Agrivoltaics: part of the local energy community

Prof. Jan Cappelle (KU Leuven campus Ghent & EnergyVille)

Adaptation of agriculture to climate change

Protection of crops against extreme weather

- Summer storms are becoming more frequent, causing among other issues, hail damage.
- In 2018 drought caused a 37% decrease in potato yield
- Only a few excessively hot days can cause permanent damage to fruit

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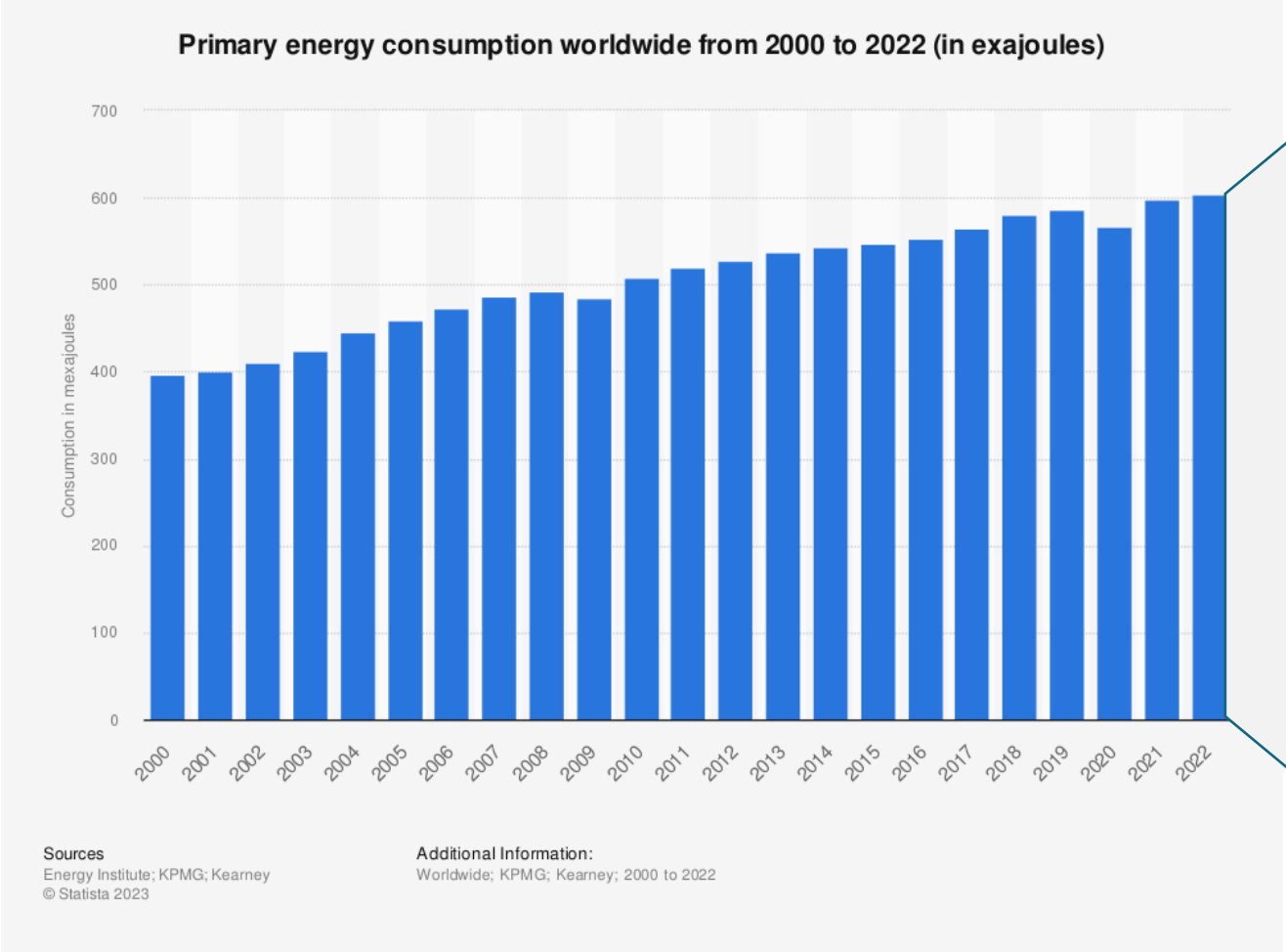
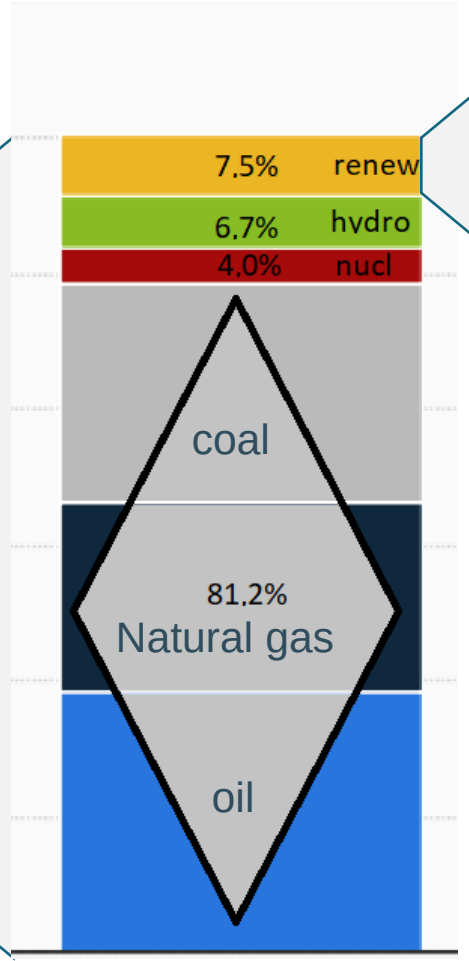
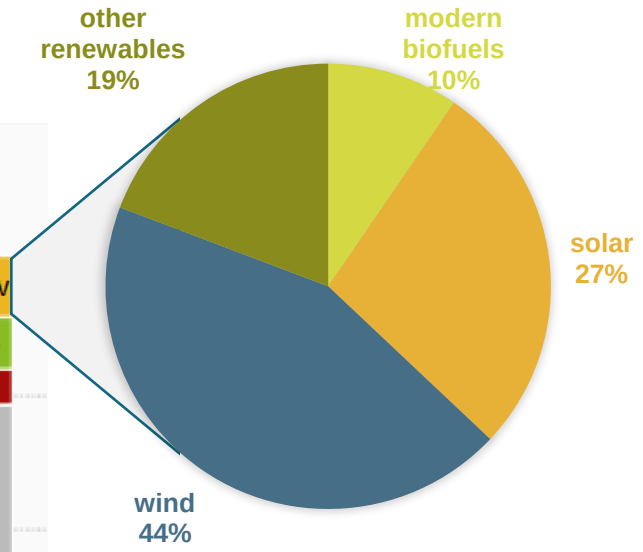
Mitigation urgently needed







2% Solar

Where to put more solar?

(B) 386 inhabitants per km^2

(B) 44% is agricultural land

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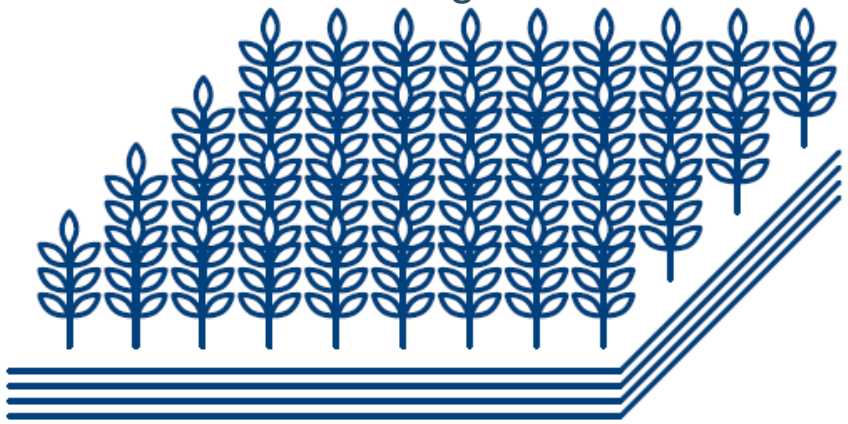
Competition between agriculture and energy?

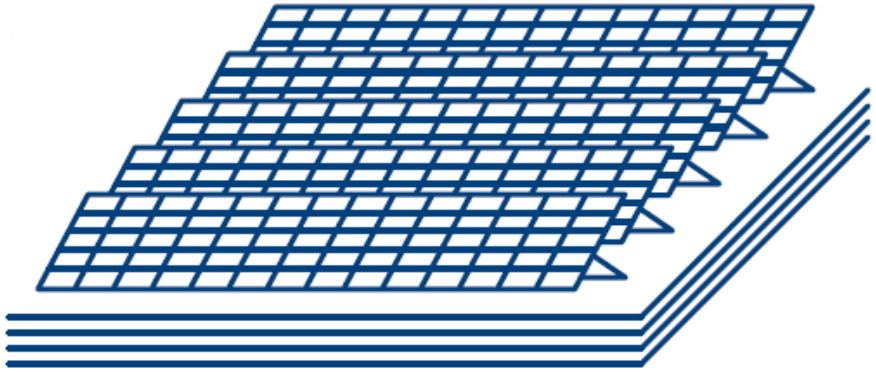
100% agriculture



Reference yield

2.050€/ha/y (peas)
|
36.000€/ha/y (Rhubarb)

100% PV



<1MWp/ha => 900MWh/ha/y

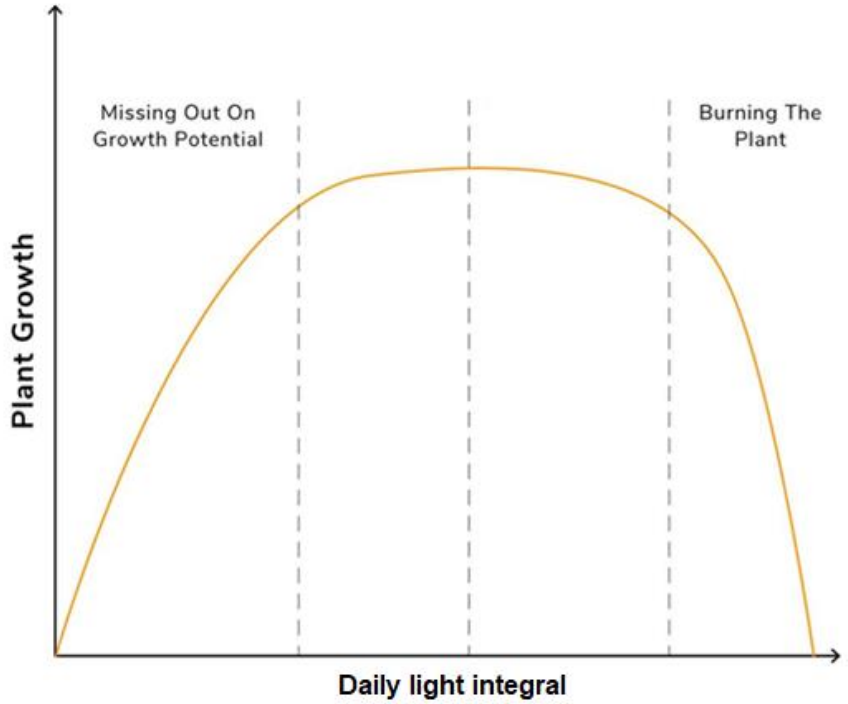
90.000€/ha/y (market price)
|
360.000€/ha/y (household)

Land efficiency = 100%

Combining energy and food production

- Plant growth is strongly related to daily available light
- At high irradation levels the impact of extra light on growth reduces.
- Too much light may lead to sunburn of plants

Use the excess light to produce energy



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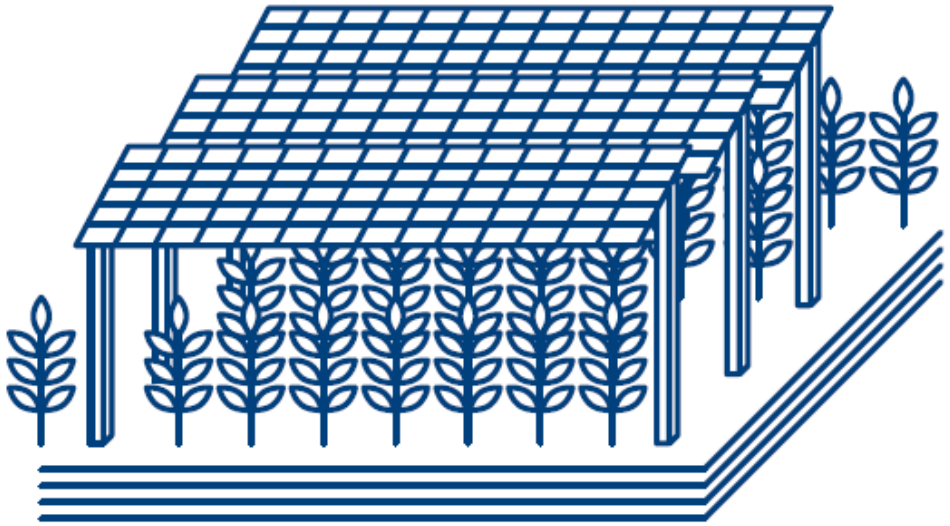
Combining energy and food production



Crop yield 80%

PV yield 80%

Land efficiency = 160%

Combining energy and food production

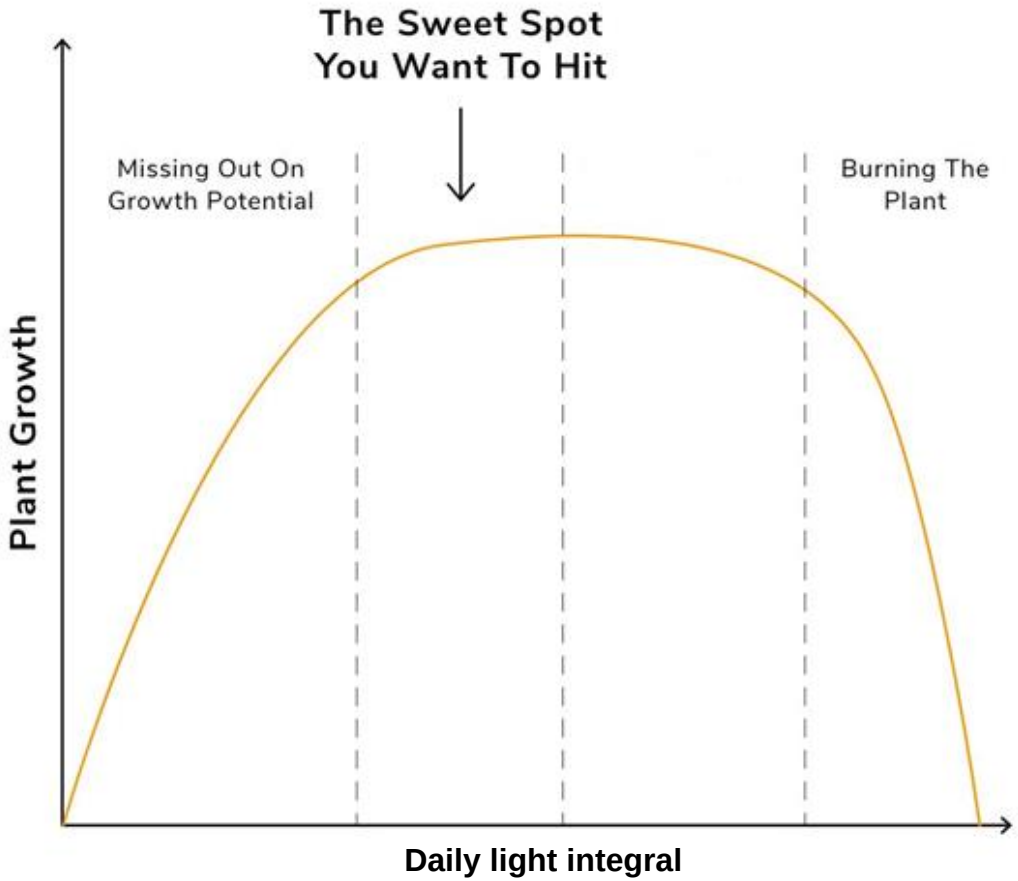
In the Belgian climate

⇒ little excess light

⇒ a reduction in light will most probably lead to loss in crop yield

Carefully looking for synergies:

- certain crops can better cope with shadow
- Other crops experience benefits (e.g. lettuce looking for more light may lead to bigger leaves)



Practical agrivoltaics metrics

Land equivalent ratio

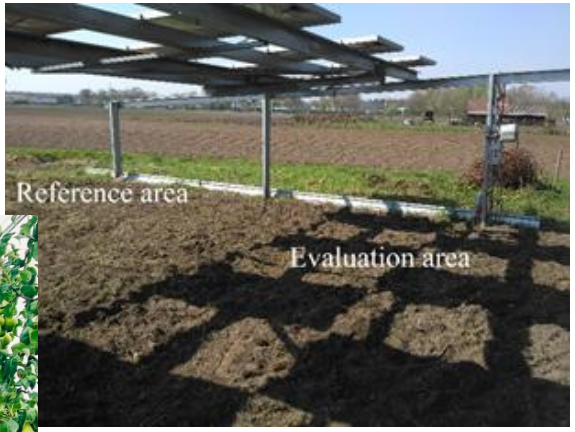
$$LER = \frac{Y_{agri,AV}}{Y_{agri,ref}} * (1 - LL) + \frac{Y_{el,AV}}{Y_{el,ref}}$$

Land Productivity Factor

$$LPF = \frac{G_{\text{rel}}}{100} + \frac{Y_{el,AV}}{Y_{el,ref}}$$

KU Leuven: field trials

- First experiment: master thesis (Ministry of Solar)



- Flemish project
  - Bierbeek (pear)
  - Grembergen (sugarbeet)

- Horizon Europe:
  - Lovenjoel (field crops)

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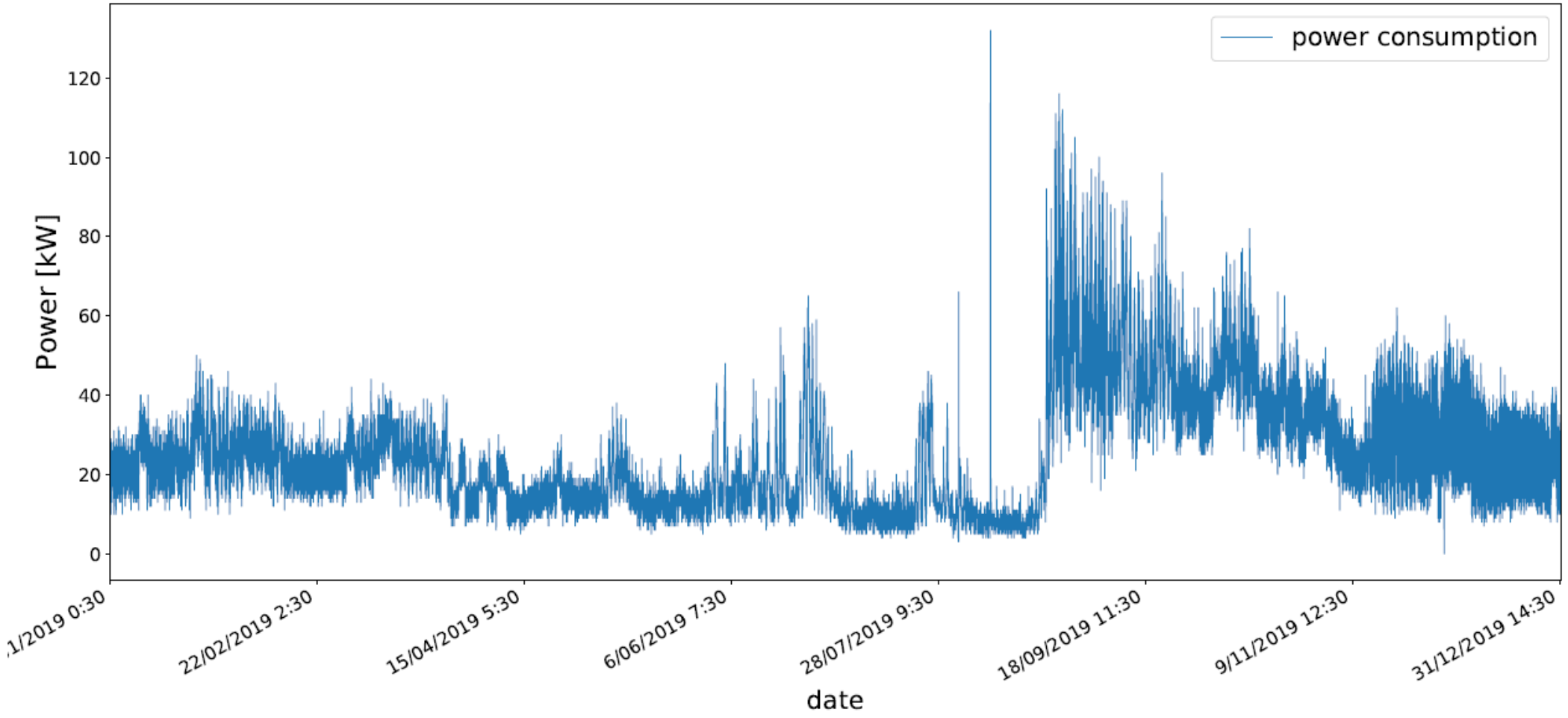
Bierbeek test field with pears

Hailnet protection system with wooden understructure

Bierbeek electricity consumption



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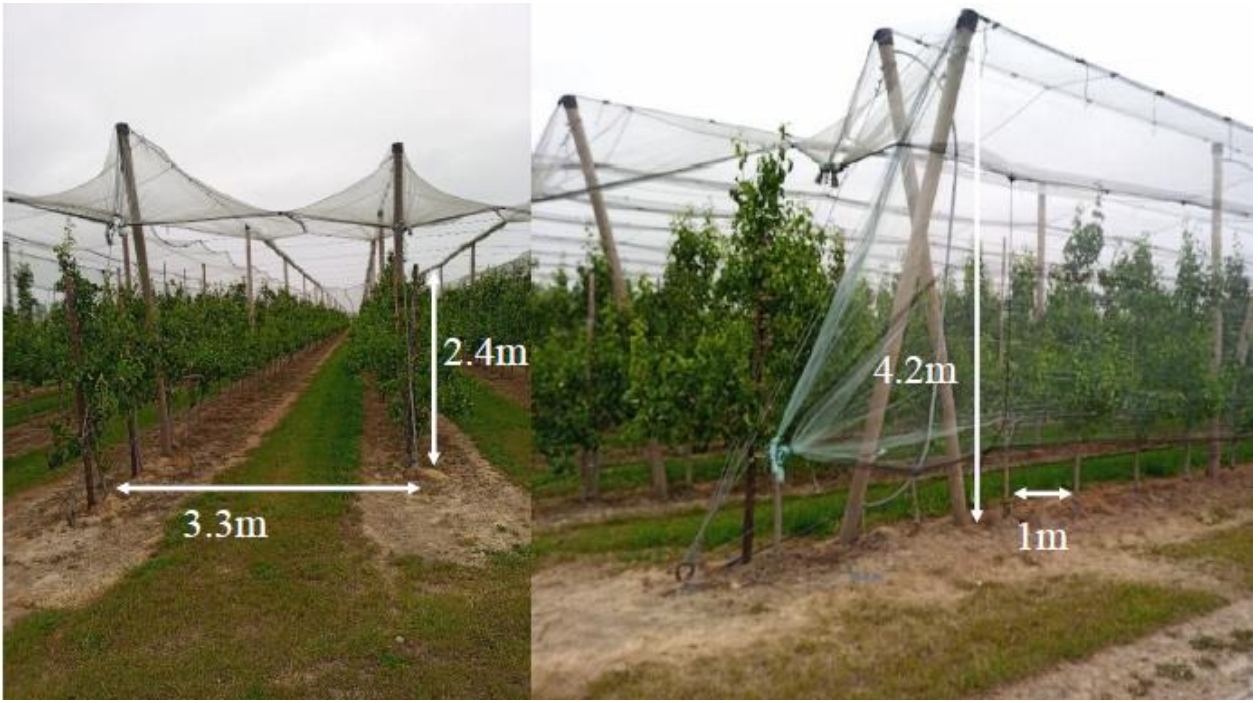
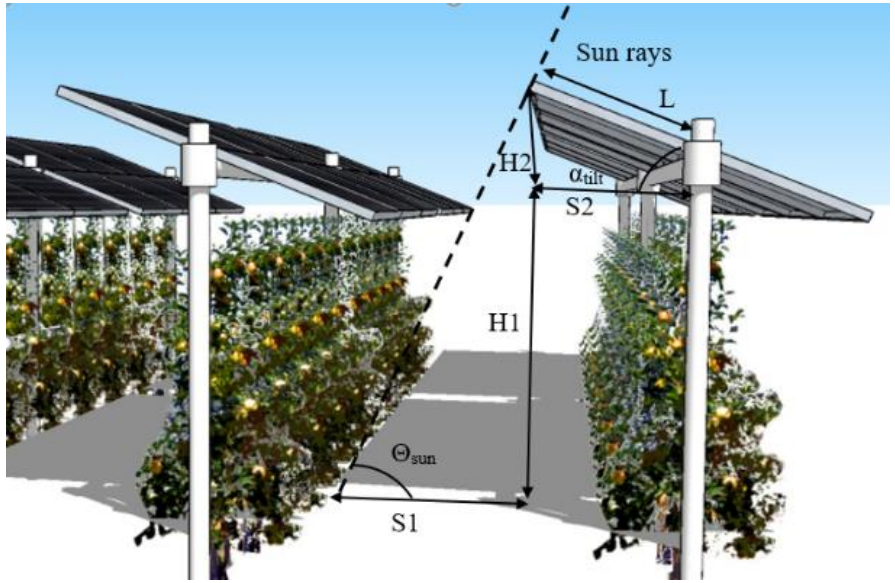
Design constraints

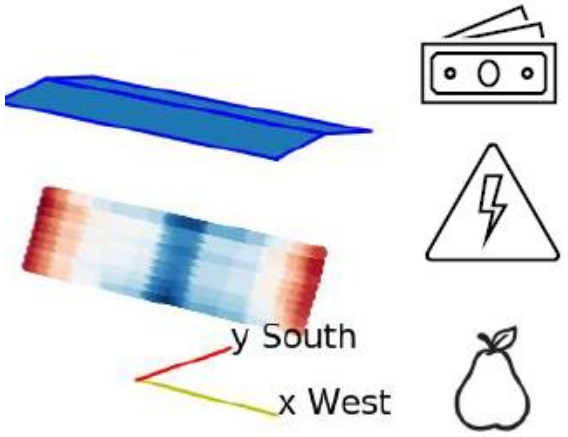


fixed

25° SE
Above pear trees to protect against hail



free



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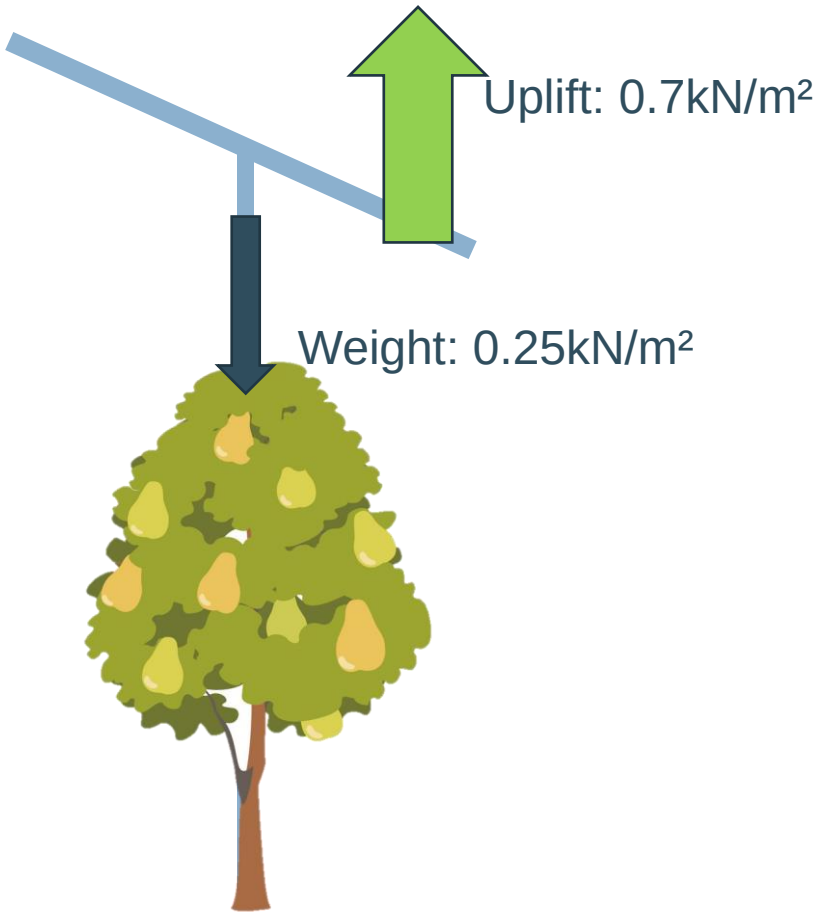
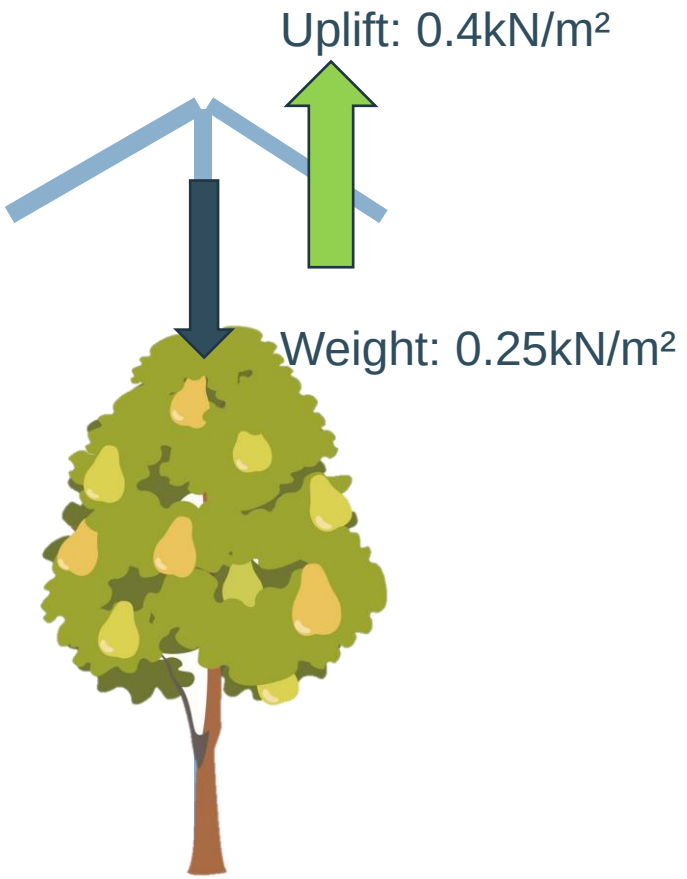
Structural design

Need to limit the lift force of the PV modules



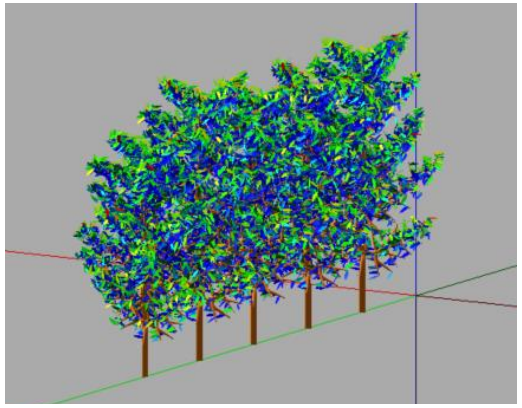
Liftforce => – 40%!
Annual PV yield => -5%

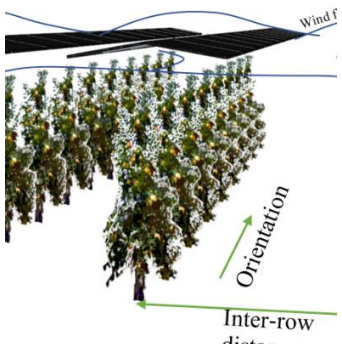


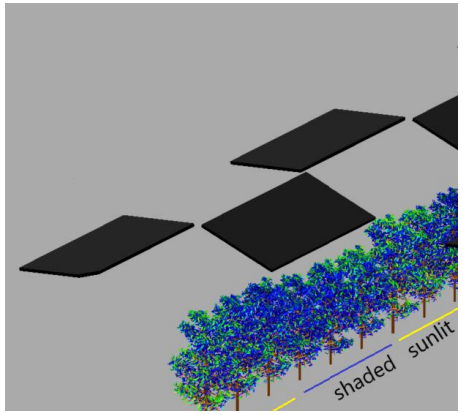
Calculations based on standard **NBN EN 1991-1-4**

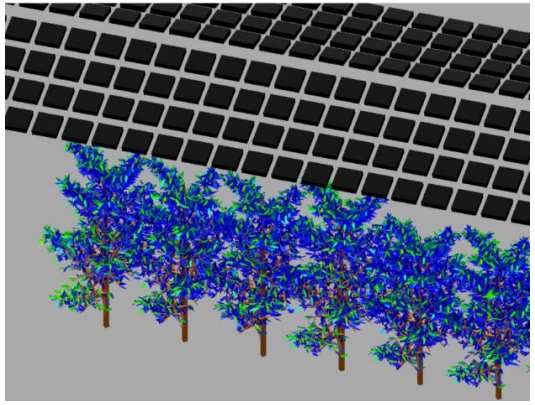
PV canopy design

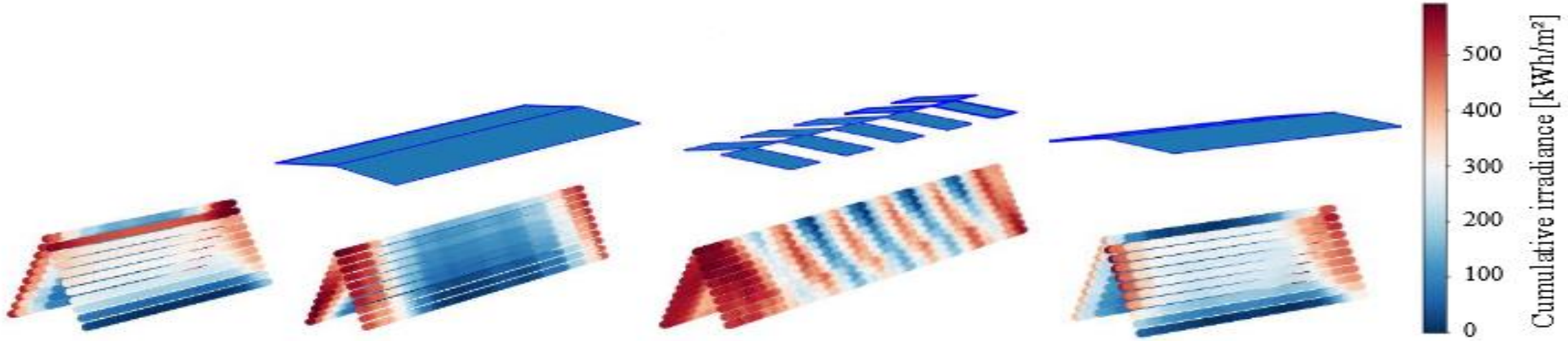
balancing between energy, light (distribution) and investment











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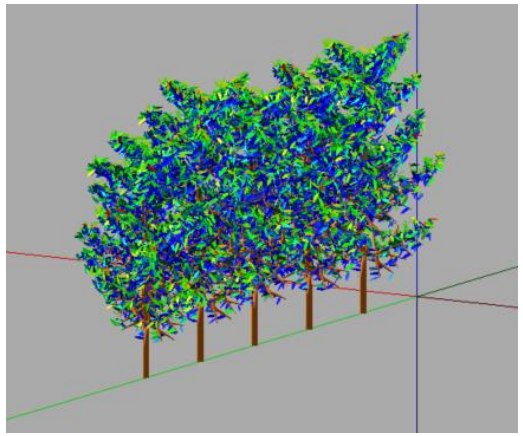
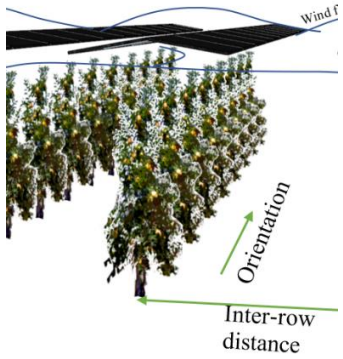
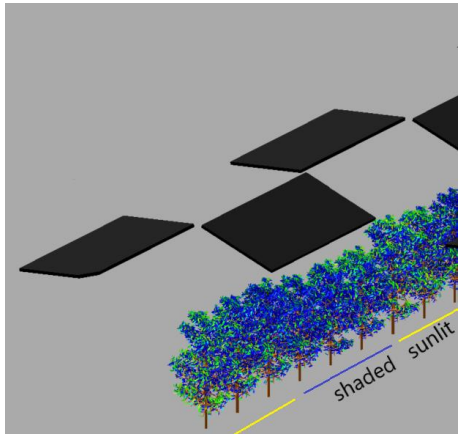
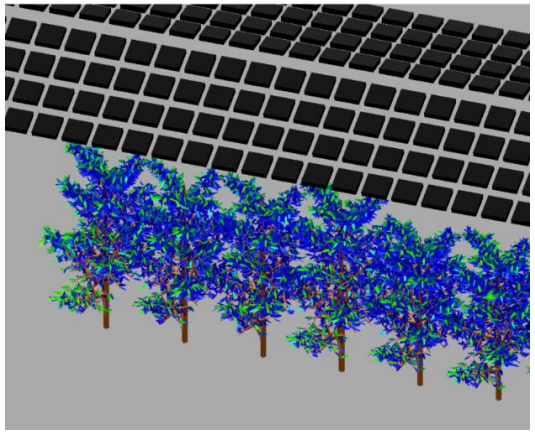
PV canopy design

balancing between energy, light (distribution) and investment



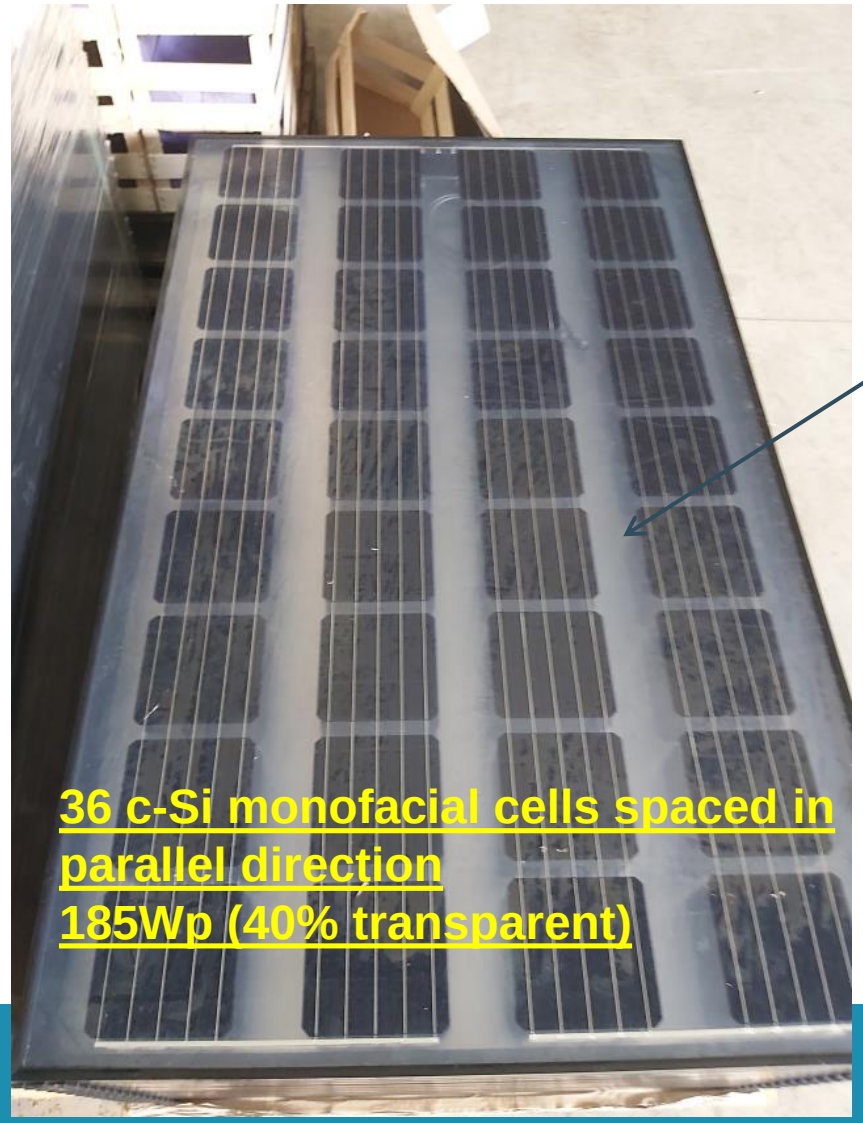






PV Capacity [kWp/ha]	0	1200	600	720
Energy [MWh/ha/y]	0	1350	680	821
LCOE [€/MWh]	0	75	100	130
Grel flowering [%]	100	55	77	72
Grel growing [%]	100	51	75	72
LPF	1	1,5	1,27	1,32

PV module design



36 c-Si monofacial cells spaced in parallel direction
185Wp (40% transparent)

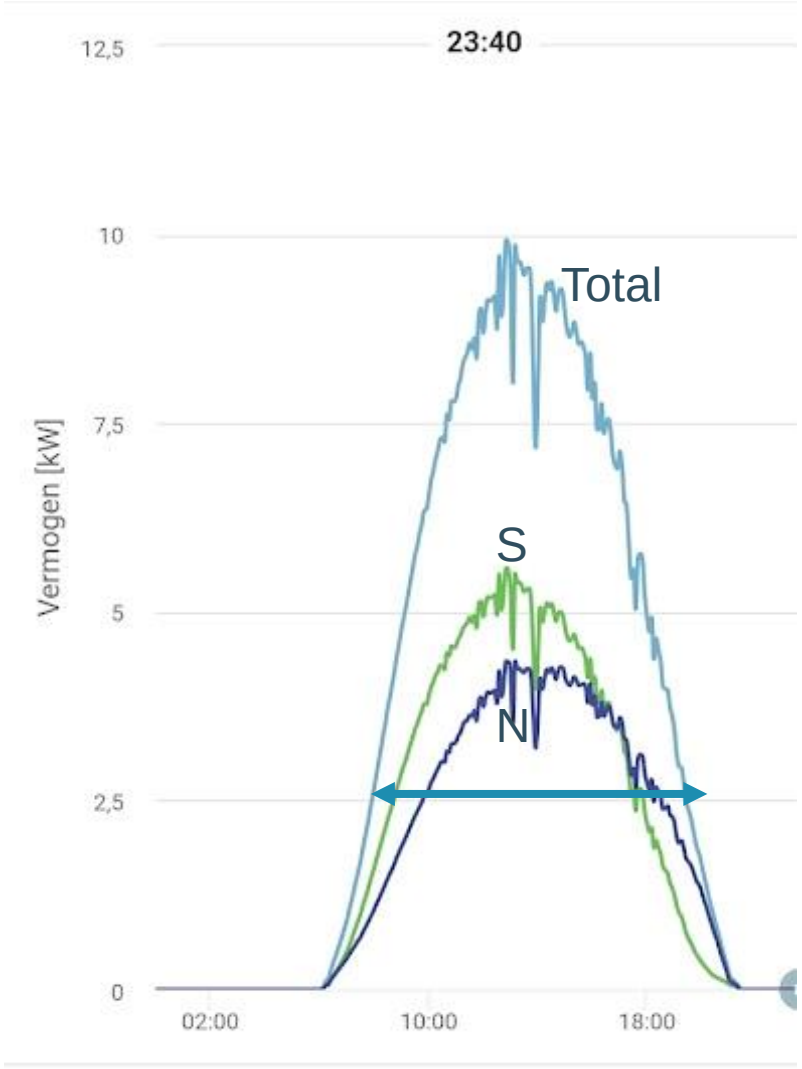
Diffuse backsheet (-10% PAR)

Resulting in a homogeneous bundle of light

PV yield: production profile

South side produces more power

- But the 25° N/S configuration spreads the production profile
- Which results in a self-consumption rate of 85%



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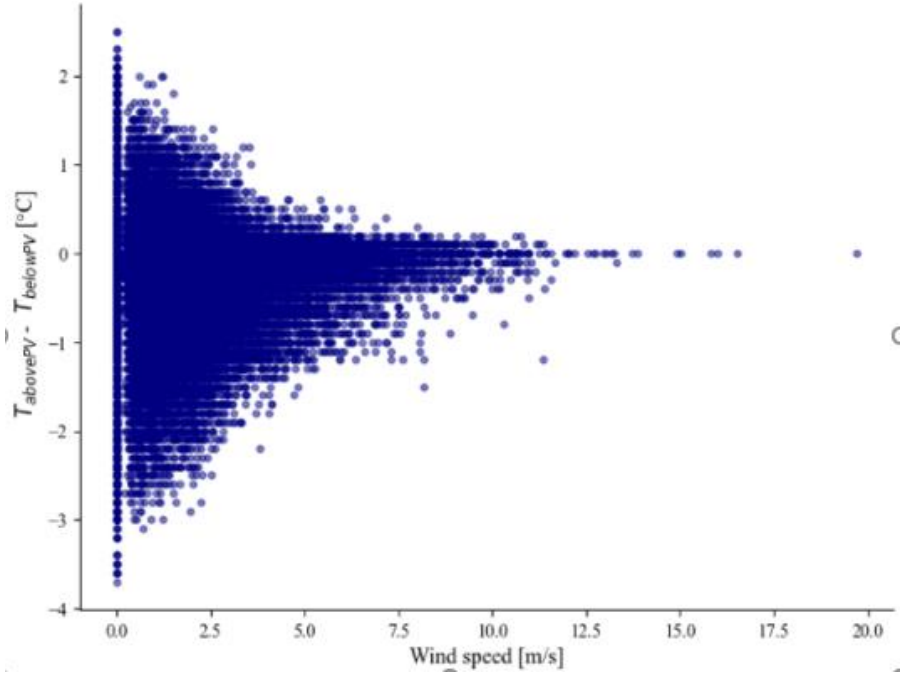
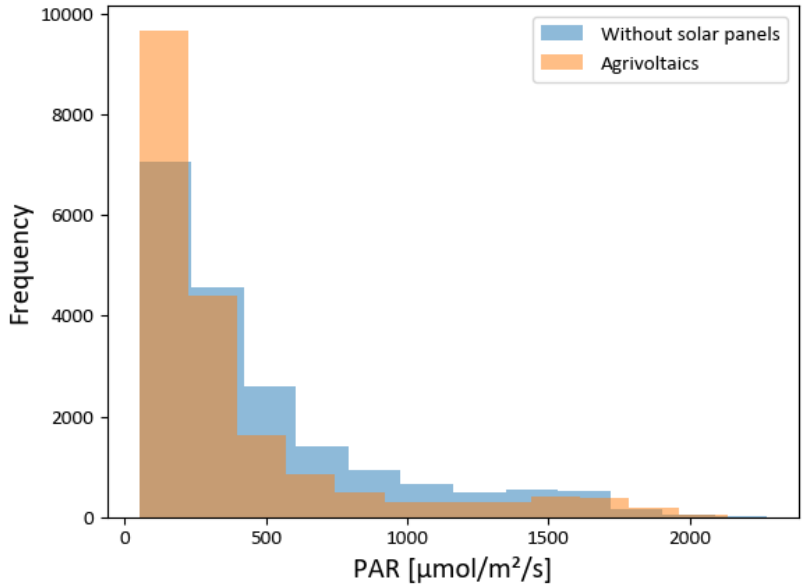
Microclimate

Air temperature
- Advantageous for crop growth / frost protection
- Difference fades out at higher wind-speeds



PAR distributions
- Higher frequency of low PAR values
- Less chance of sunburn



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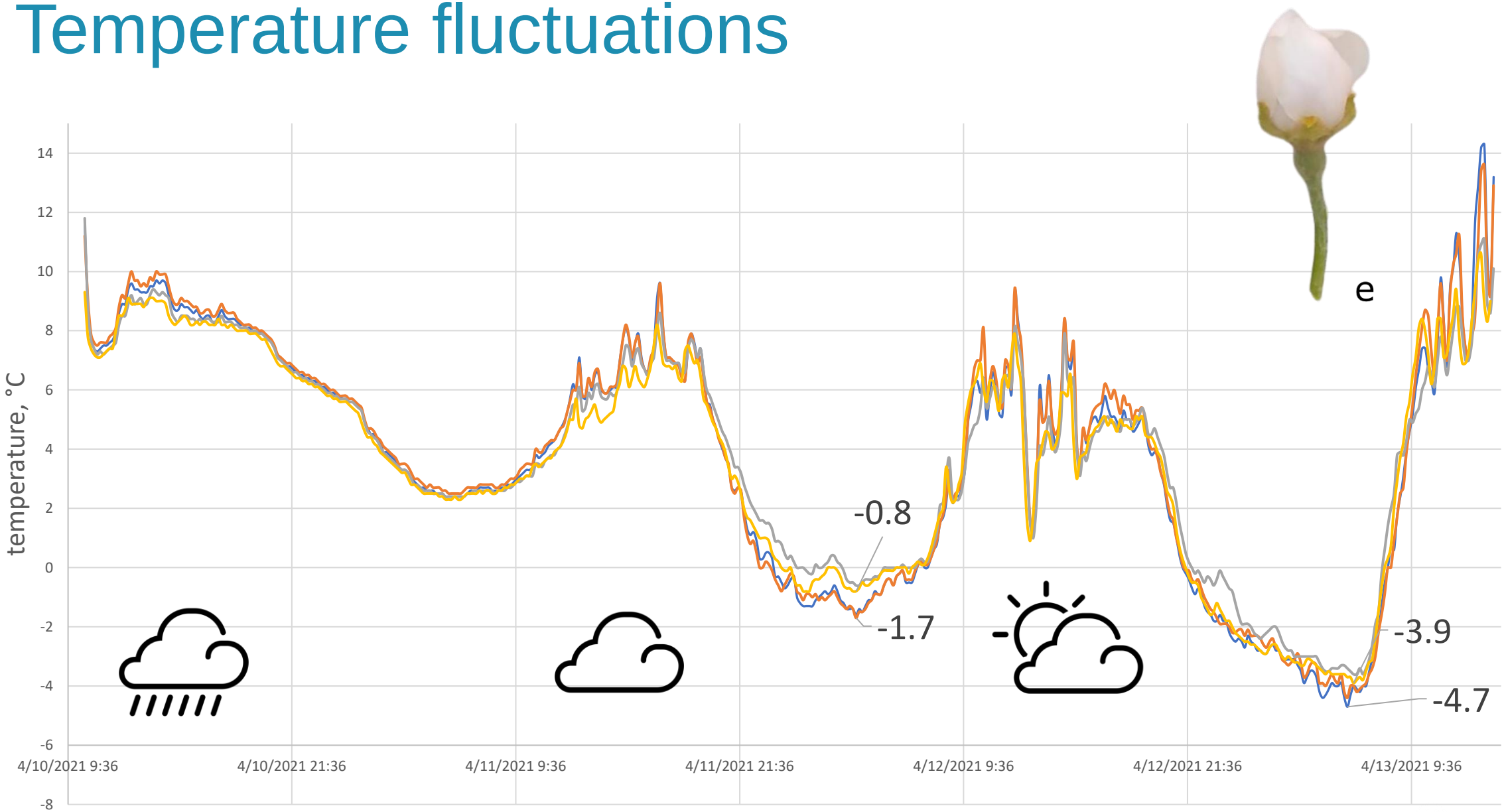
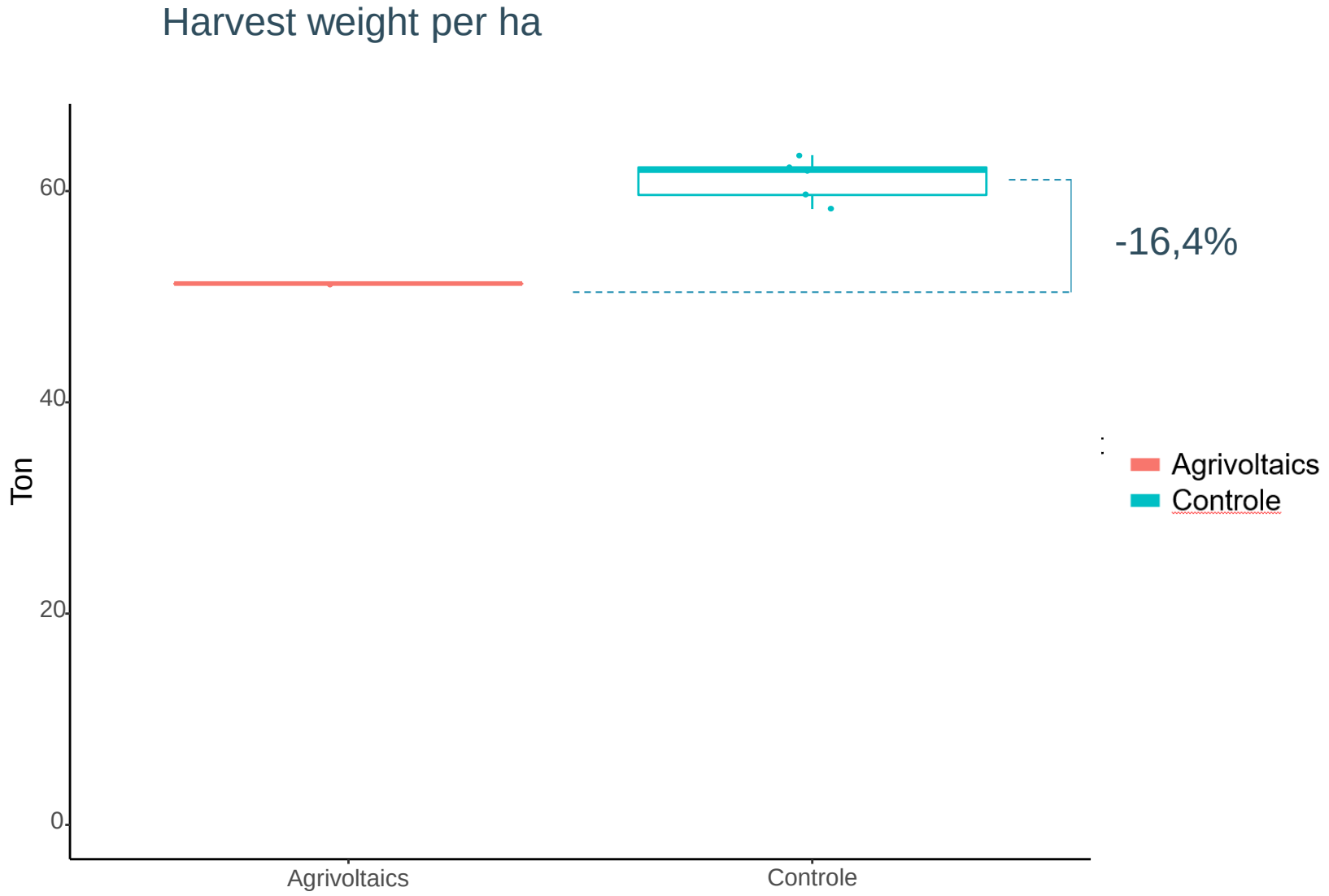
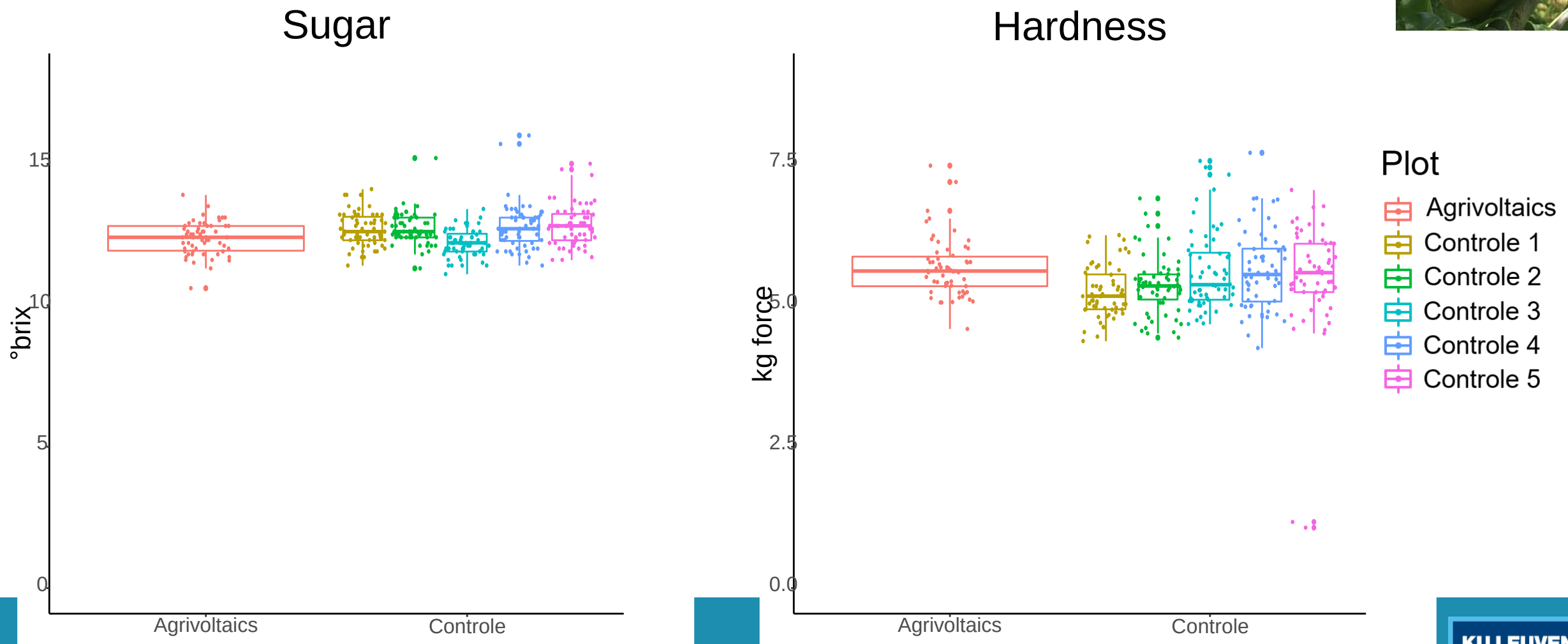
Temperature fluctuations



Pear yield


Harvest weight per ha
60
40
20
0
Ton
Agrivoltaics
Controle
-16,4%
Agrivoltaics
Controle

Pear quality



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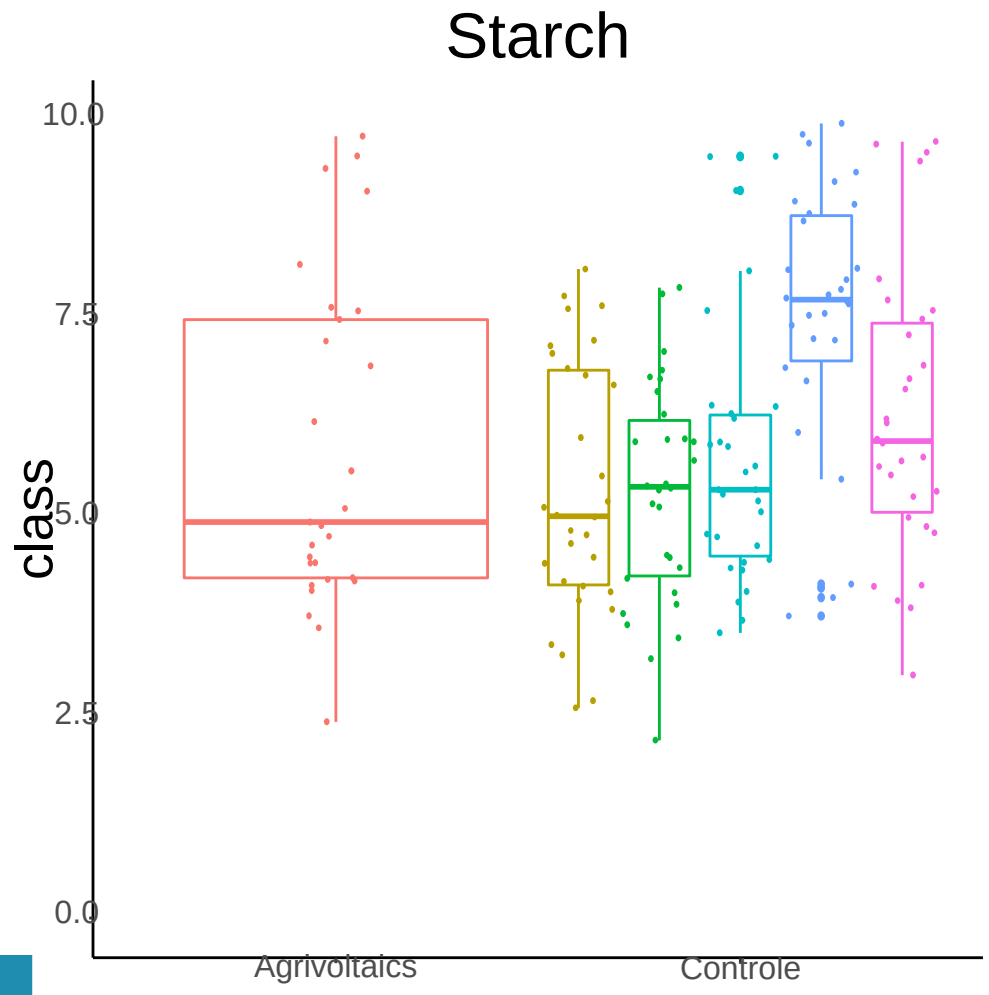
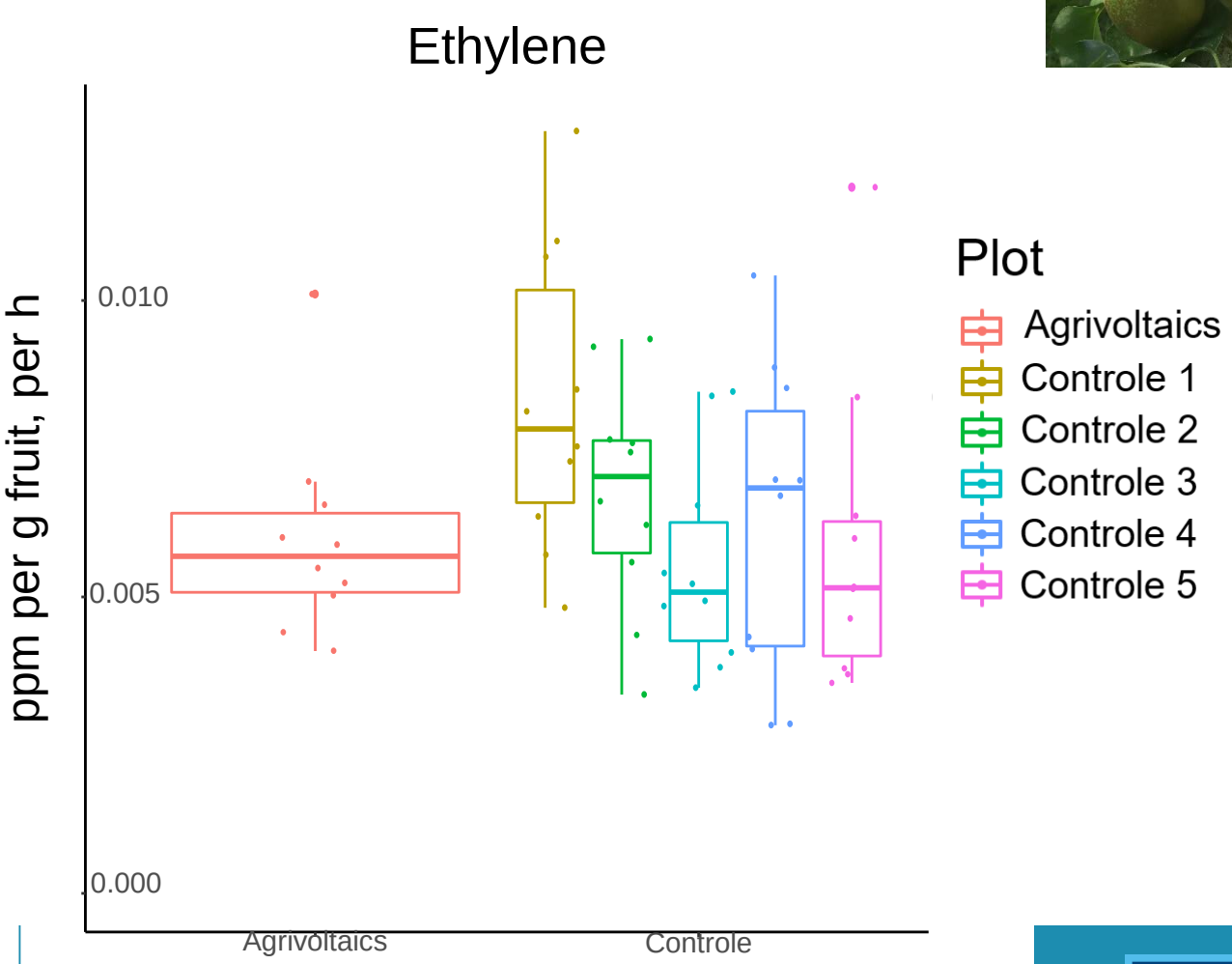
Pear quality

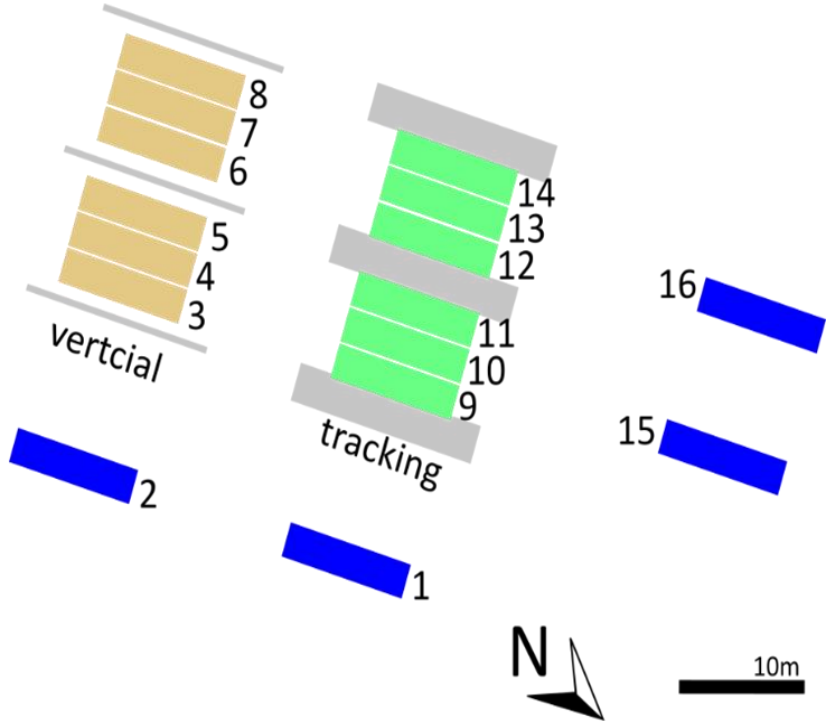




Grembergen test field sugarbeet

A

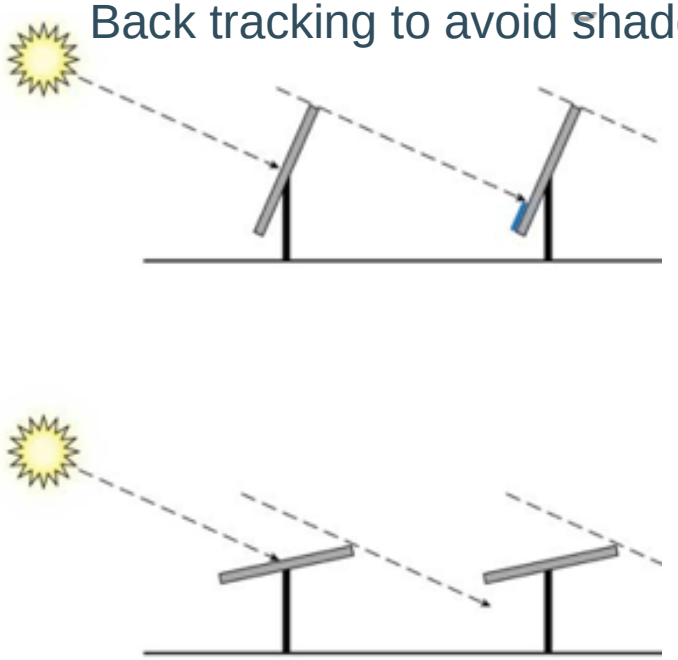
B



Smart tracking

Full tracking

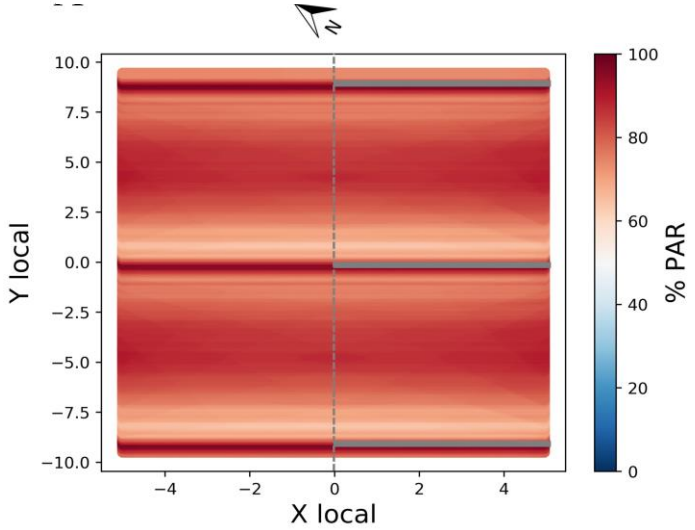
Back tracking to avoid shadow



Smart tracking based on crop needs

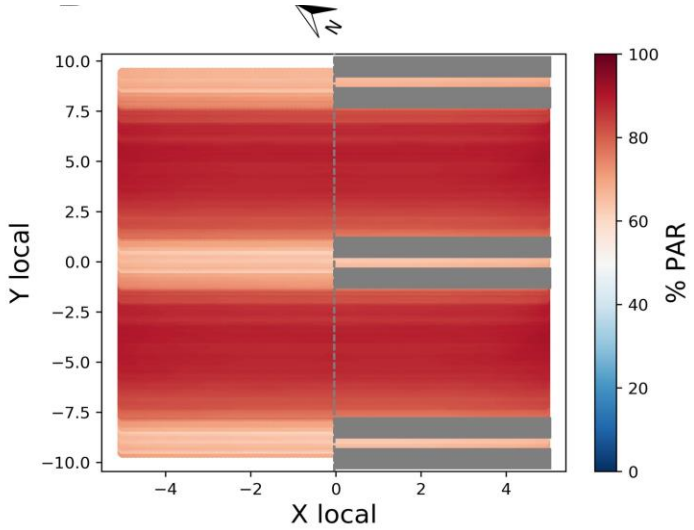
Grembergen relative radiation distribution

Vertical bifacial



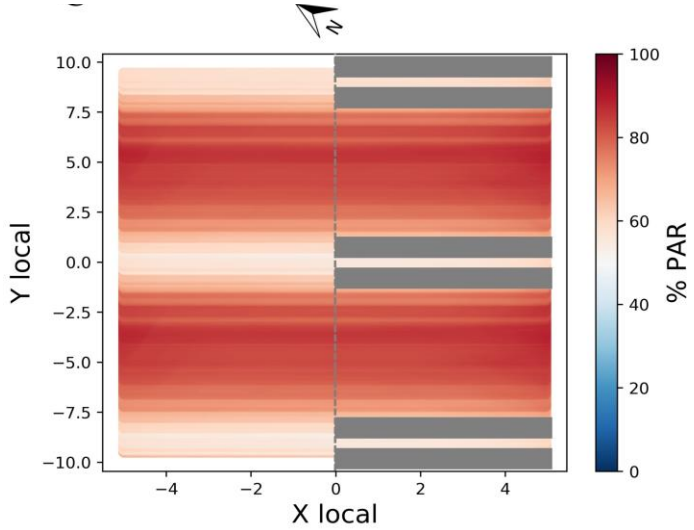
Grel=86%±0.7%

Smart tracking



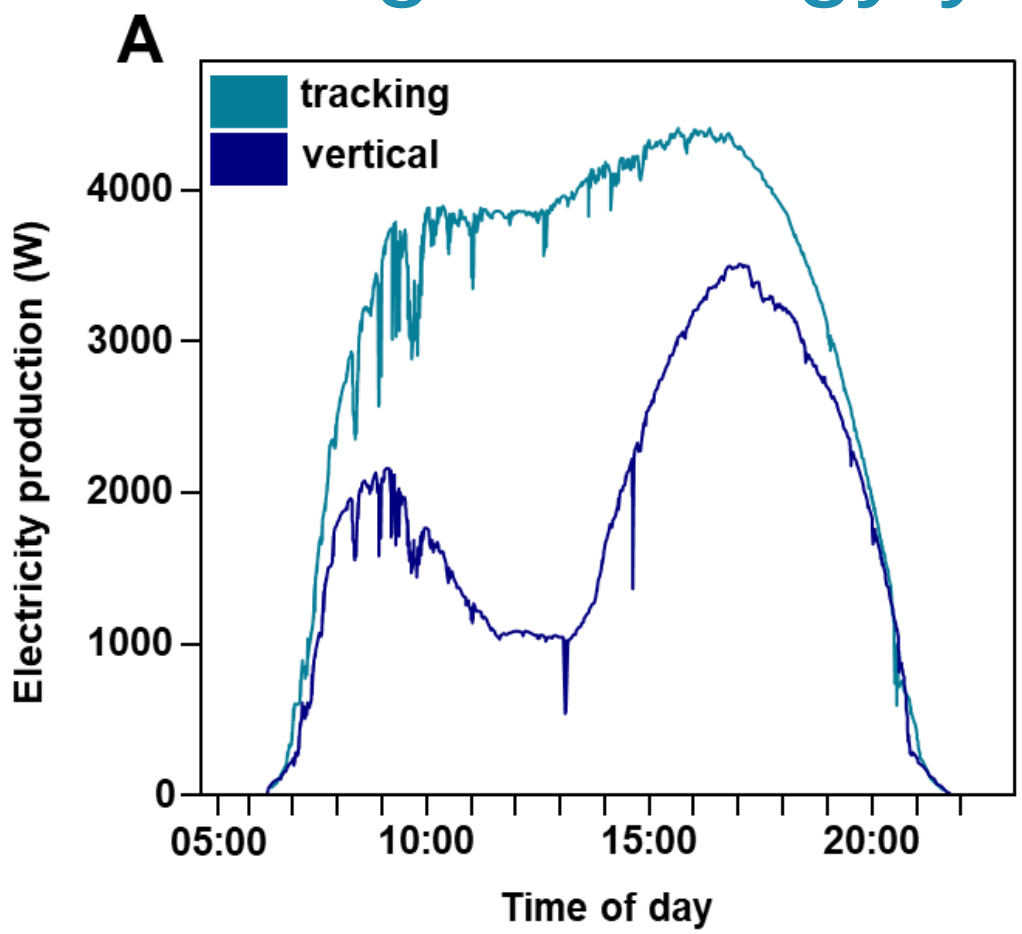
Grel=88%±0.2%

Full tracking

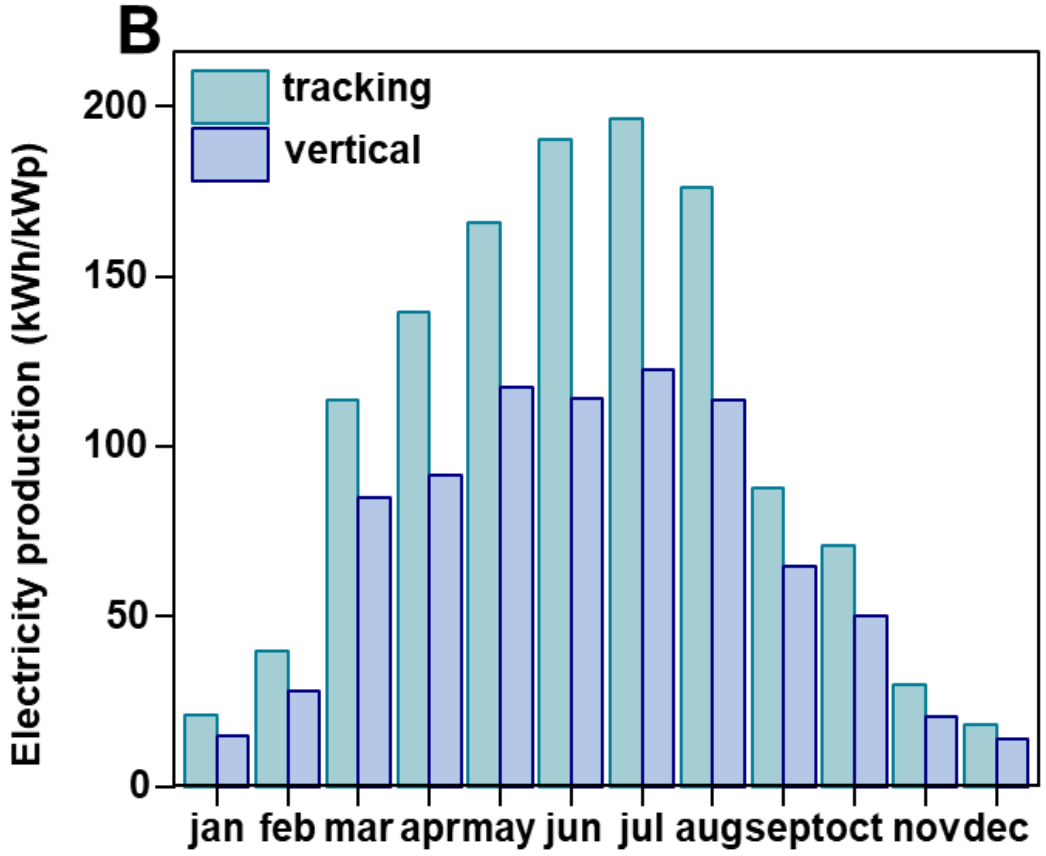


Grel=83%±0.7%

Grembergen energy yield

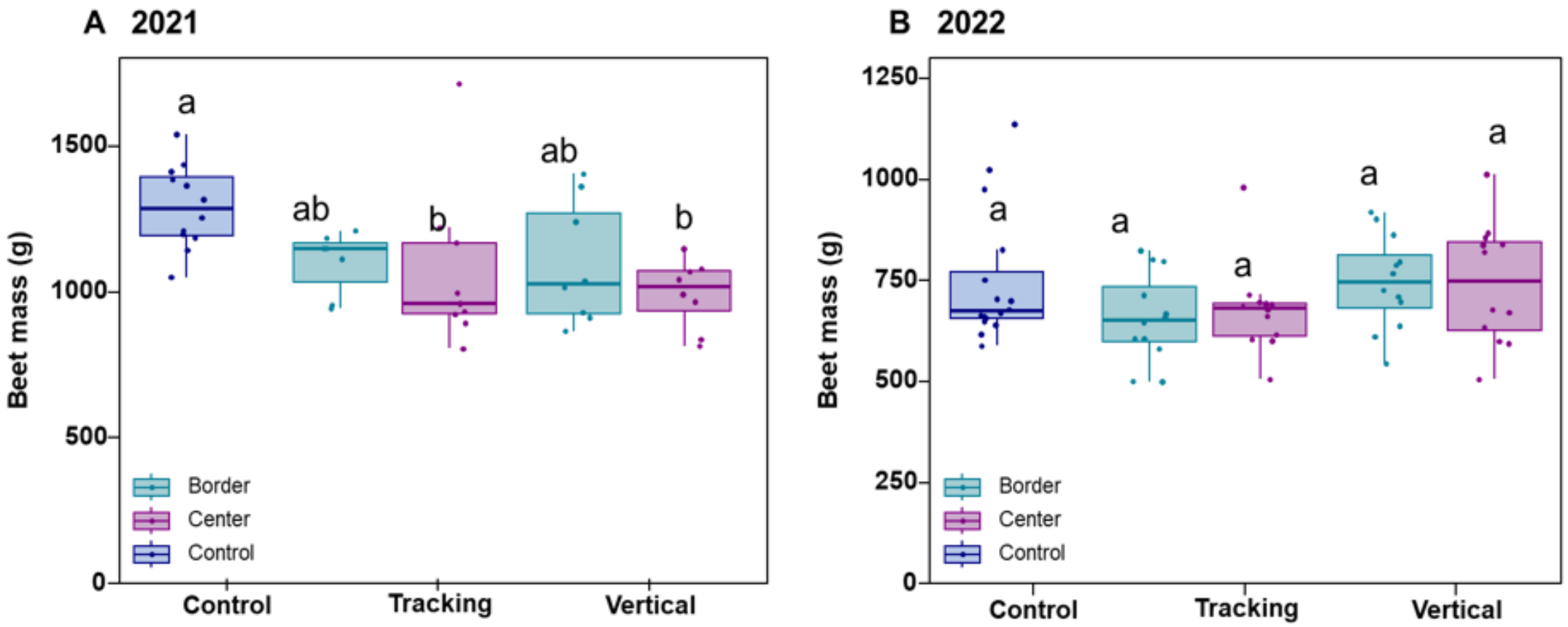


Electricity production on 18/7/2022



Measured monthly electricity production in 2022

Grembergen beet yield



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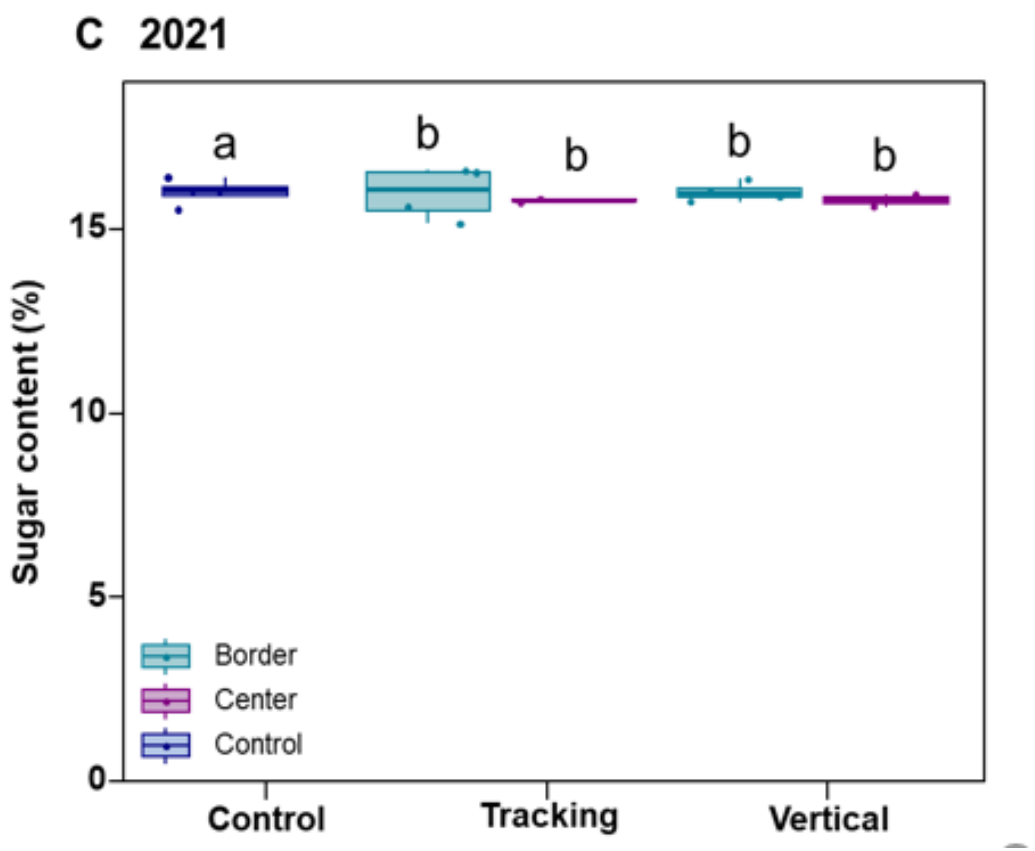
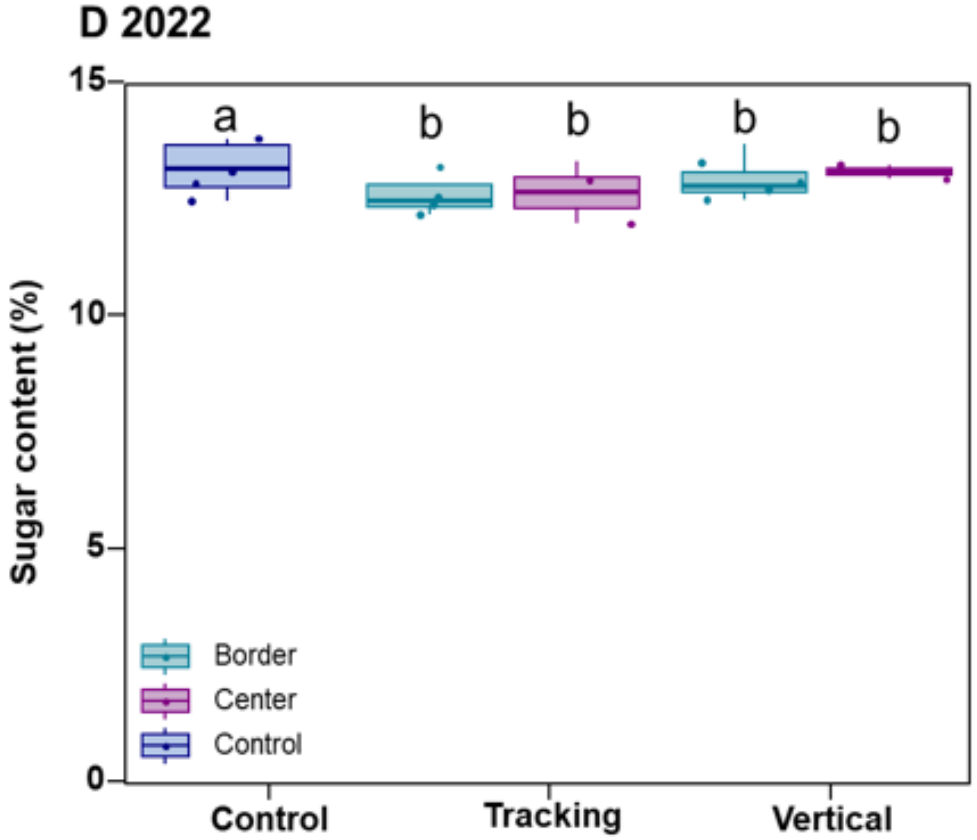
Grembergen beet quality





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Results Grembergen sugar beets

	Vertical		Tracking	
Season	2021	2022	2021	2022
Power (kWp/ha)	450	450	450	450
Specific electricity yield (kWh/kWp)	835*	835	1245*	1245
Electricity yield (MWh/ha)	376	376	560	560
LCOE (€/MWh)	117	117	88	88
Land Loss (%)	11 %	11 %	11 %	11 %
Crop yield (% of control)	81 %	100 %	84 %	89 %
Crop quality (% of control)	99 %	91 %	99 %	91 %
LER (-)	1.00	1.18	1.17	1.22

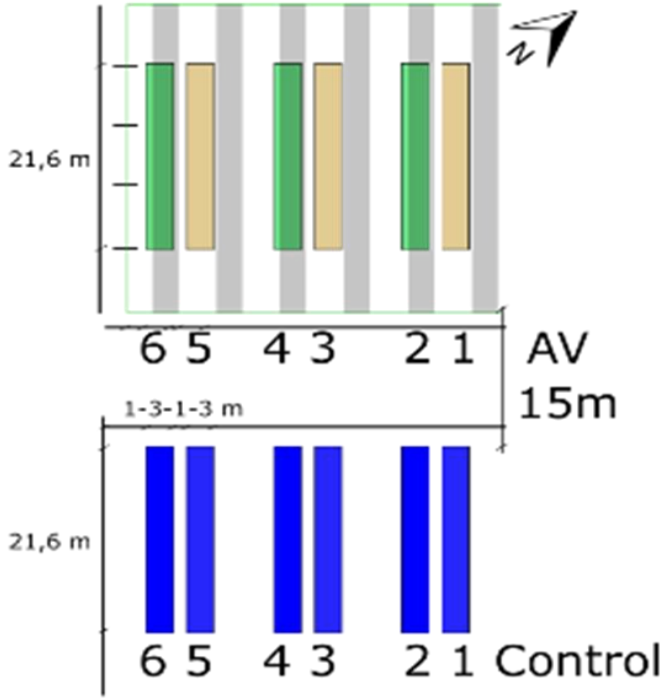
*** Not a full year of measurement data was available so data from 2022 is being used.**

Transfarm test site wheat

Variable GCR

A

B



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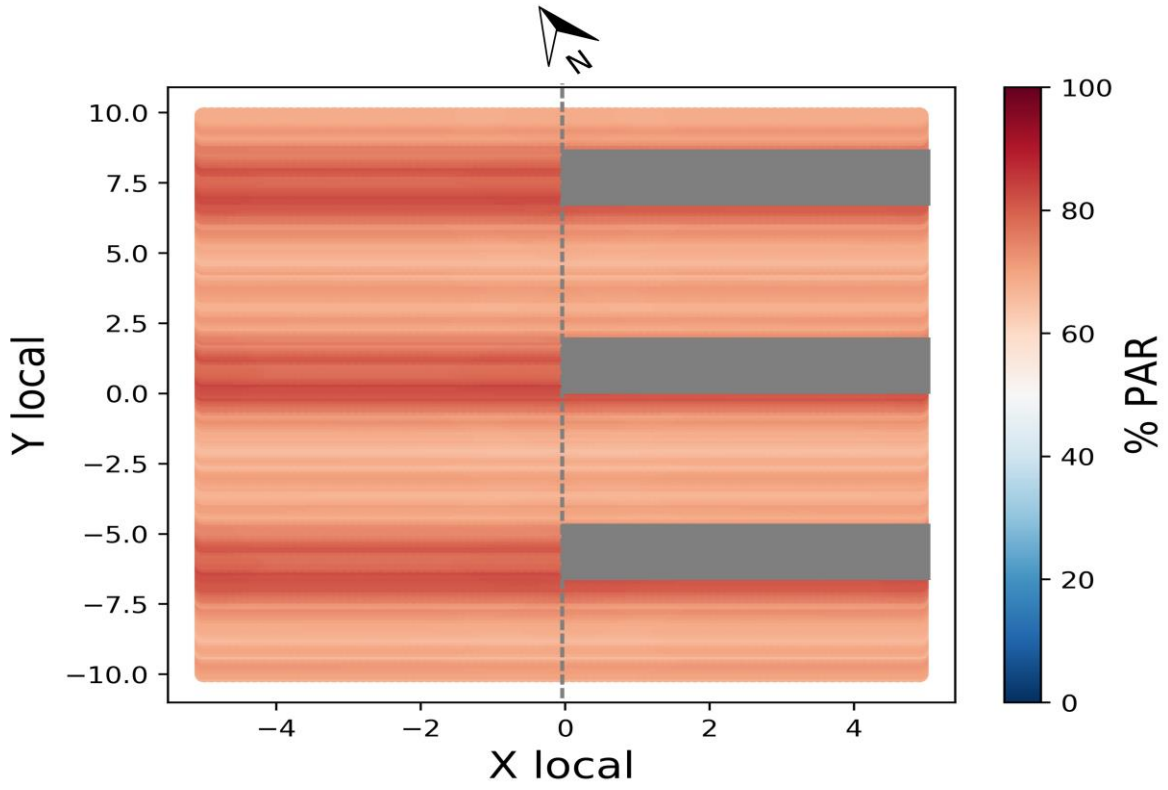
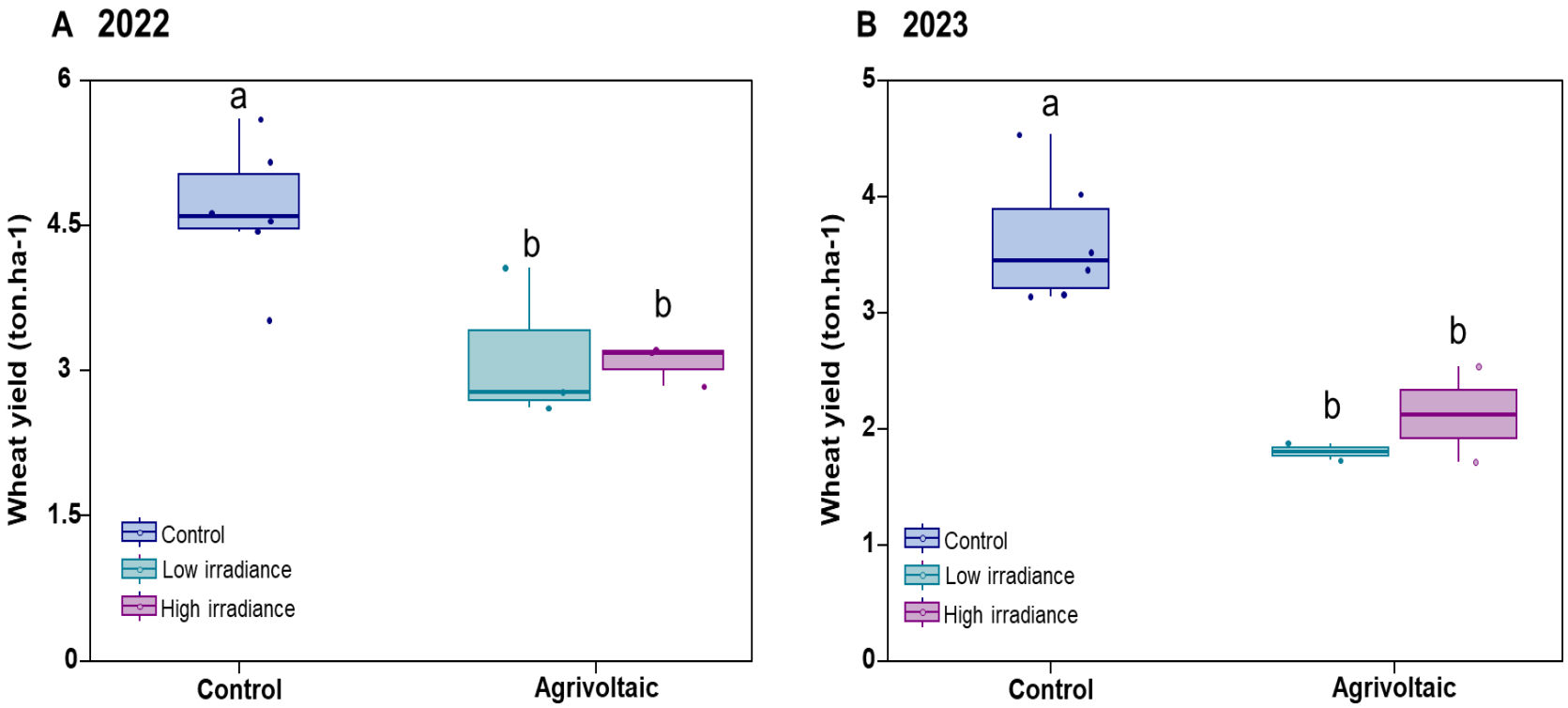
Transfarm relative radiation distribution



Grel=78%±2.9%

Transfarm wheat yield



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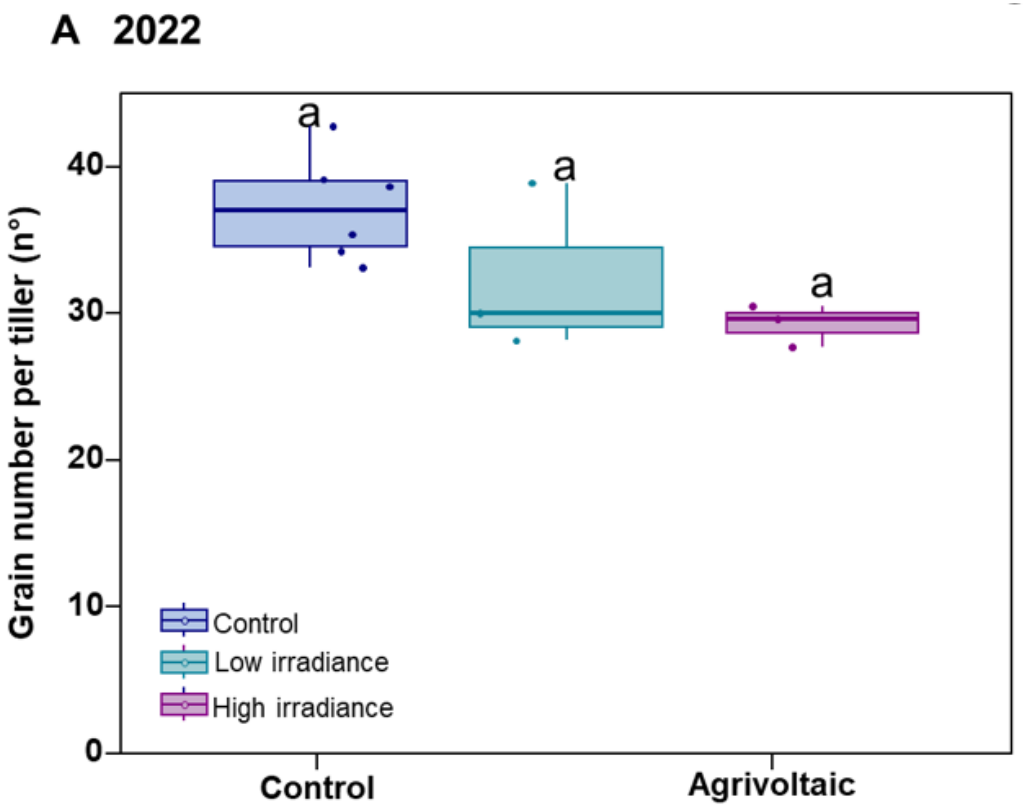
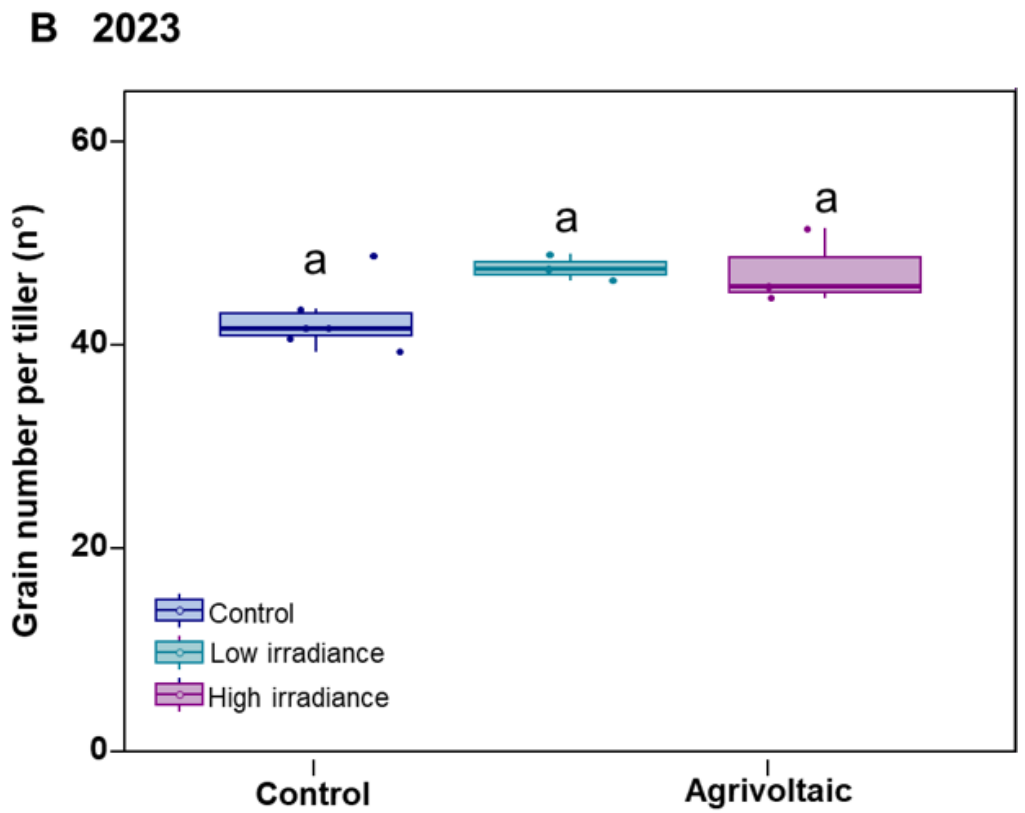
Transfarm wheat quality





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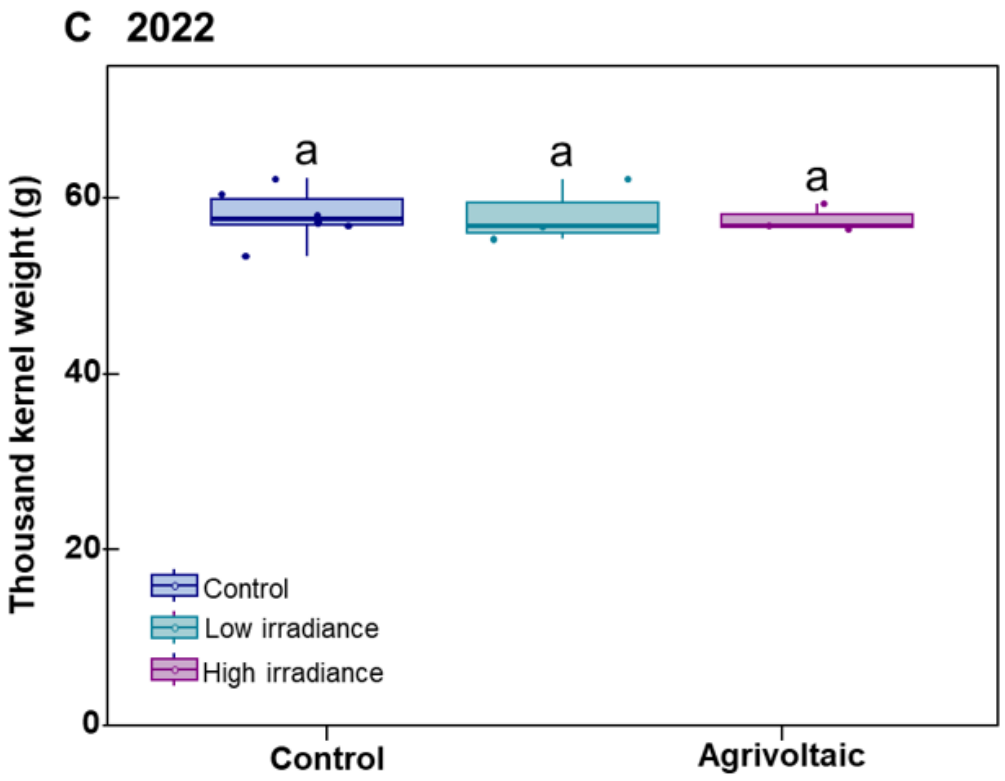
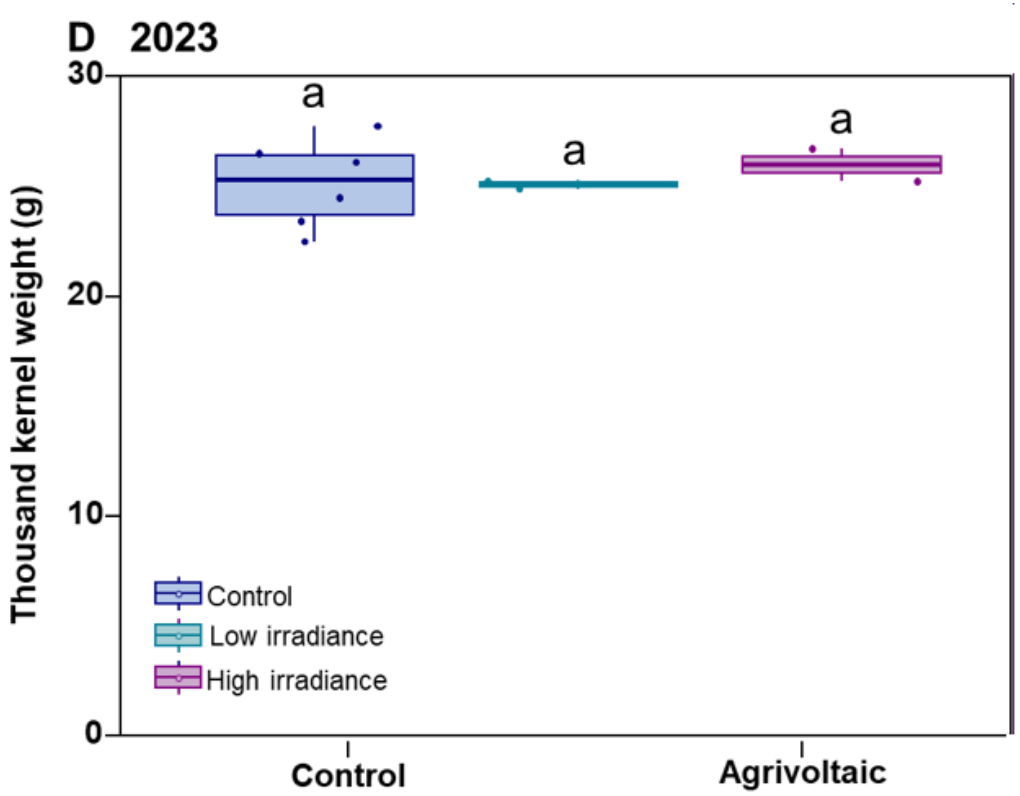
Transfarm wheat quality





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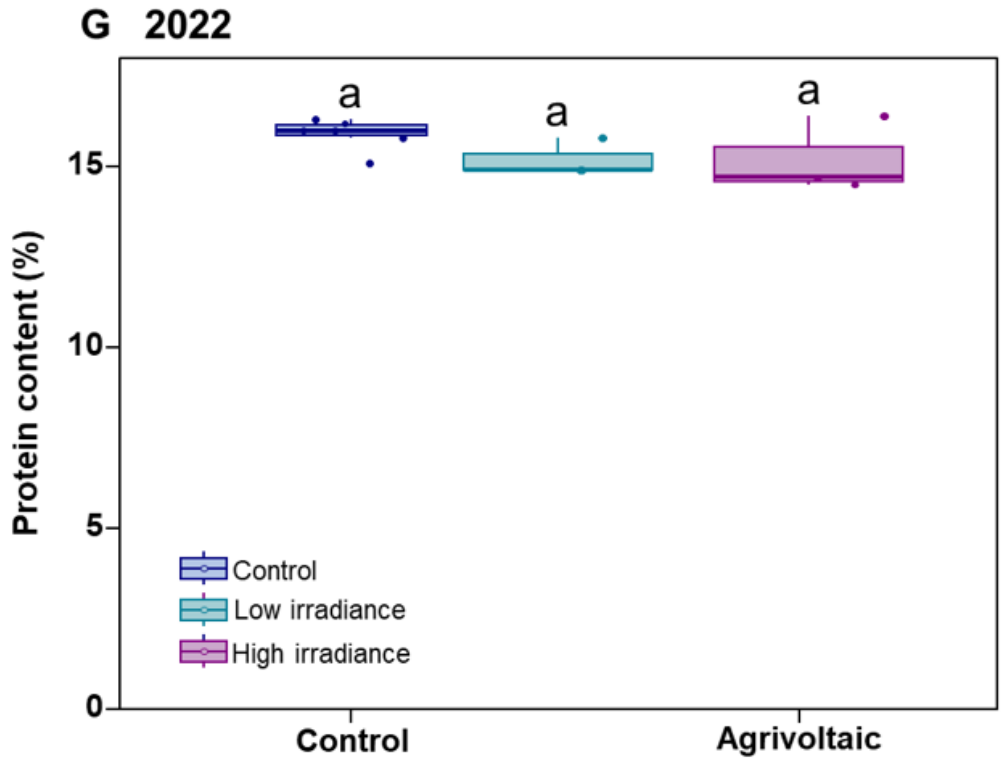
Transfarm wheat quality



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Results Transfarm Wheat

	Elevated	
Season		
Power (kWp/ha)	645	645
Specific electricity yield (kWh/kWp)	1185**	1185**
Electricity yield (MWh/ha)	764	764
LCOE (€/MWh)	158	158
Land Loss (%)	8 %	8 %
Crop yield (% of control)	67 %	54 %
Crop quality (% of control)	90 %	
LER (-)	1.20	1.08

** Simulated electricity yield using local weather and TMY data.

Questions?