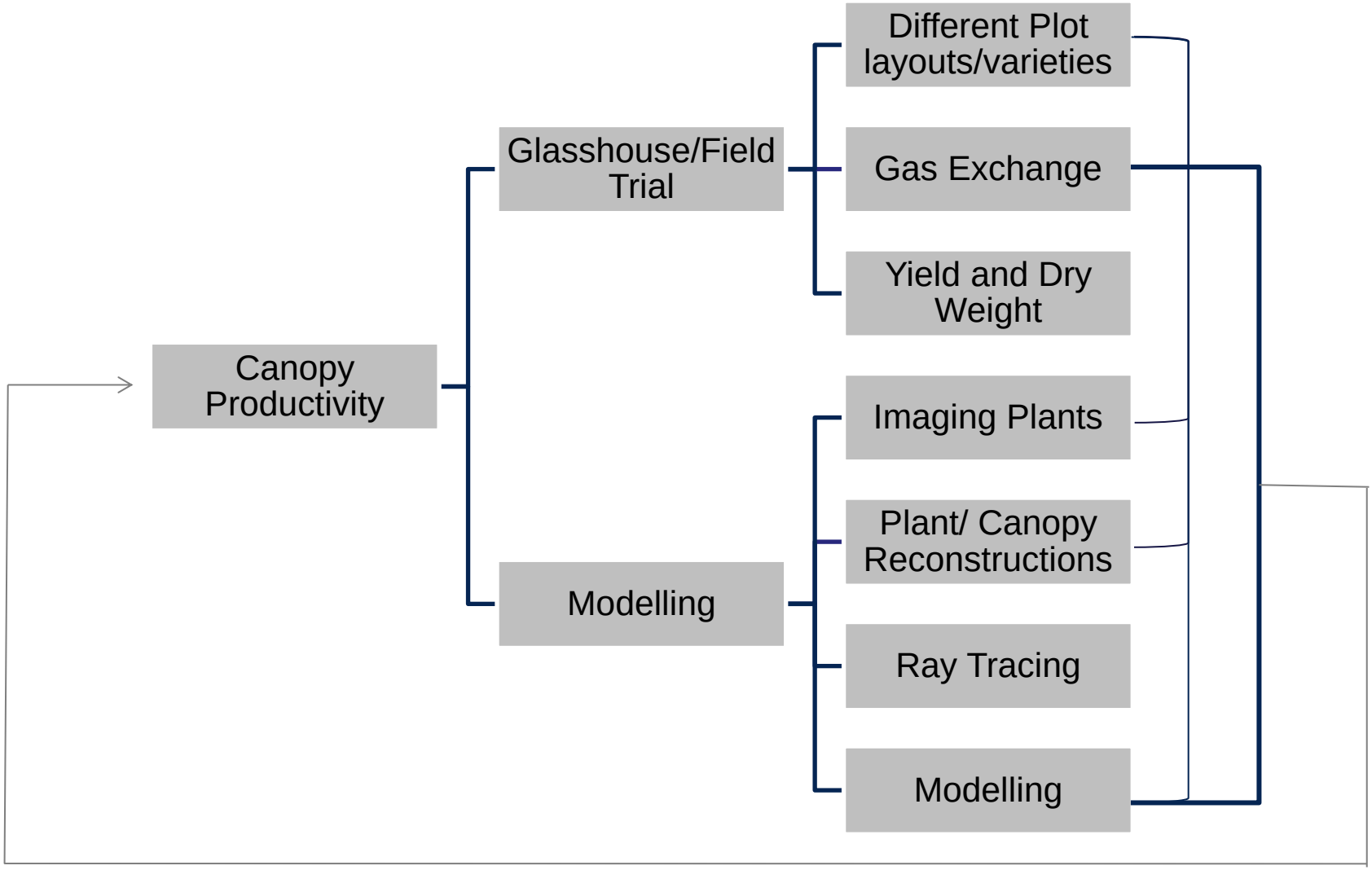
- more horizontal leaves



Upright canopy

- more vertical leaves

Assessing Canopy Productivity



Digital Plant Reconstruction

Work by Dr Michael Pound

(CPIB, University of Nottingham)

- Method consisting of four stages:
  - Image Capture
  - Point Cloud Reconstruction
  - Surface Estimation
  - Canopy Formation

Pound MP, French AP, Murchie EH, Pridmore TP (2014) Automated Recovery of Three-Dimensional Models of Plant Shoots from Multiple Color Images. Plant Physiology **166**: 1688–1698

Stage 1: Image Capture

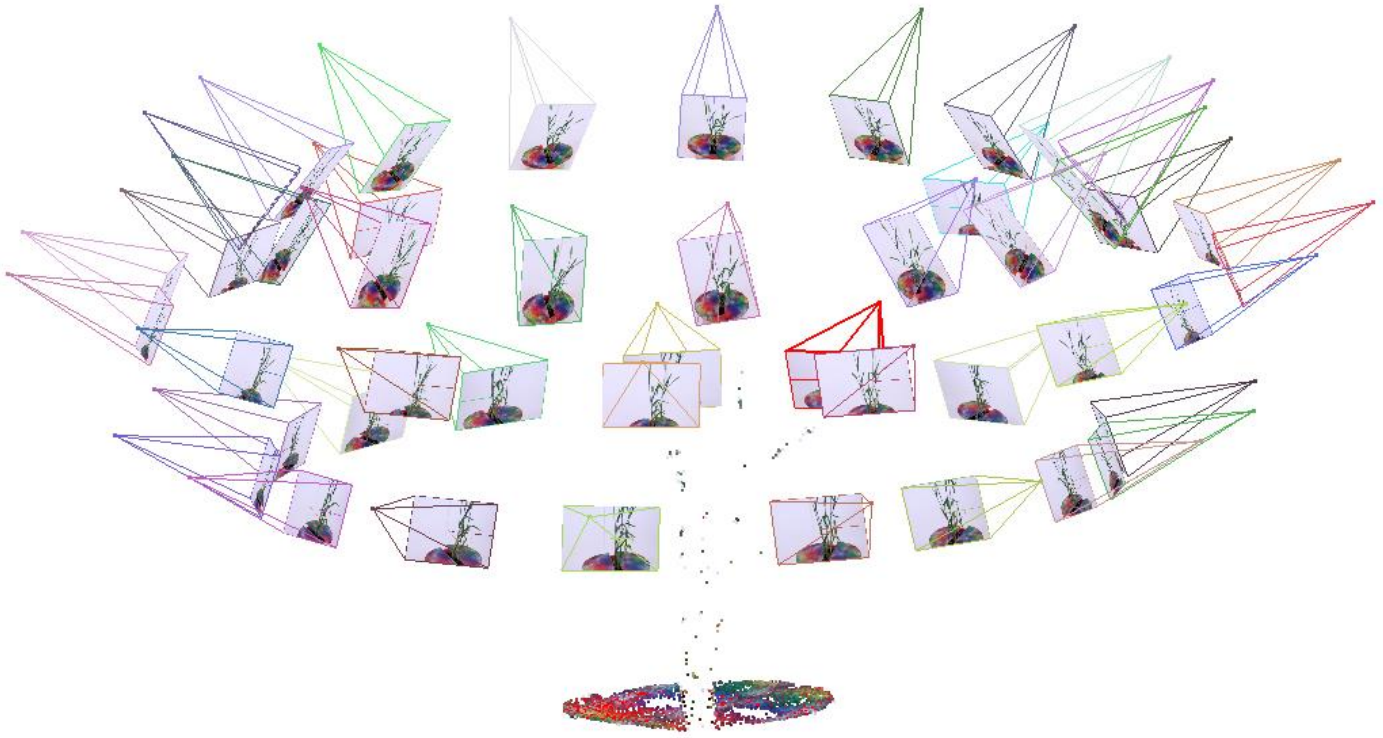
- 3 cameras
- Turntable
- Backing paper
- Calibration target
- Lighting

- Plants grown in a canopy (glasshouse/growth room/field) and dug up
- Taken to 360° imaging studio

Alternatively

- Image capture from plants growing *in situ* in the field/glasshouse

Stage 2: Point Cloud Reconstruction



- VisualSFM (Wu, 2011) is used to to perform automatic camera calibration and PMVS (Patch-based Multi-view Stereo, Furukawa and Ponce, 2010) to reconstruct a three-dimensional point cloud model of a plant and scene, based on multiple two dimensional input images.

Stage 3: Surface Estimation

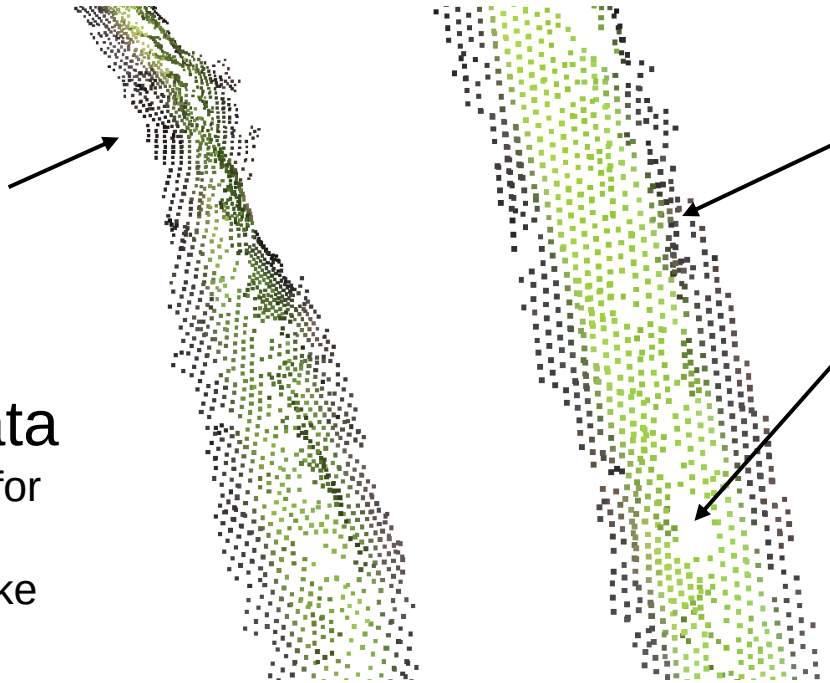
- There are a number of problems that must be solved before our model is suitable for use in ray tracing:

Noise

- Difficult to extract a surface from even a small section of leaf

No surface data

- Cannot be used for ray tracing
- Measurements like area are hard to compute



Non-leaf points

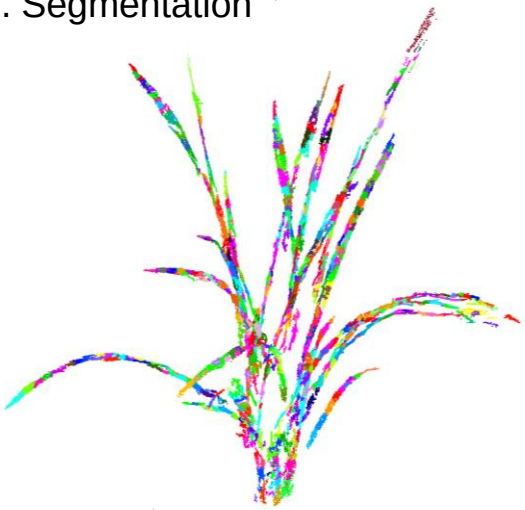
- Must not be included in a final reconstruction

Missing Data

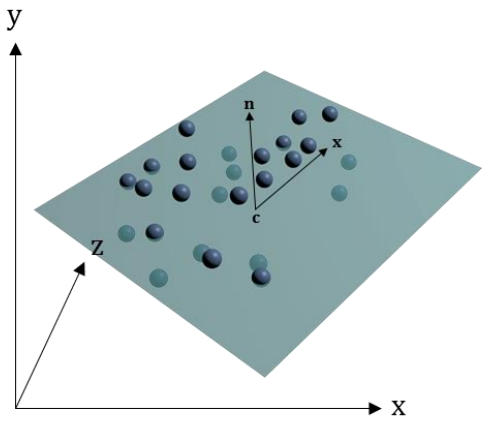
- Should be reconstructed

Stage 3: Surface Estimation

1. Segmentation



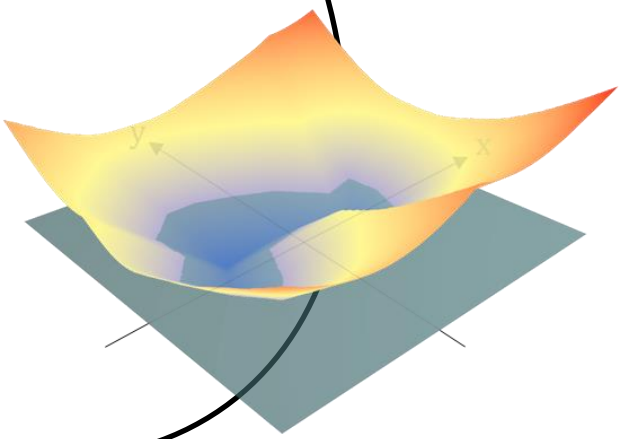
2. Plane Fitting



3. Orthogonal Projection

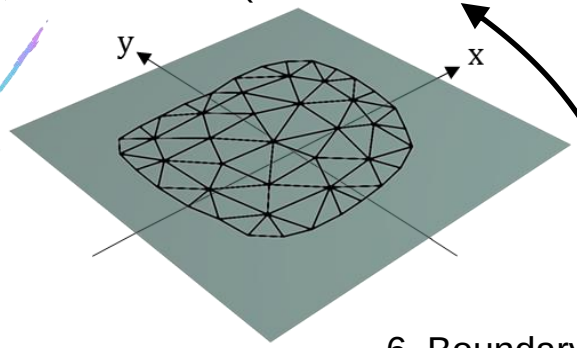
4. Triangulation (α-shapes)

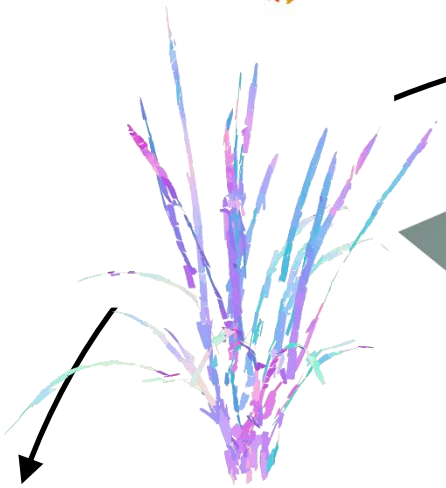
5. Initialising Level Sets



6. Boundary Refinement

7. Triangulation (constrained Delaunay)

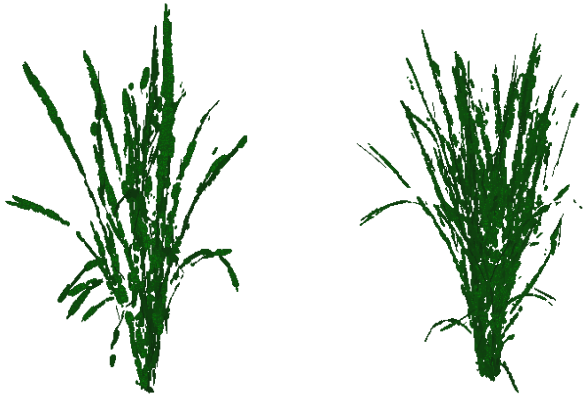




8. Model Output

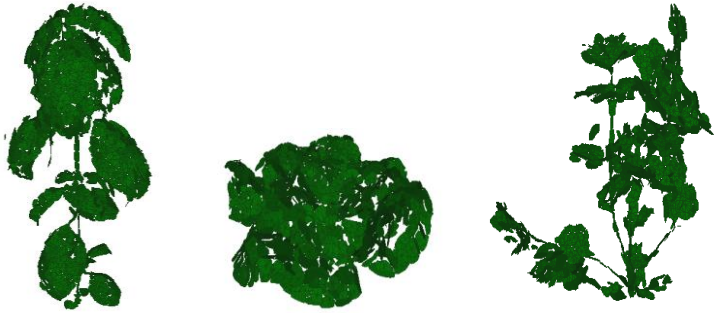
Overview: Single Plant Reconstructions

Wheat



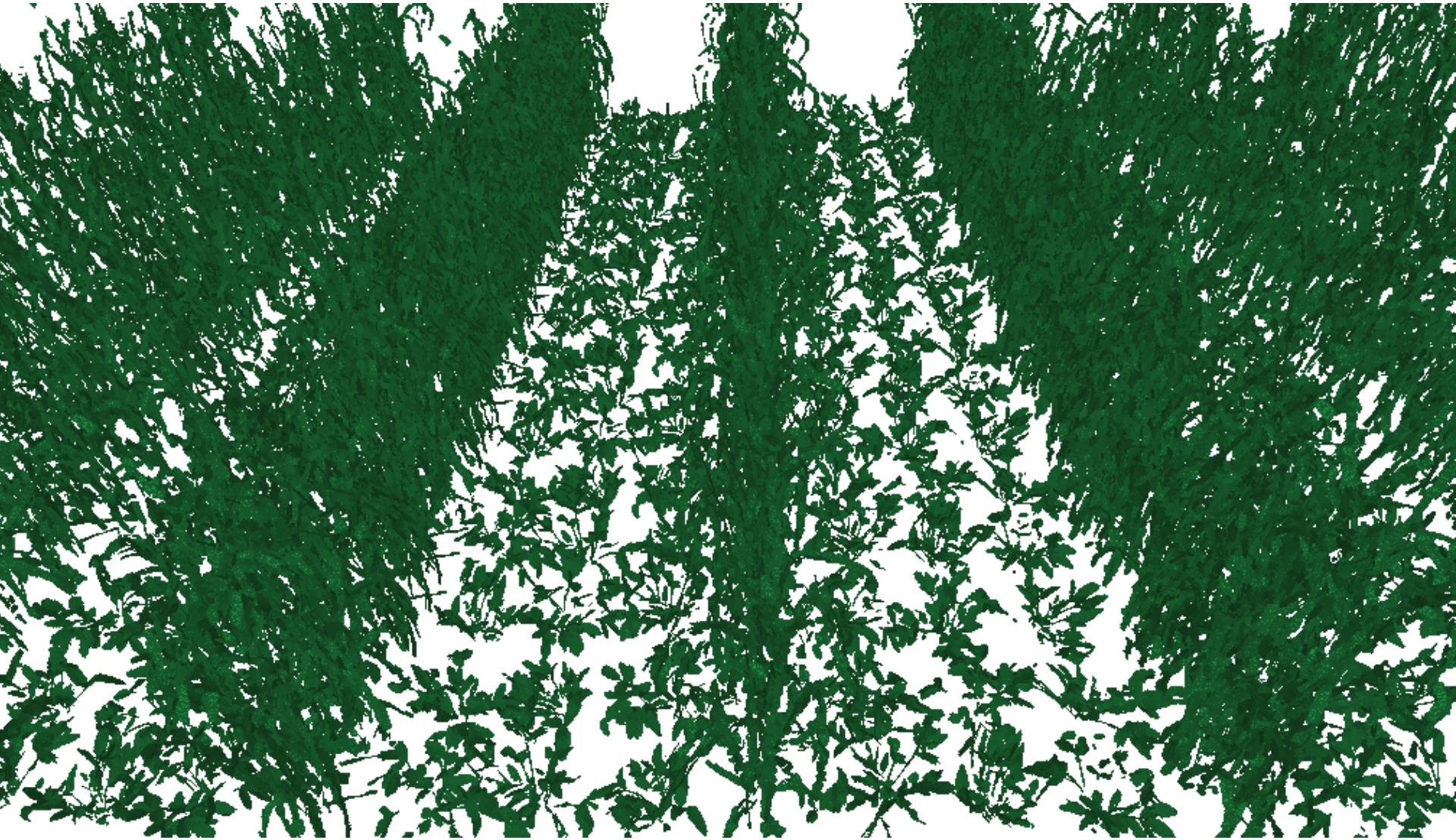
Rice

Bambara Groundnut (Dip-C)



Basil Lettuce Coriander

Stage 4: Canopy Population

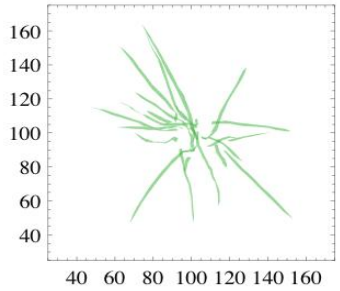


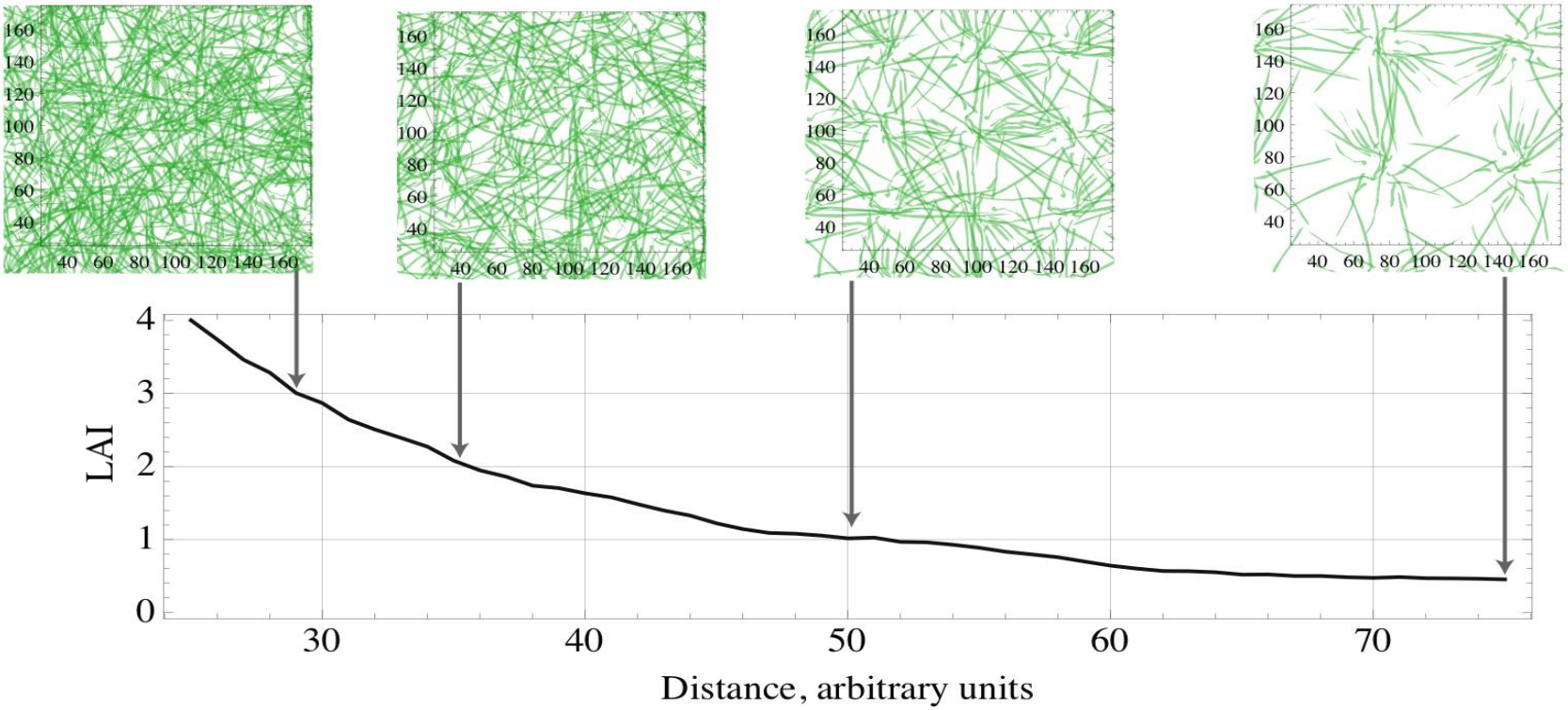
Stage 4: Canopy Population

Application: Canopy Measurements

Altering Canopy Properties

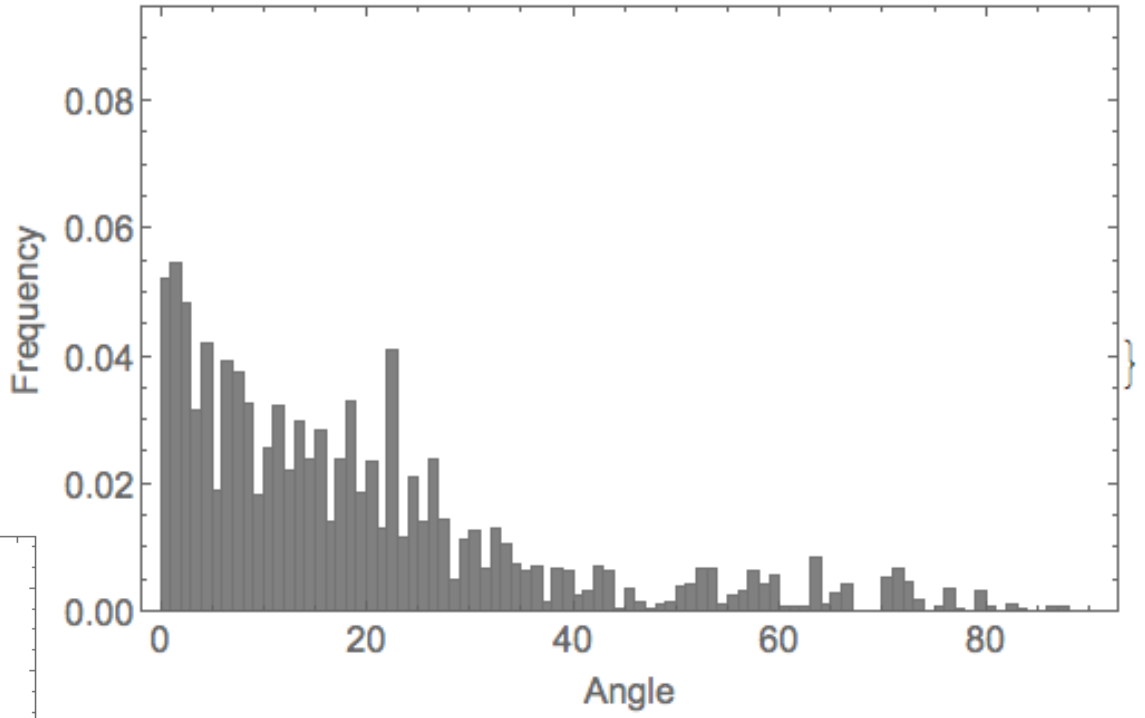
Single plant

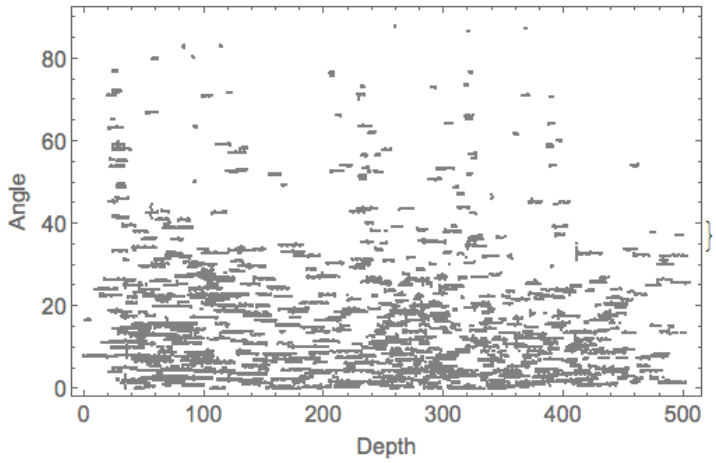


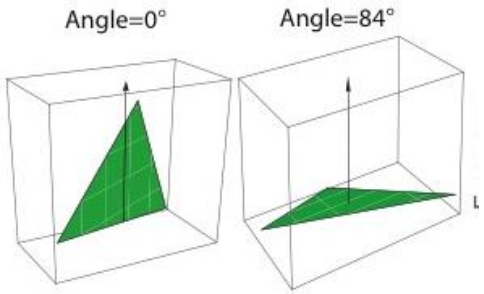


Application: Canopy Measurements

Leaf Angle Distributions







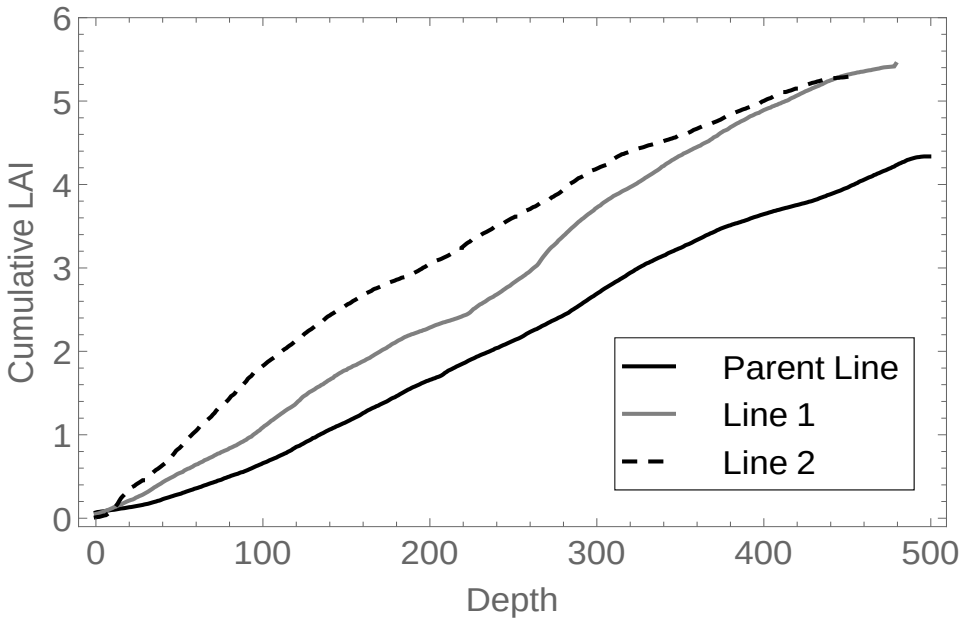
Application: Canopy Measurements

Cumulative Leaf Area Index

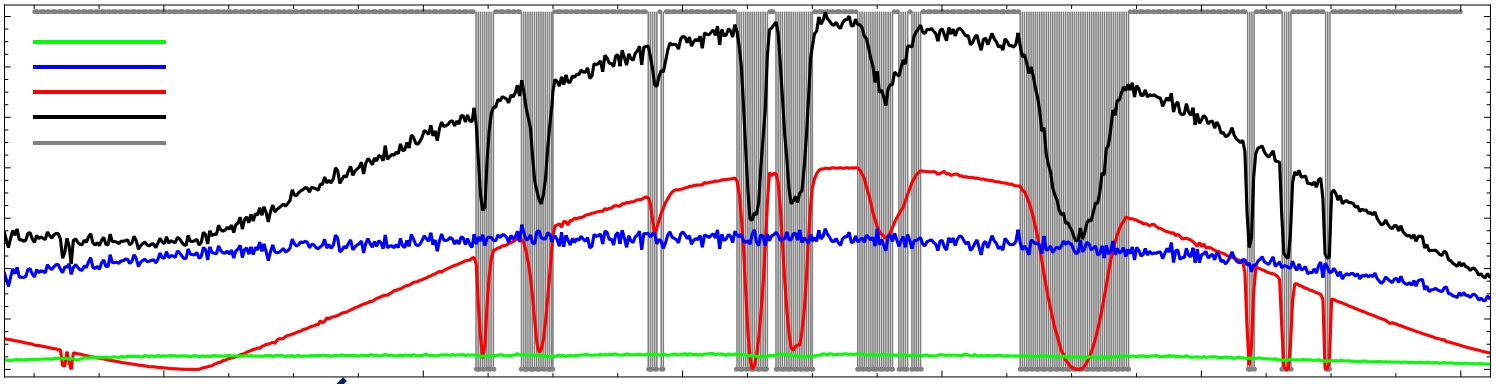
Parent Line

Line 1

Line 2



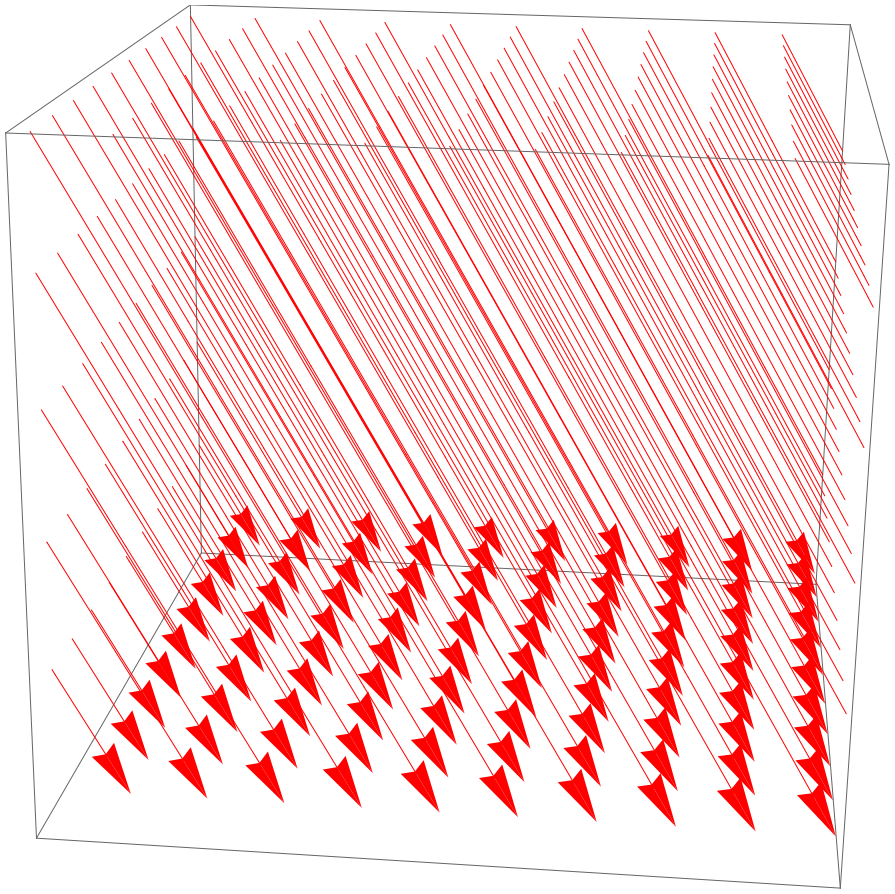
Linking Canopy Architecture and the Environment



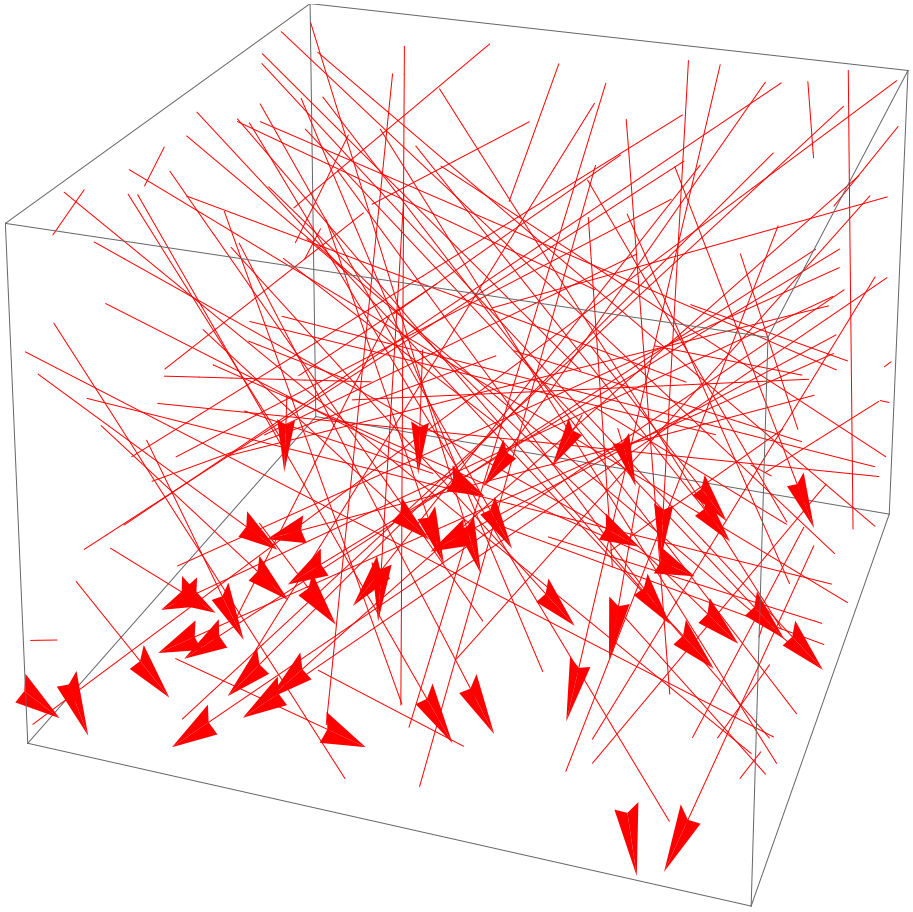
- Highly variable light environment in both time and space. Difficult to predict canopy levels responses.
- Solution: Ray tracing

Predicting Solar Movement: Ray Tracing

Direct light

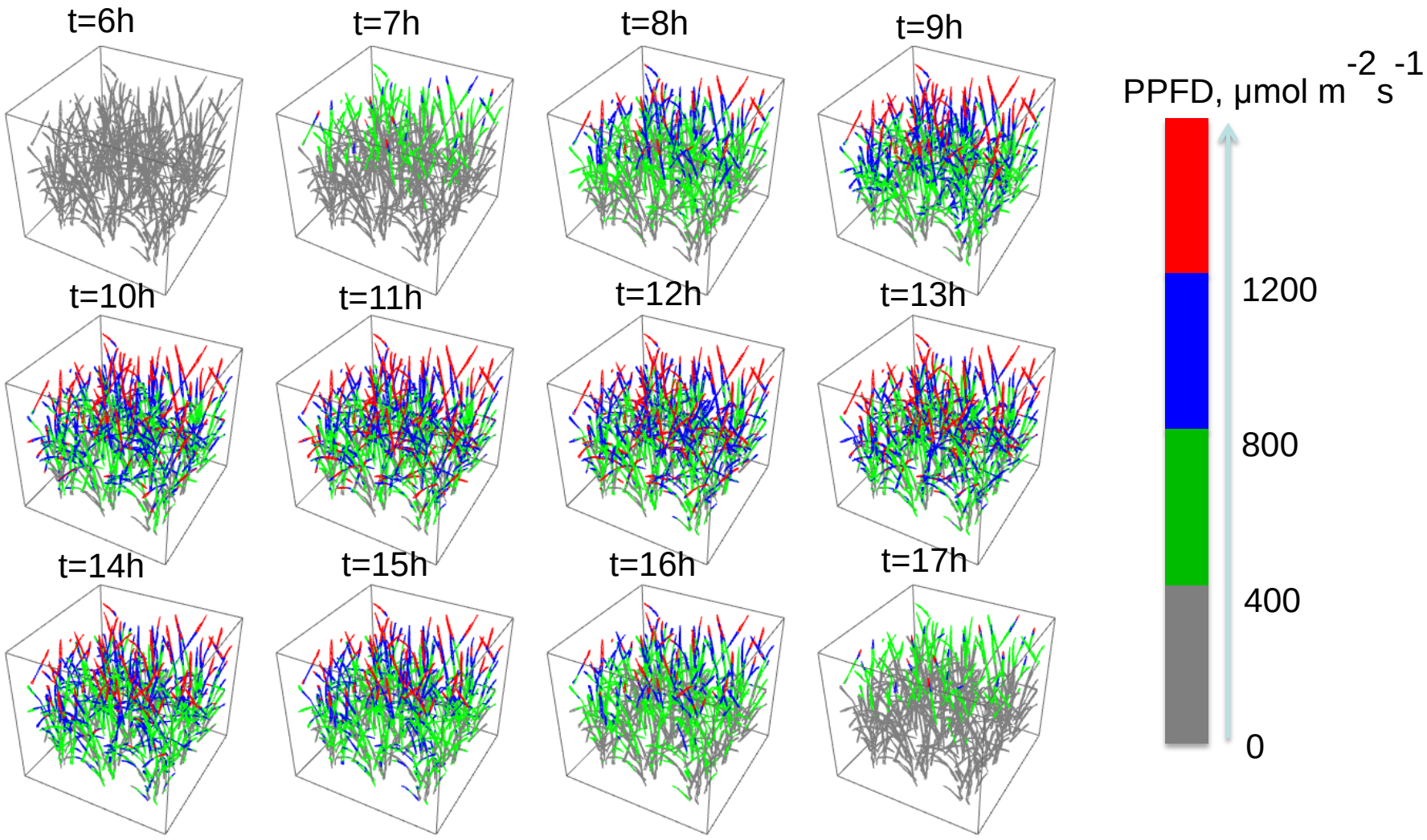


Diffused light

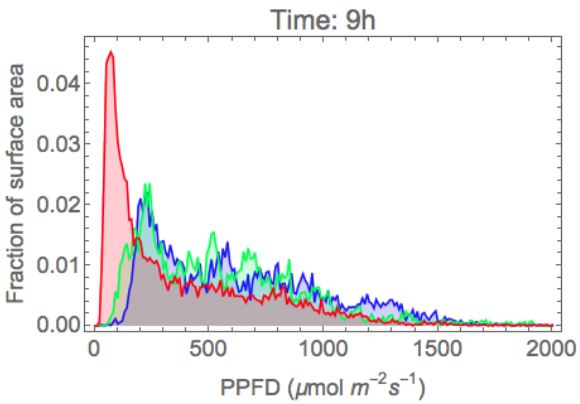


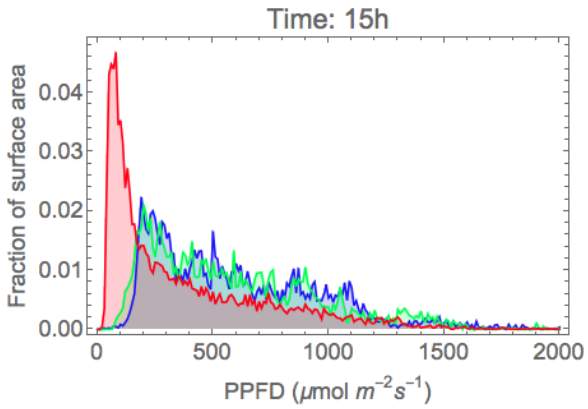
fastTracer (Song *et al.* 2013).

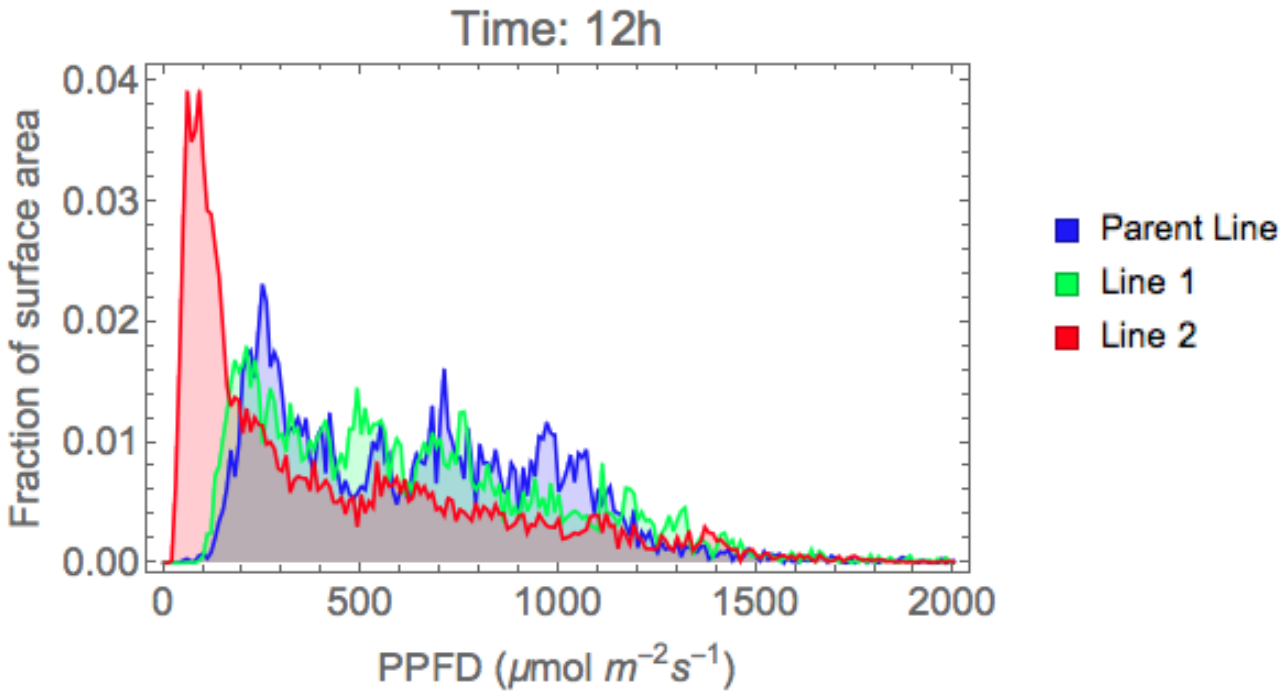
Application: Canopy Light Distribution



Application: Canopy Light Distribution

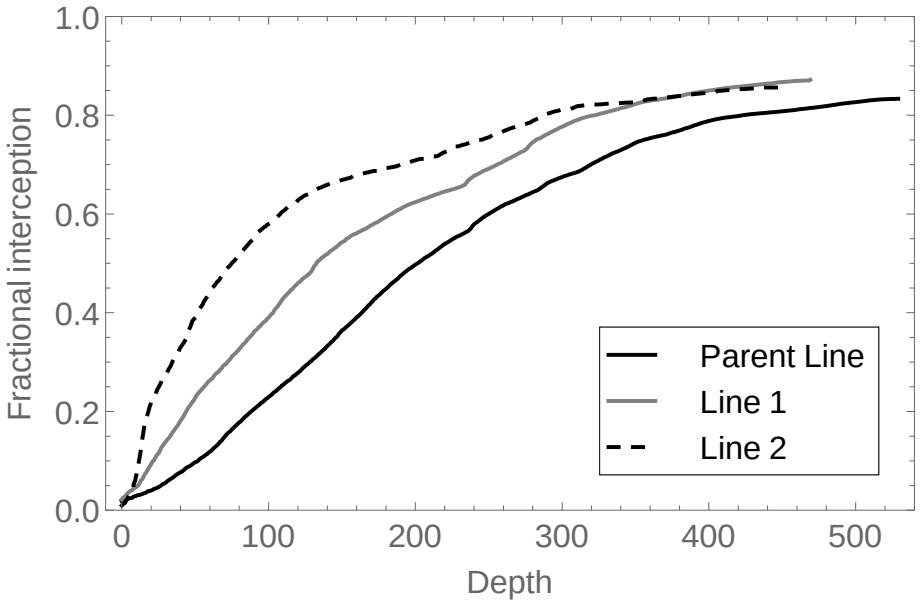


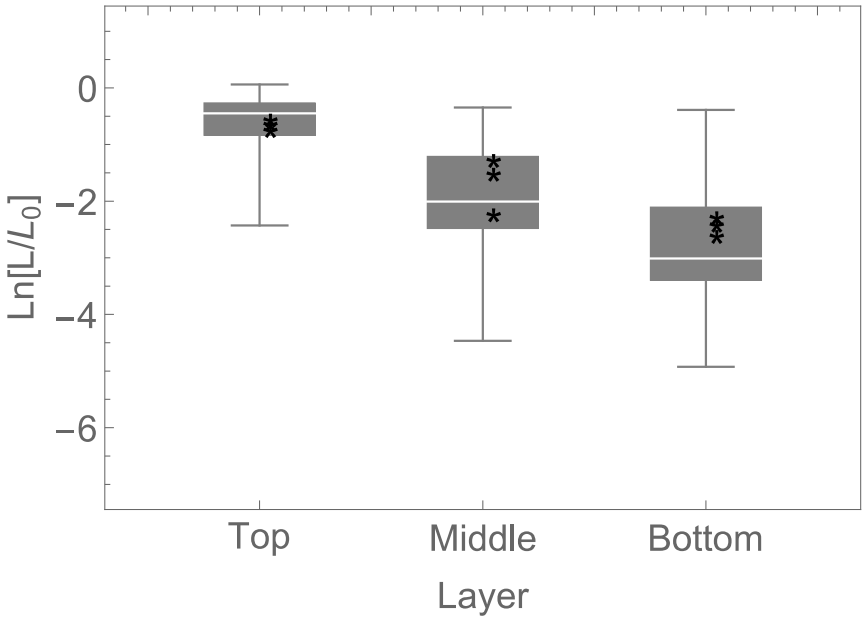




Application: Canopy Measurements

Light





Application: Photosynthesis Modelling

with Dr Renata Retkute

Ray Tracing
- Light levels within canopy

Data:
- Gas Exchange
- Fluorescence

Model Output
- Acclimation: what is the optimal P_{max} value for a section of leaf? And at the whole canopy scale?
- Photoinhibition: what is the effect of too much light on Carbon gain?

Burgess AJ, Retkute R… (2015) High-resolution 3D structural data quantifies the impact of photoinhibition on long term carbon gain in wheat canopies in the field. *Plant Physiology 2015 : pp.15.00722v1-pp.00722.2015*

Acclimation Model: Wheat

Parent Line (Ashby)
- Upright Canopy
- Lower LAI

Line 1
- Intermediate leaf curling
- Higher LAI

Line 2
- Extreme leaf curling
- Higher LAI

Future Work

- Reconstructions
  - Optimise the Reconstruction Method
  - Improve surface detail- separate out leaves and reduce gaps
  - Automate the reconstruction process
    - Automated Turntable
    - Robot Arm
  - Incorporate movement

- Photosynthetic Modelling
  - Canopy Level Acclimation

    Extension of: Retkute R, Smith-Unna SE, Smith RW, Burgess AJ, Jensen OE, Johnson GN, Preston SP, and Murchie EH (2015). Exploiting heterogeneous environments: does photosynthetic acclimation optimize carbon gain in fluctuating light? *Journal of experimental botany*: erv055.

- Assessing further canopies and light distributions

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