Disease regulation in intercropping systems depends on spatial arrangement – a modelling study

Audrey I. DEHEINZELIN*[1], Tiphaine VIDAL[2], Patrice LECHARPENTIER[1], Marie LAUNAY[1], Marie-Odile BANCAL[3]

[1]*INRAE, US Agroclim, 84000, Avignon, France*
[2]*INRAE, UR Bioger, 91120, Palaiseau, France,*
[3]*Université Paris-Saclay, INRAE, AgroParisTech, UMR EcoSys, 91120, Palaiseau, France*
**Corresponding author: audrey.deheinzelin@inrae.fr*

Funded by the European Union

XIVth STICS seminar, 17-19 March 2026, organized by ULiege-GxABT & INRAE

Agricultural systems in crisis: *Produce more with less?*

Increasing pressures

- Looming climate change,
- Loss of arable land,
- Considering pollution, social and health impacts,
- Reducing chemical inputs,
- Maintaining production levels,
- Changing disease/epidemics dynamics.

INRAE

Agricultural systems in crisis: *Produce more with less?*

Increasing pressures

- Looming climate change,
- Loss of arable land,
- Considering pollution, social and health impacts,
- Reducing chemical inputs,
- Maintaining production levels,
- Changing disease/epidemics dynamics.

➢ *Explore new solutions:*

➢ *Agroecology and crop diversification*

INRAE

What Is Intercropping?

Diverse Crops, One Field

- Intercropping: *two species or more* growing simultaneously in the same field
- *Historical context*: Common practice for centuries; especially in tropical agriculture
- *Renewed interest*: Climate change + disease pressure + pesticide restrictions

INRAE

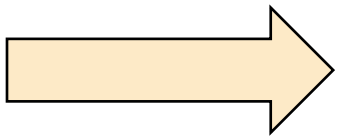
What Is Intercropping?

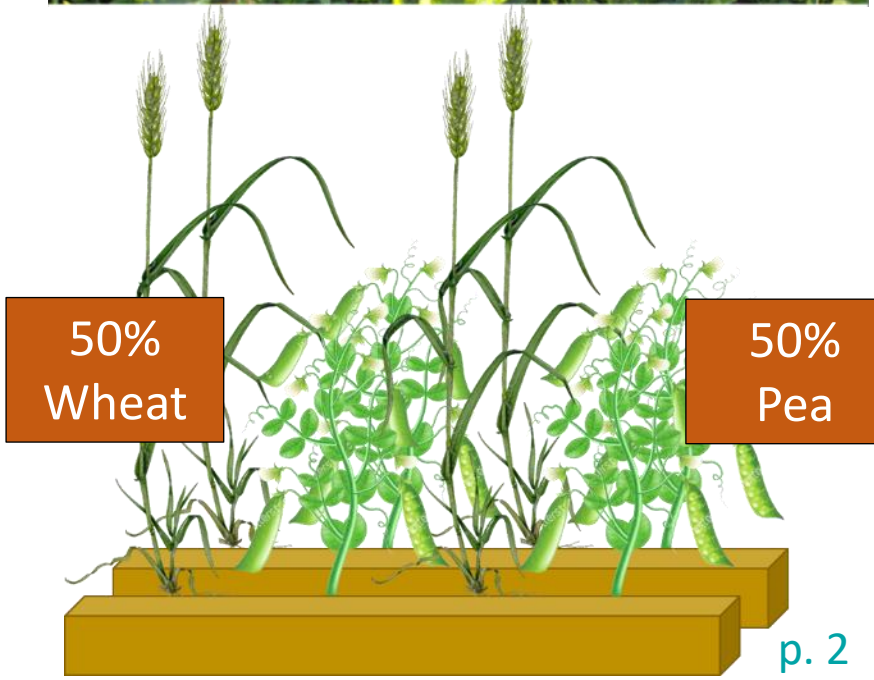
Diverse Crops, One Field

- Intercropping: *two species or more* growing simultaneously in the same field
- *Historical context*: Common practice for centuries; especially in tropical agriculture
- *Renewed interest*: Climate change + disease pressure + pesticide restrictions

➢ Farming rediscovering its “roots“: resilience via ecosystem services

example





INRAE

The Problem: Why Design Matters

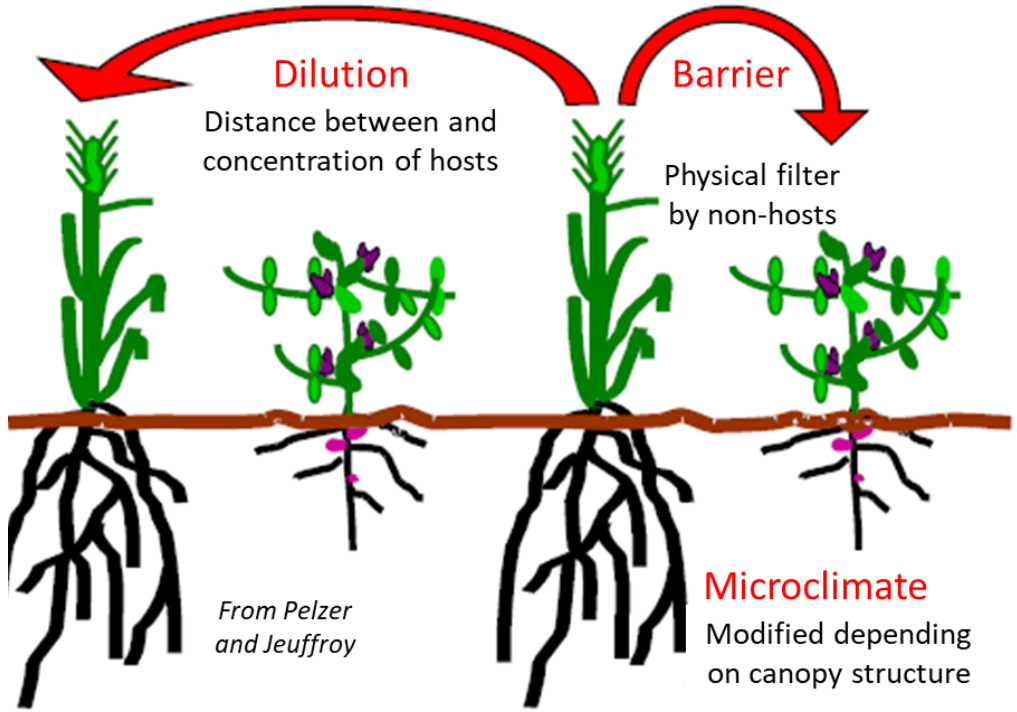
Not All Intercropping is Equal

- Intercropping is *generally good* for disease control

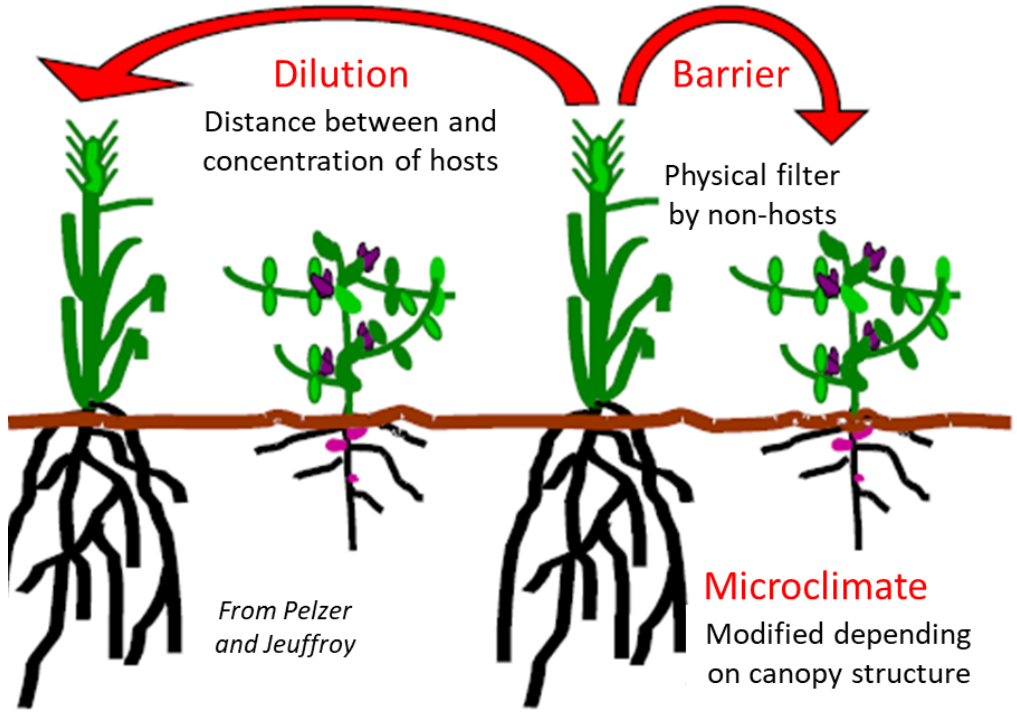
The Problem: Why Design Matters

Not All Intercropping is Equal

- Intercropping is *generally good* for disease control
- Identified mechanisms:
  - dilution effect with a smaller concentration of host plant and availability of susceptible organs,
  - barrier effect with an alteration in spore interception thanks to a physical obstacle to spore deposition,
  - change in canopy microclimate with an impact mainly on other disease processes such as infection, latency and sporulation.



The Problem: Why Design Matters

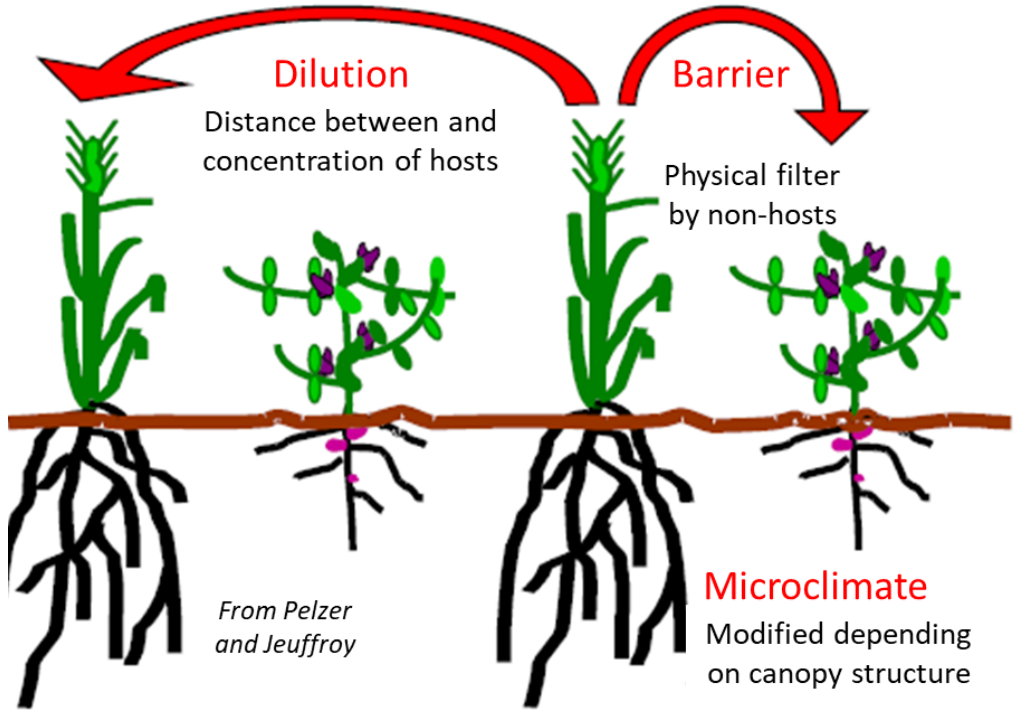


Not All Intercropping is Equal

- Intercropping is *generally good* for disease control
- Identified mechanisms:
  - dilution effect with a smaller concentration of host plant and availability of susceptible organs,
  - barrier effect with an alteration in spore interception thanks to a physical obstacle to spore deposition,
  - change in canopy microclimate with an impact mainly on other disease processes such as infection, latency and sporulation.
- Results *vary* wildly
  - Spore dynamics hard to measure in field
  - Scale of effects highly dependant on experimental set up,
  - Large range of disease reduction (30 to over 80%), large choice of field designs
  - Interactions between variables, e.g. microclimate on infection (temperature x surface wetness duration)

INRAE

The Problem: Why Design Matters



Not All Intercropping is Equal

- Intercropping is *generally good* for disease control
- Identified mechanisms:
  - dilution effect with a smaller concentration of host plant and availability of susceptible organs,
  - barrier effect with an alteration in spore interception thanks to a physical obstacle to spore deposition,
  - change in canopy microclimate with an impact mainly on other disease processes such as infection, latency and sporulation.
- Results *vary* wildly
  - Spore dynamics hard to measure in field
  - Scale of effects highly dependant on experimenta
  - Large range of disease reduction (30 to over 80%), la
  - Interactions between variables, e.g. microclimate e… …urface …etness duration)

Many questions!

➢ Many interactions, many scenarios, many variables

INRAE

The Problem: Why Design Matters

The known unknows

- Ranking mechanisms?
  - Provide a barrier to spores?
  - Reduce pathogen habitat?
  - Provide adverse microclimatic conditions for the pathogen?
- Conceptualise field designs?
  - How much of each species?
  - How far apart should plants be?

INRAE

The Problem: Why Design Matters

The known unknows

- Ranking mechanisms?
  - Provide a barrier to spores?
  - Reduce pathogen habitat?
  - Provide adverse microclimatic conditions for the pathogen?
- Conceptualise field designs?
  - How much of each species?
  - How far apart should plants be?

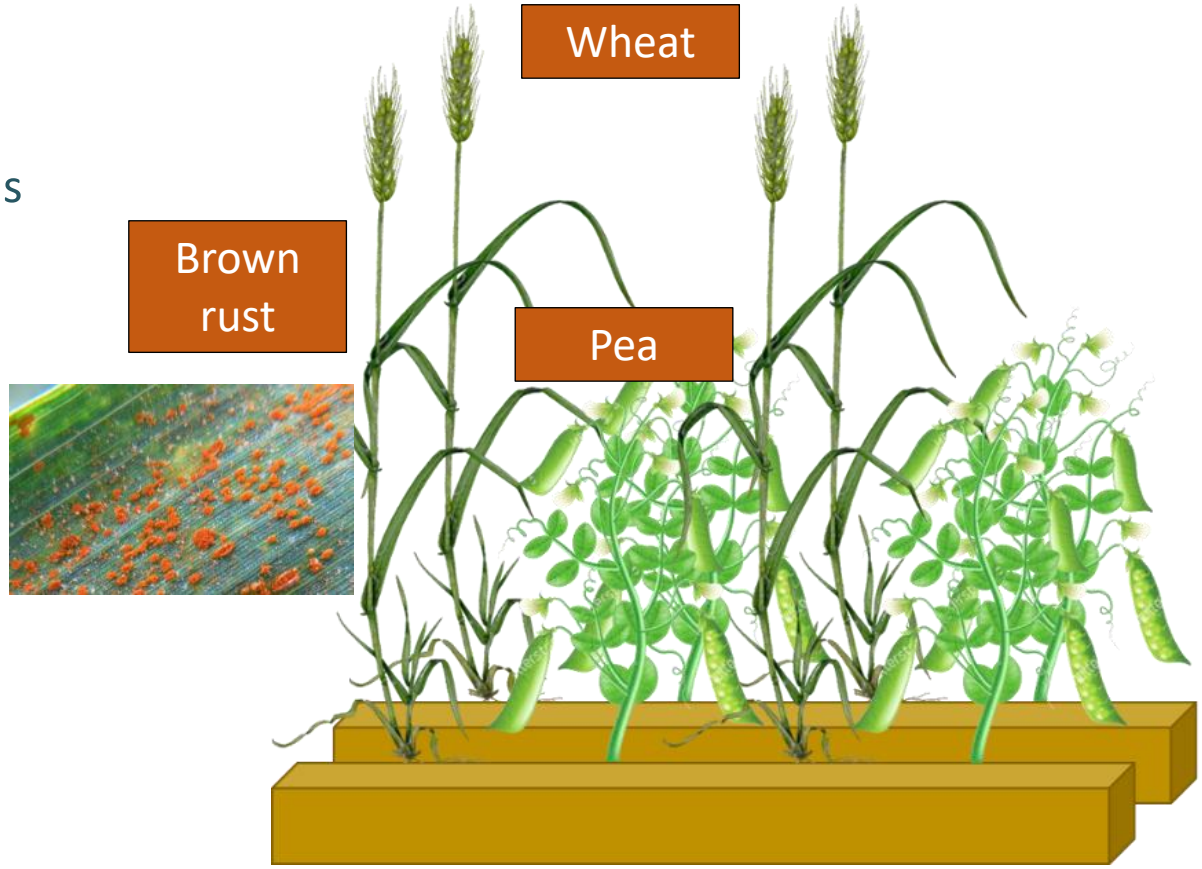
➢In short, which agronomic levers are worth considering and why?

INRAE

Modelling to the rescue!

Contribute response elements to field-level questions

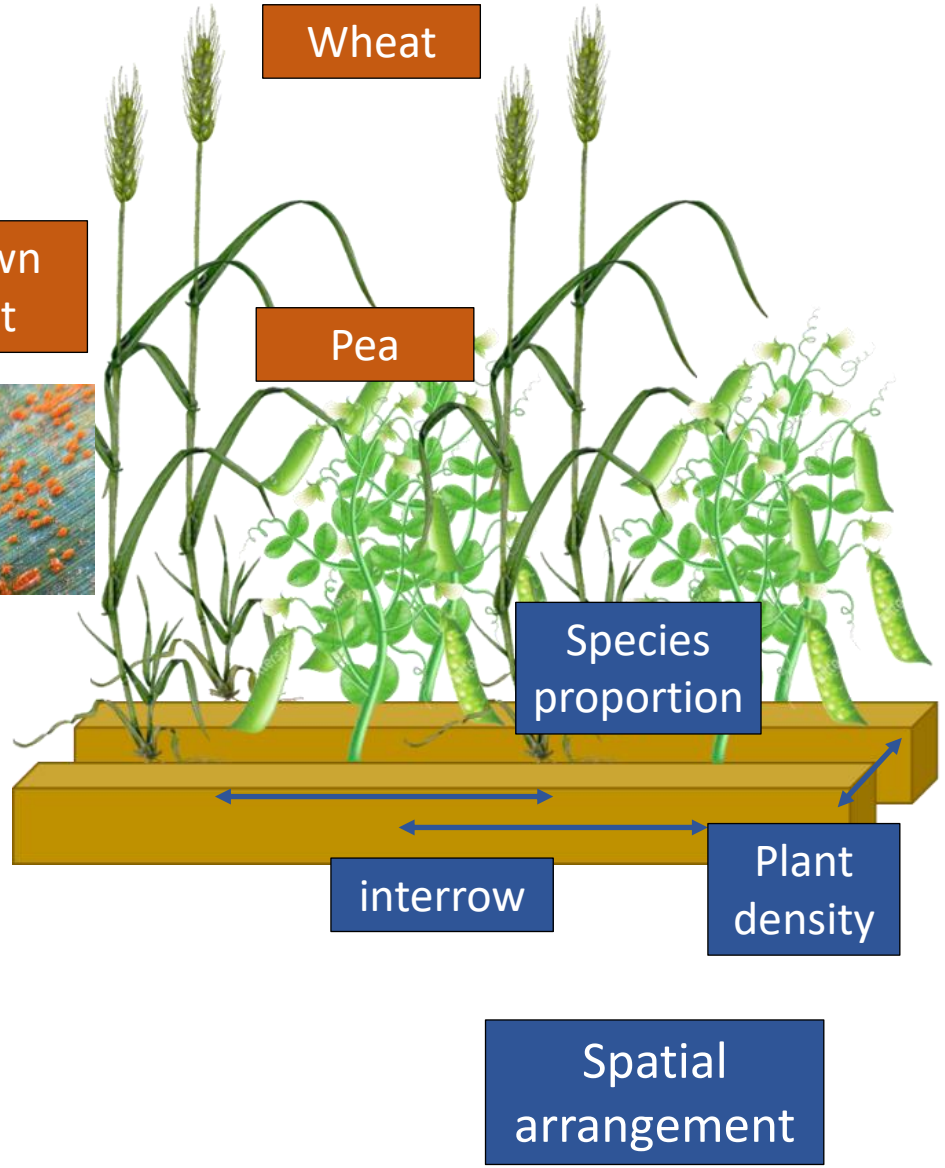
- Wheat/pea/brown rust case study



Modelling to the rescue!

Contribute response elements to field-level questions

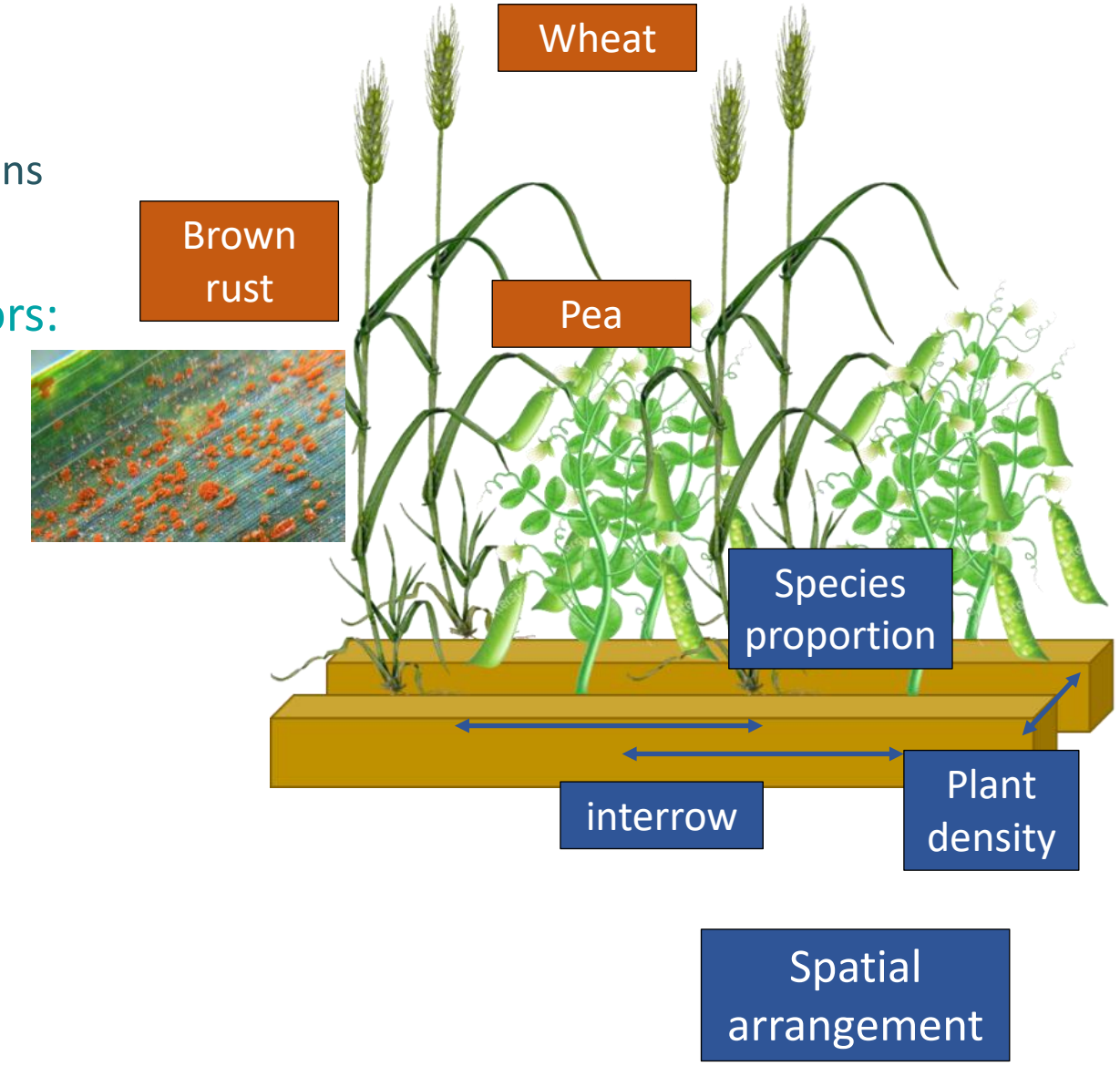
- Wheat/pea/brown rust case study
- Testing 150 different field designs with 3 factors:
  - Species proportion
  - Plant density
  - Distance between rows

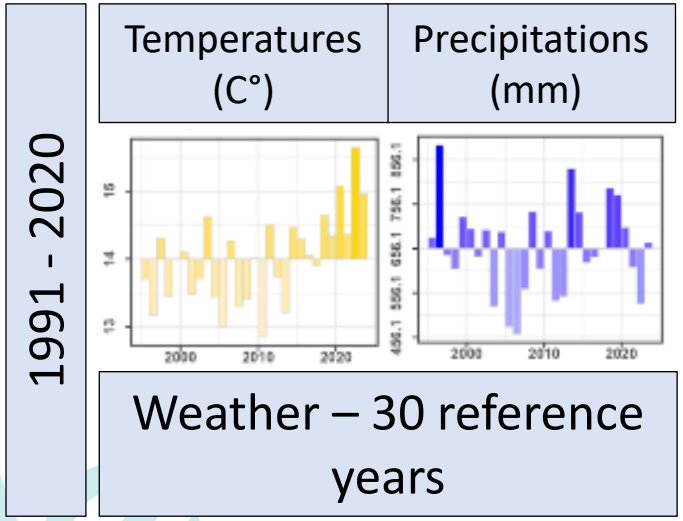


Modelling to the rescue!

Contribute response elements to field-level questions

- Wheat/pea/brown rust case study
- Testing 150 different field designs with 3 factors:
  - Species proportion
  - Plant density
  - Distance between rows
- 30 years of weather data = average trends

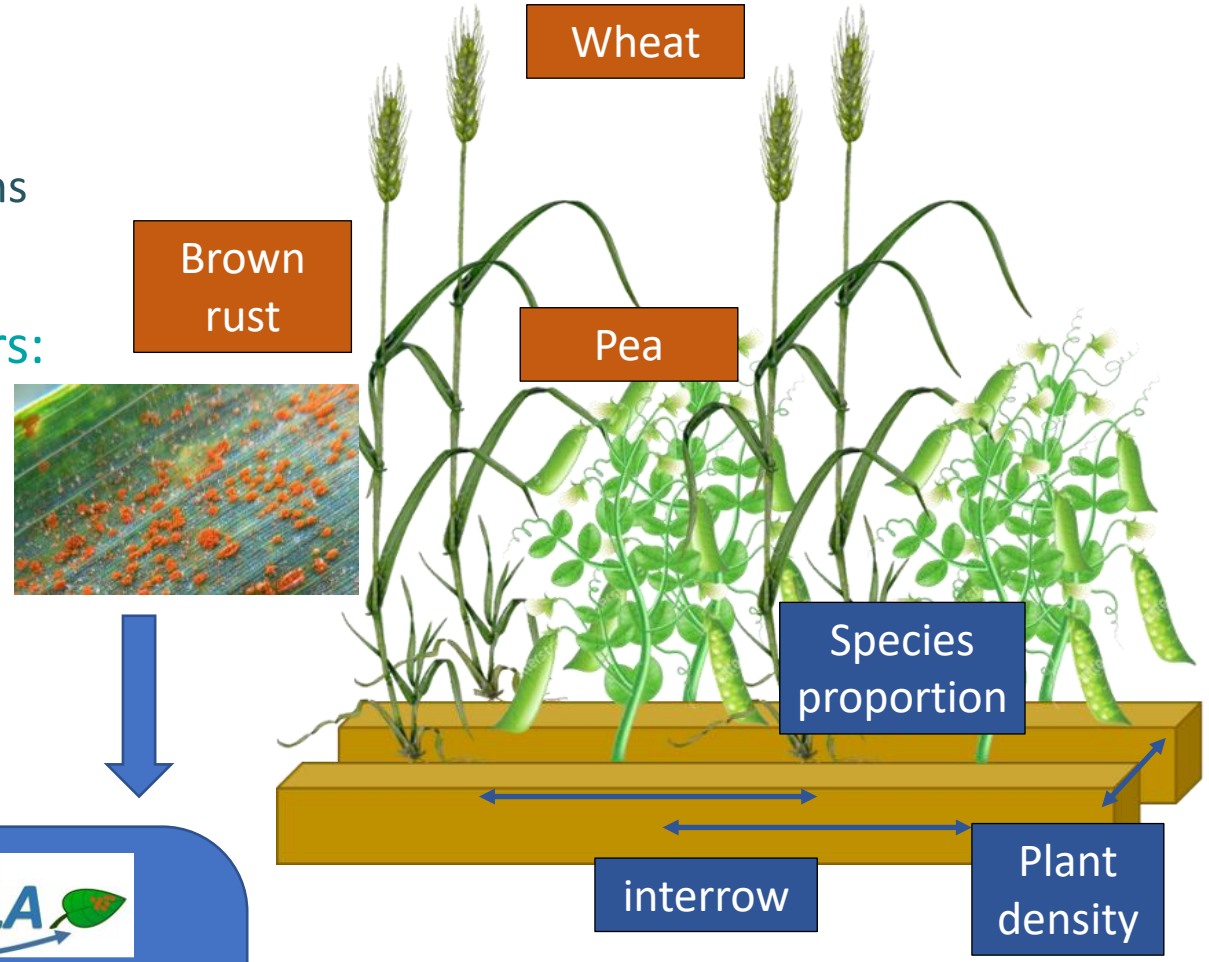


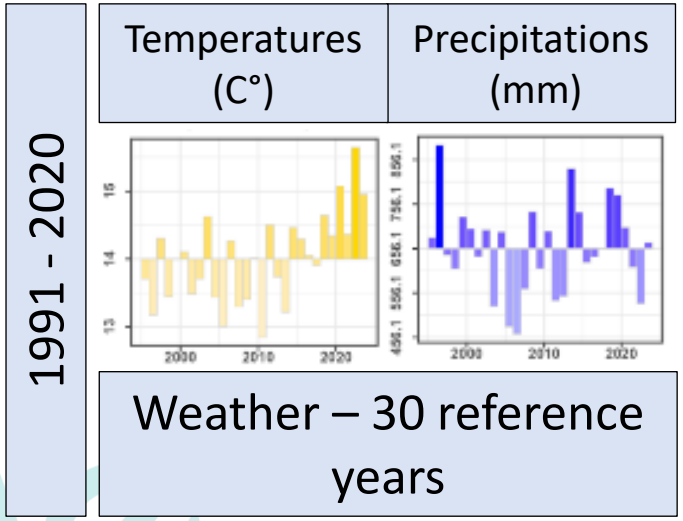


Modelling to the rescue!

Contribute response elements to field-level questions

- Wheat/pea/brown rust case study
- Testing 150 different field designs with 3 factors:
  - Species proportion
  - Plant density
  - Distance between rows
- 30 years of weather data = average trends
- Coupled crop and disease models

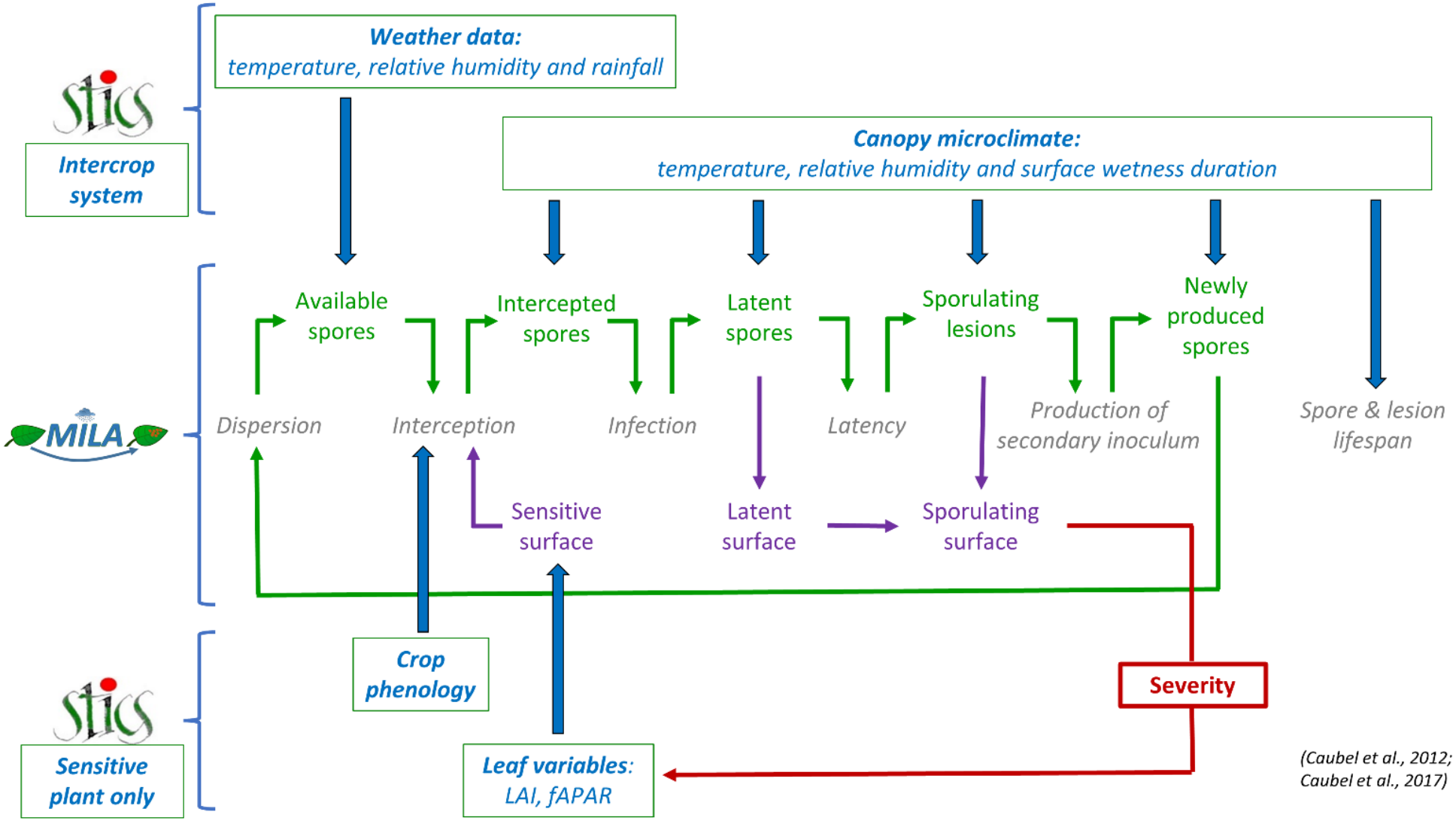




Spatial arrangement

A word on MILA-STICS

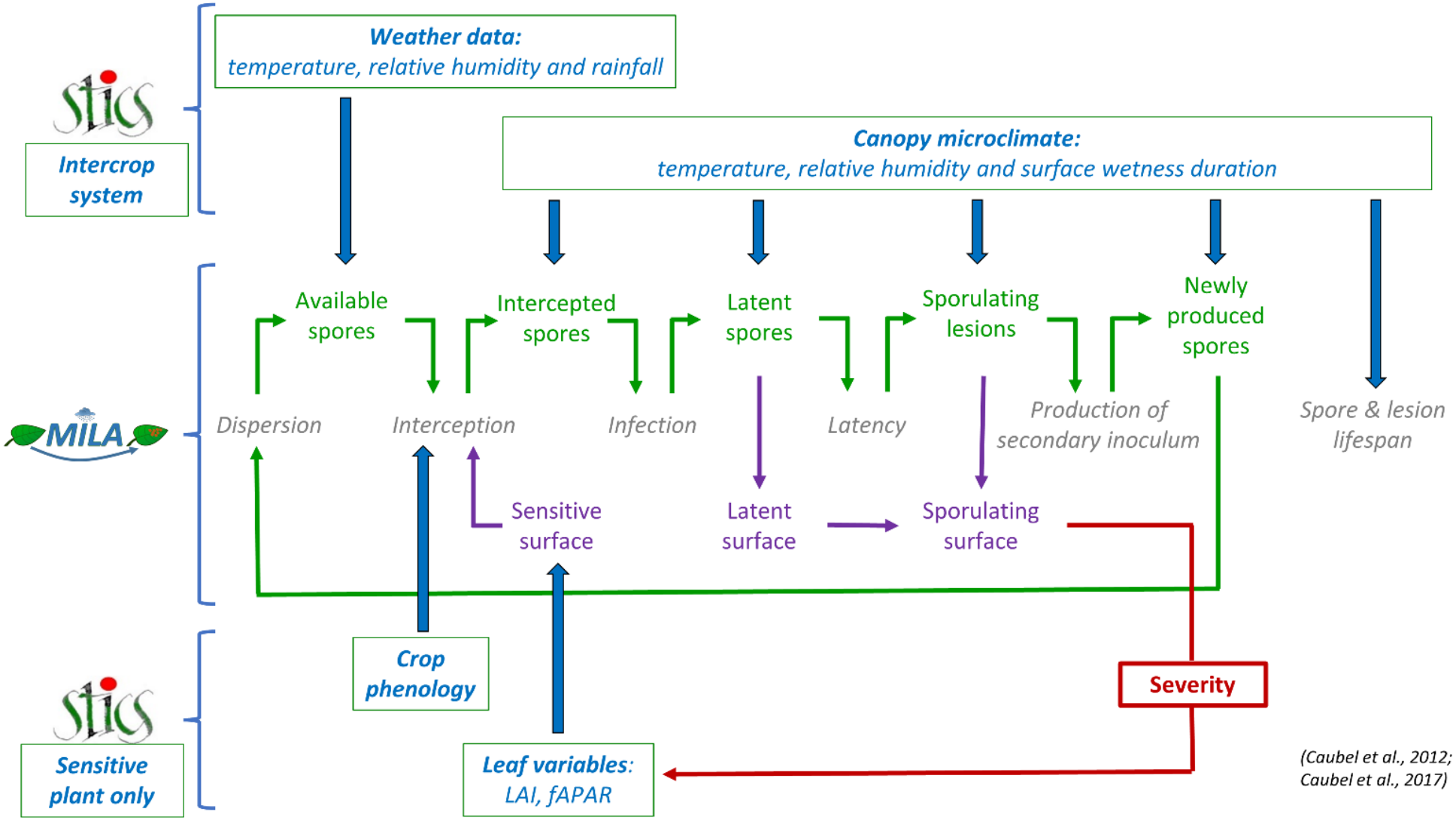
Process-based, mechanistic models, daily time step



(Caubel et al., 2012; Caubel et al., 2017)

A word on MILA-STICS

Process-based, mechanistic models, daily time step



(Caubel et al., 2012; Caubel et al., 2017)

Driven by parameters, including disease characteristics and technical management to test agronomic practices

A word on MILA-STICS

Outputs

Disease processes

+

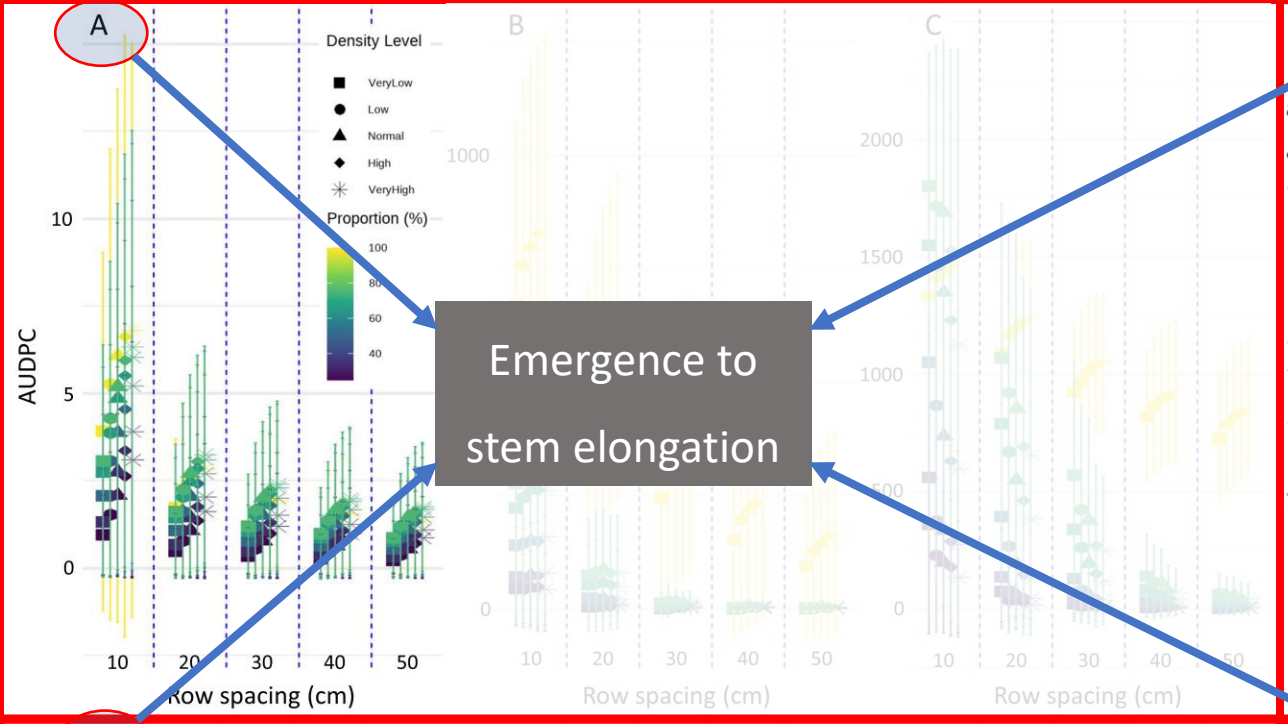
Crop variables

- Disease intensity (AUDPC)
- Sporulation rate
- Latency duration
- Infection rate
- Spore interception

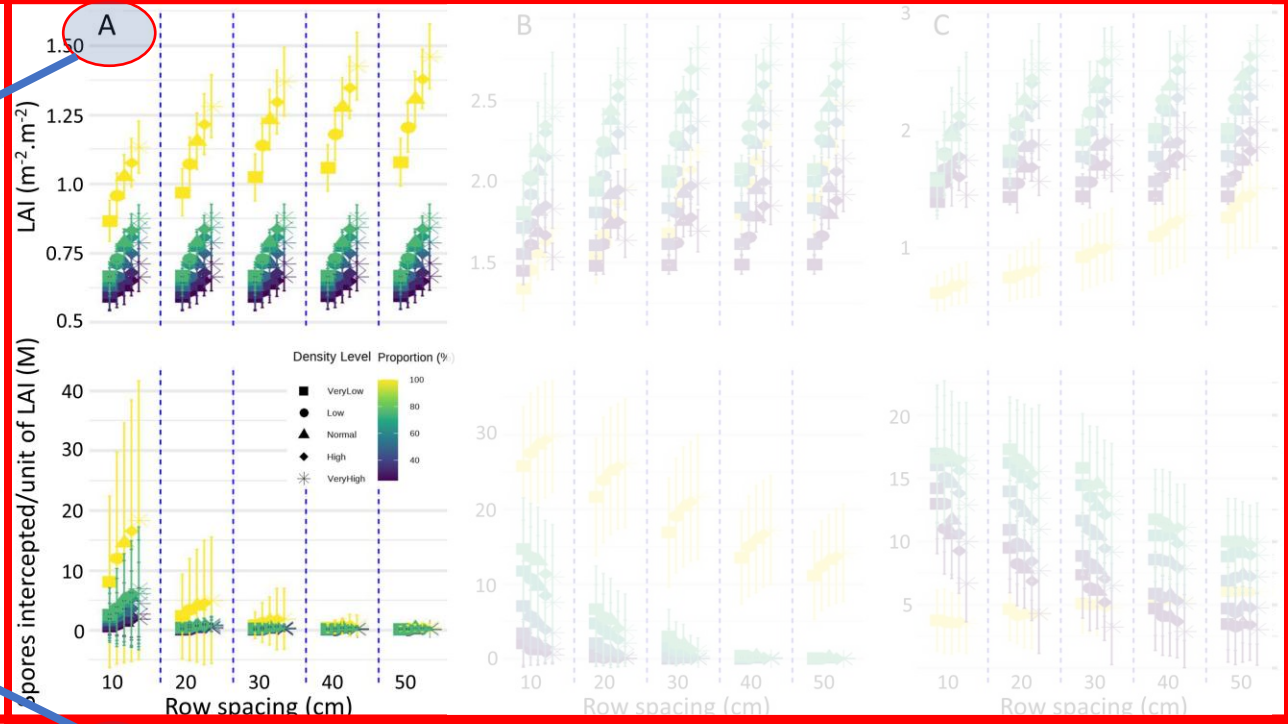
Microclimate
- Wetness duration
- Temperature

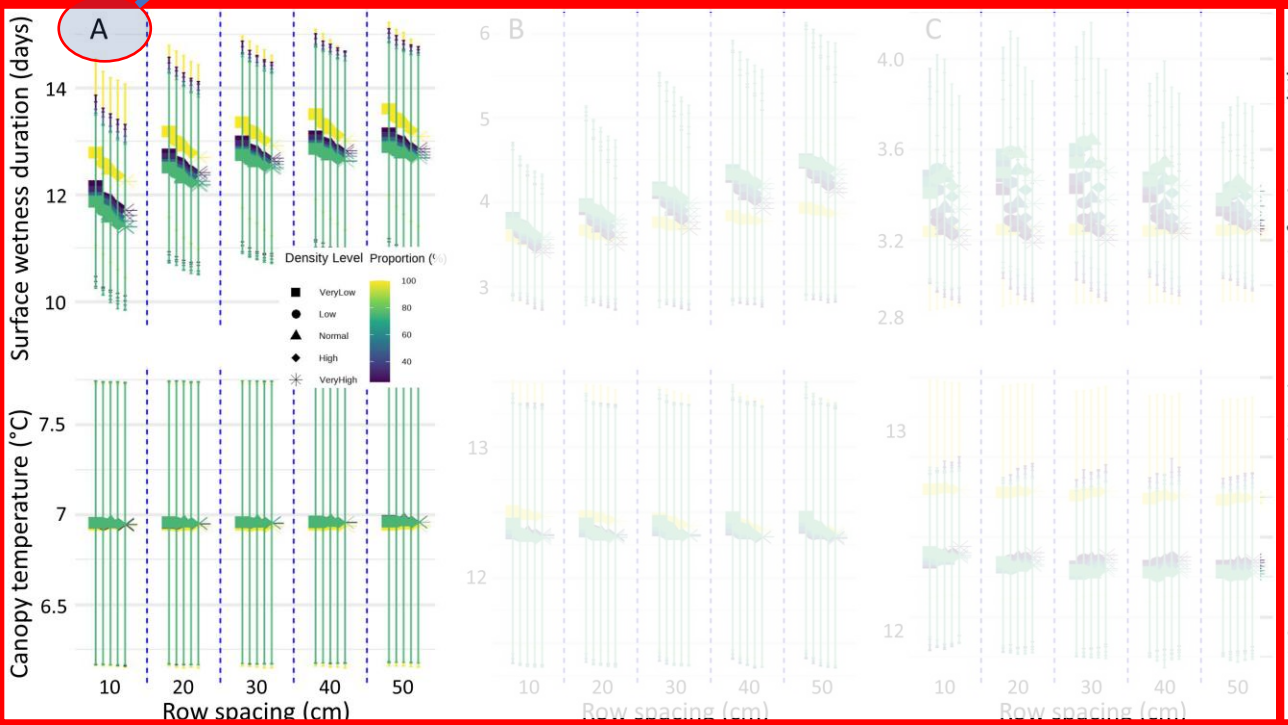
- Crop heights
- Crop leaf surfaces
- Canopy LAI and porosity

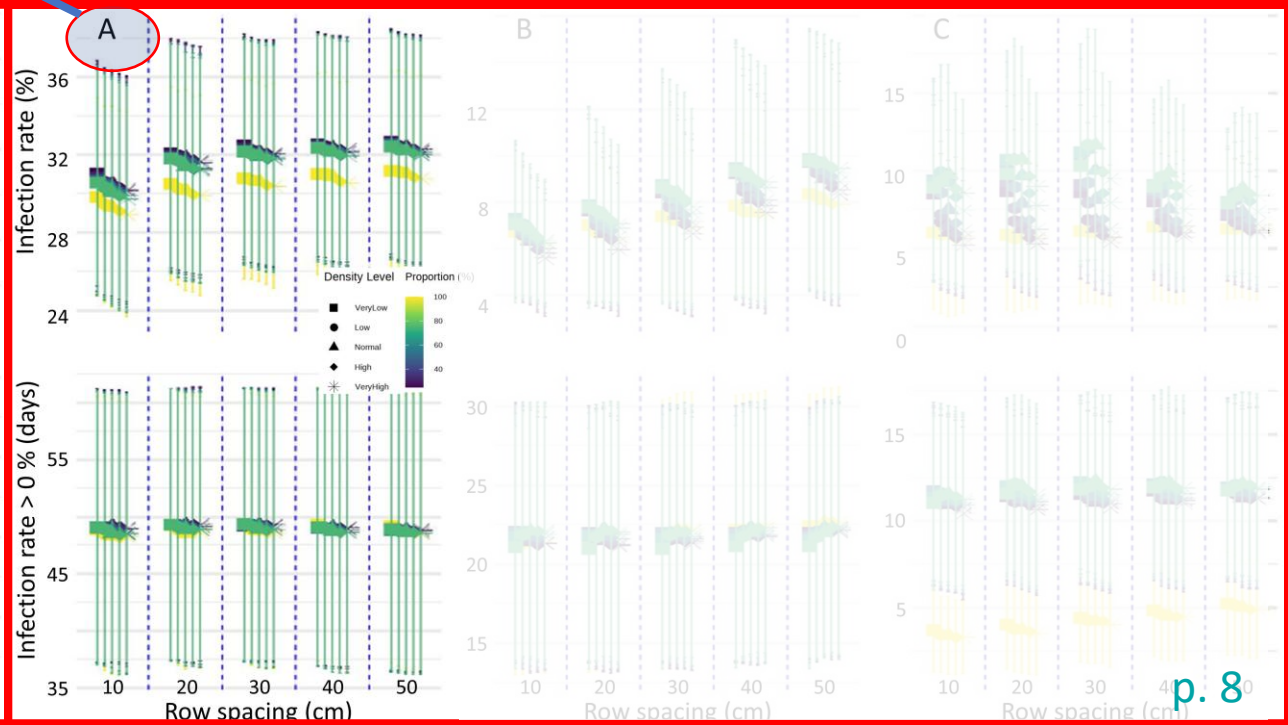
INRAE

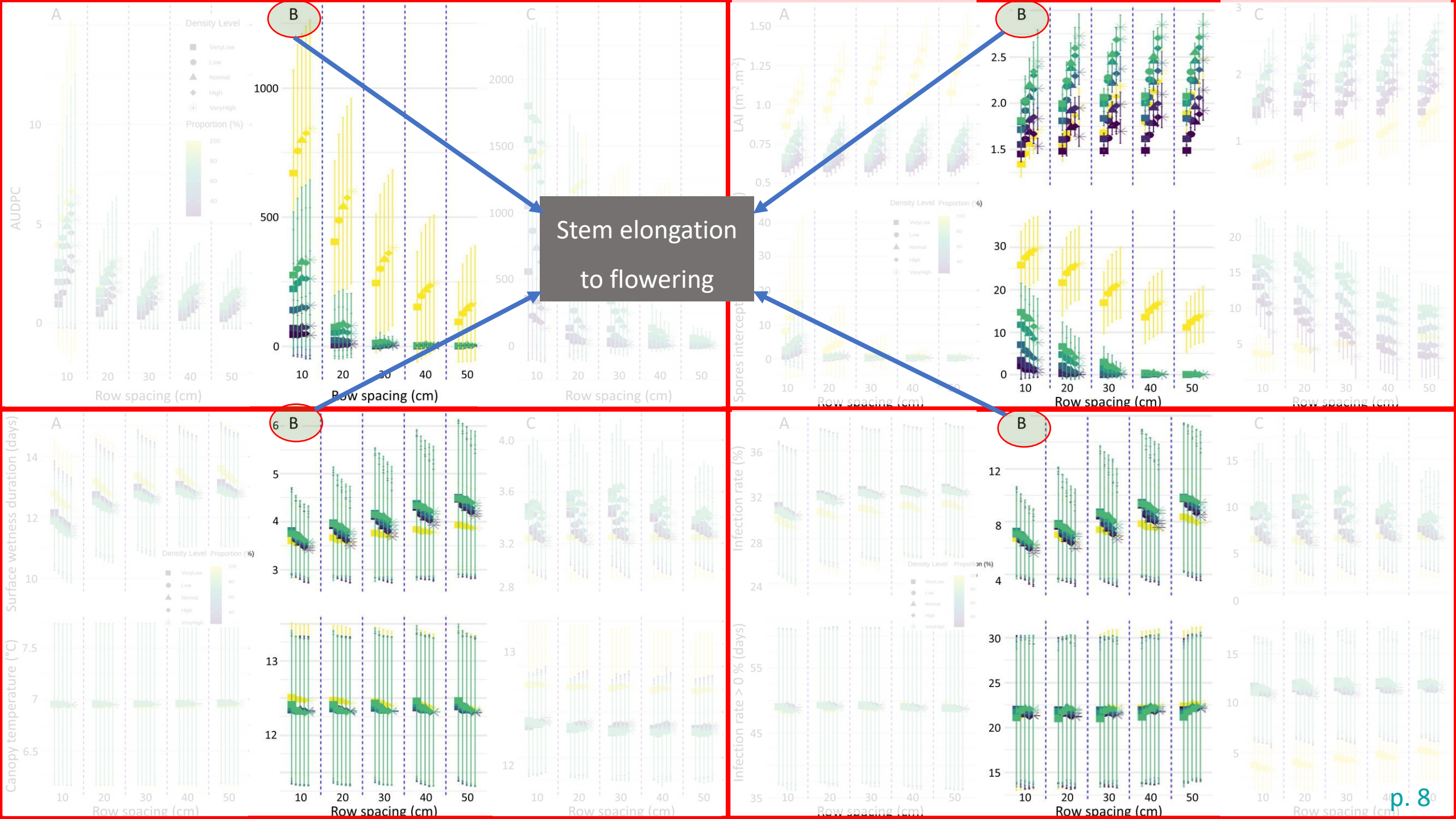


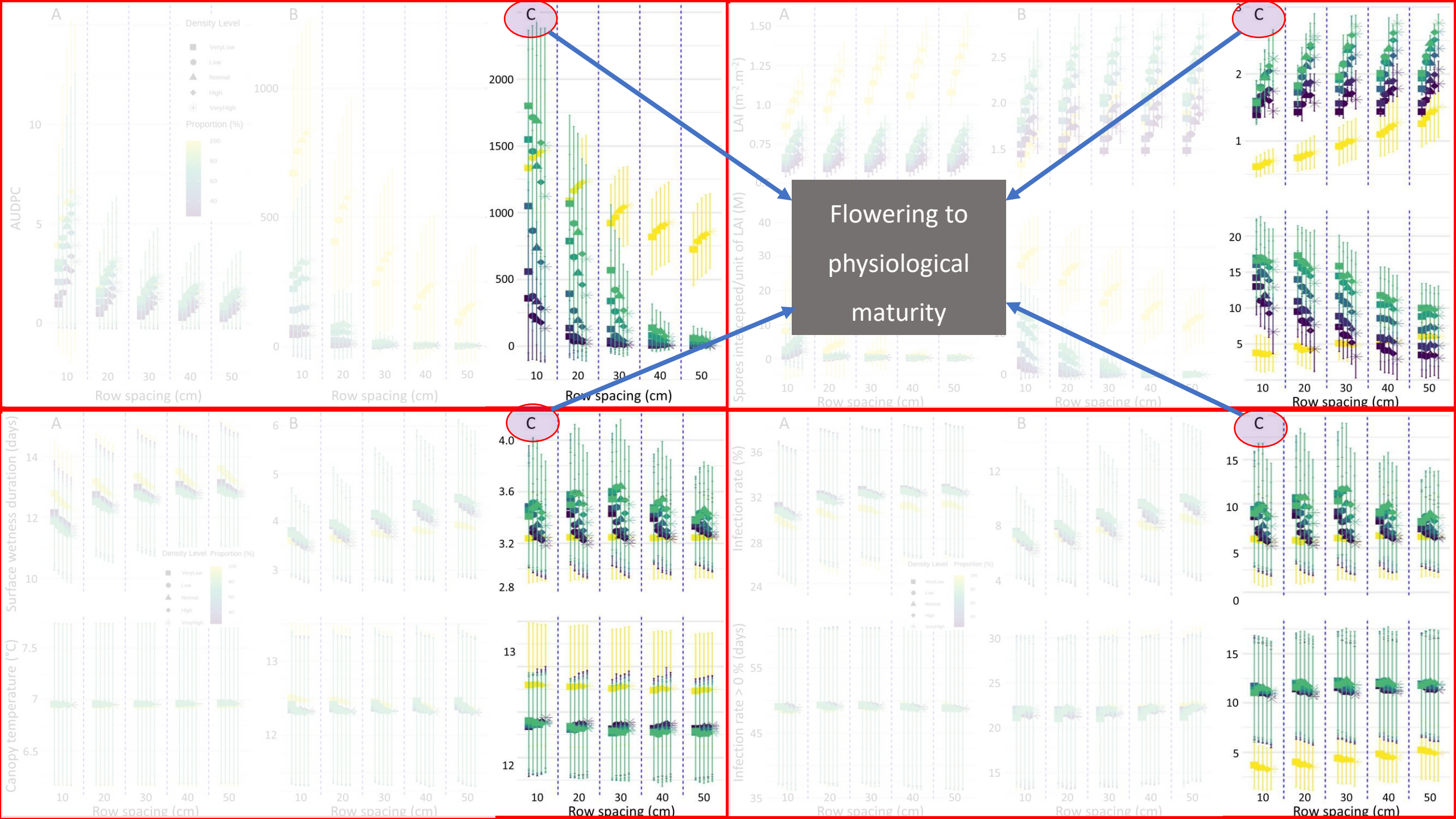
Emergence to stem elongation

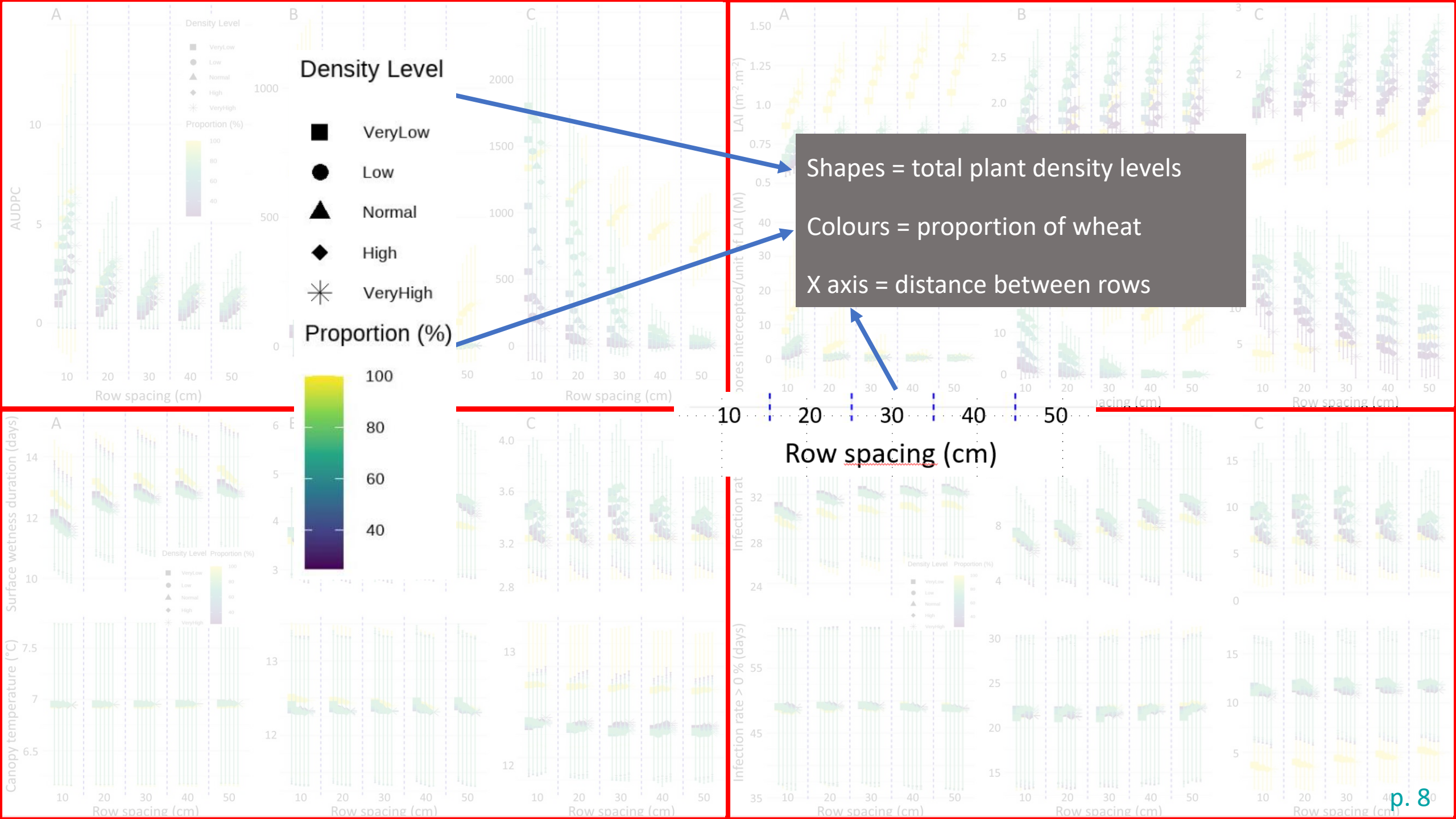


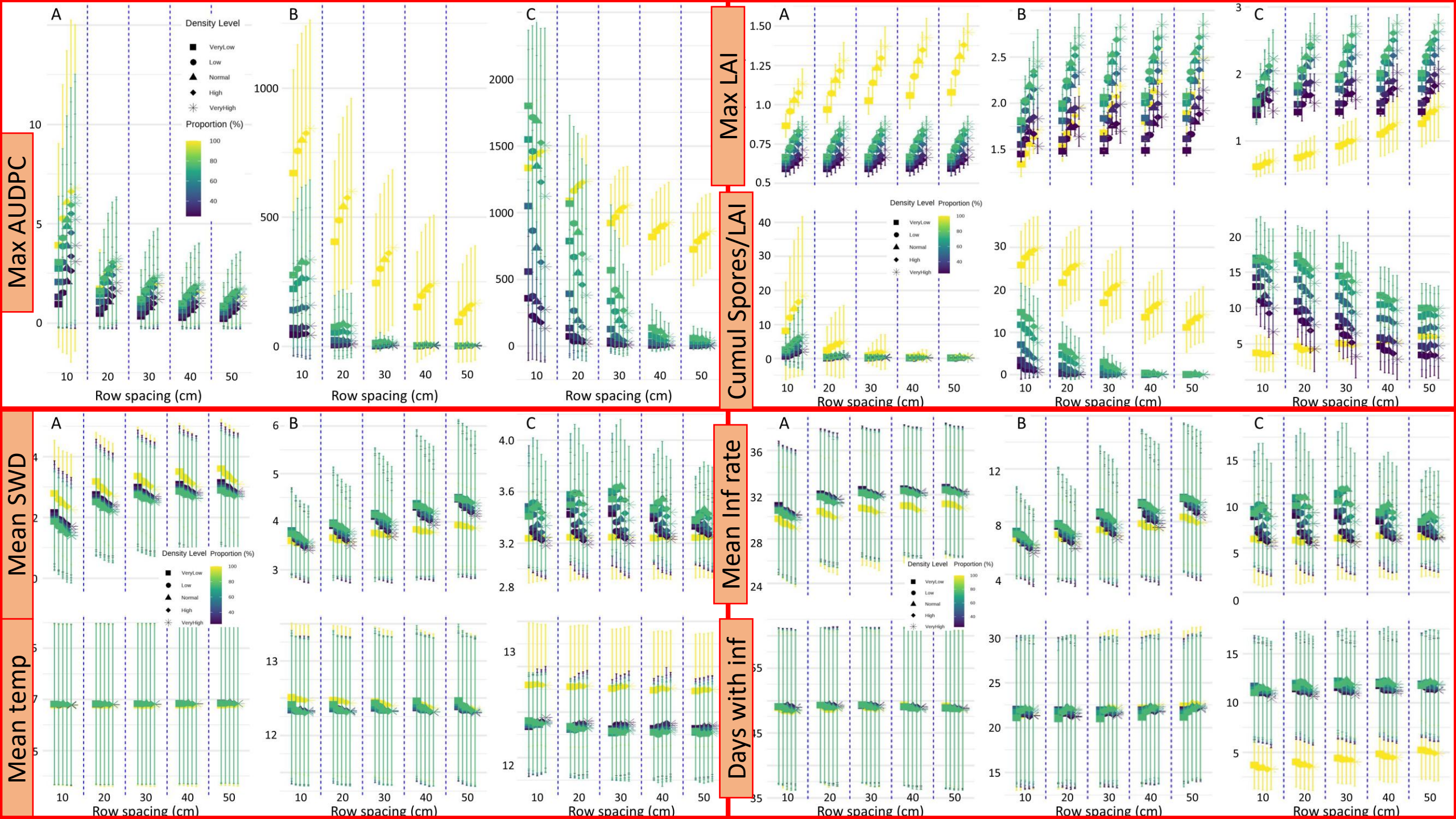


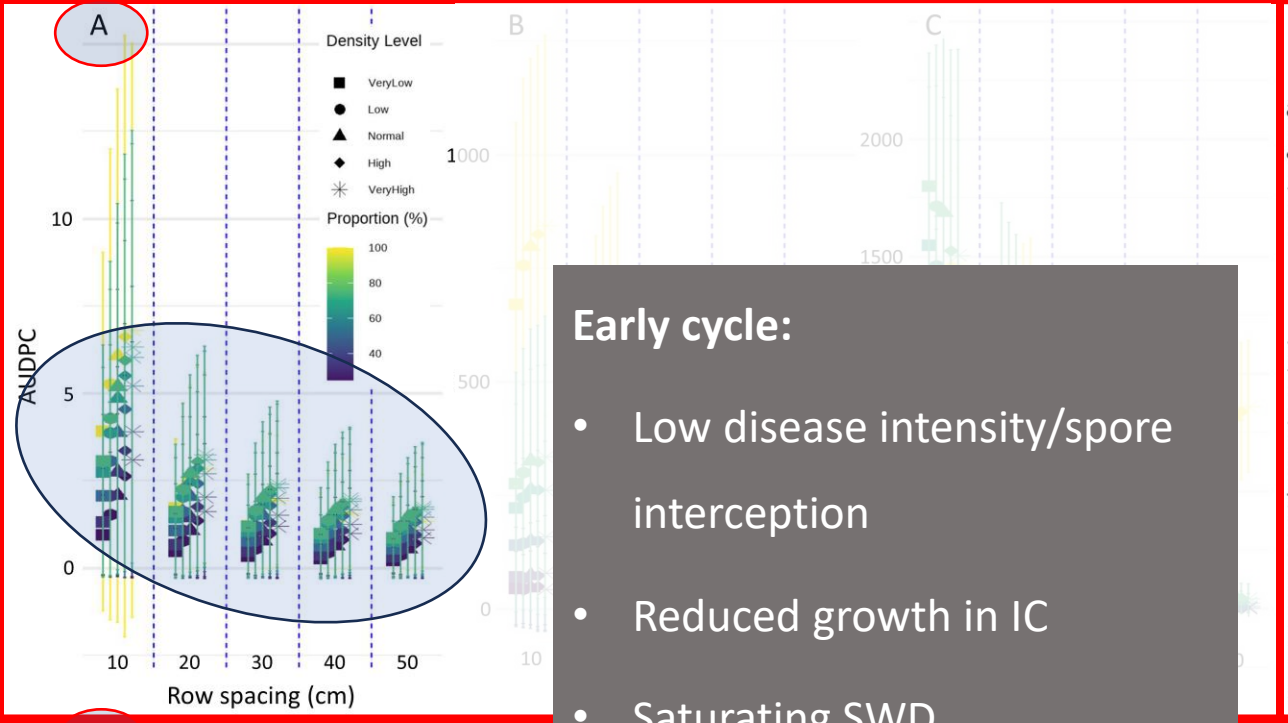


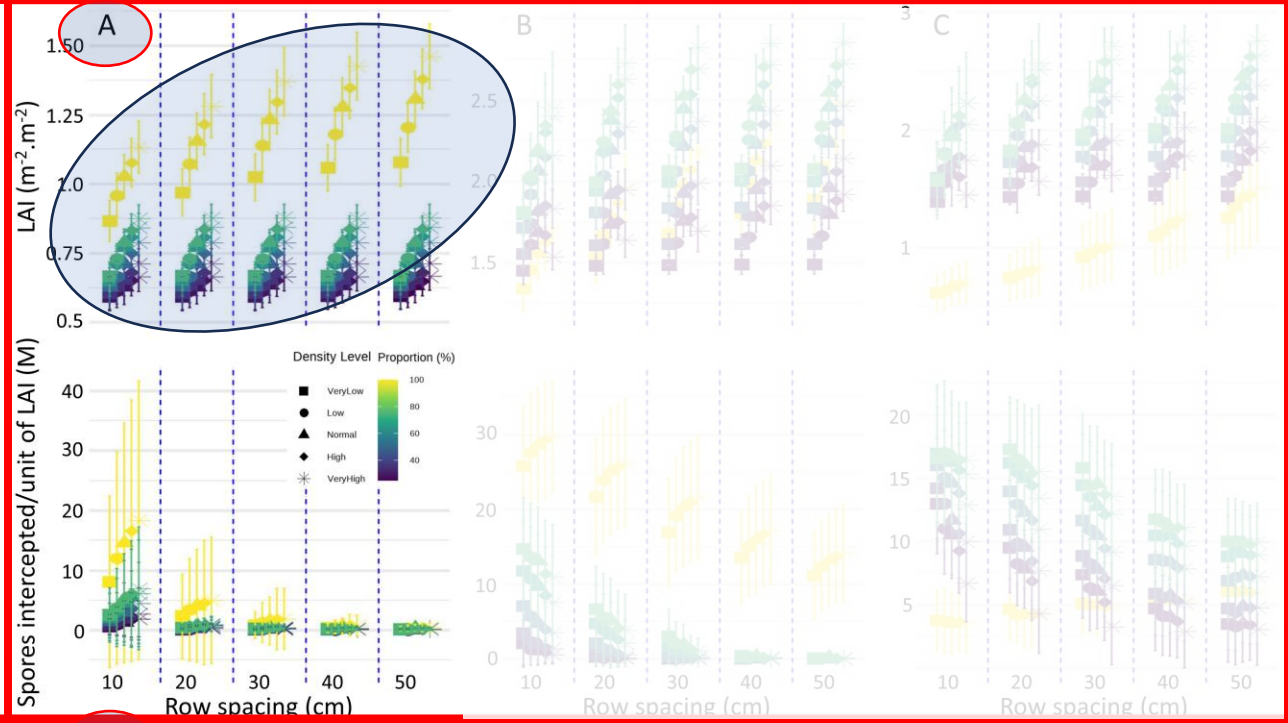

A
B
C
Stem elongation to flowering
AUDPC
Row spacing (cm)
Density Level
VeryLow
Low
Normal
High
VeryHigh
Proportion (%)
LAI (m².m⁻²)
Spores intercept
Surface wetness duration (days)
Canopy temperature (°C)
Infection rate (%)
Infection rate > 0 % (days)


A
B
C
Density Level
VeryLow
Low
Normal
High
VeryHigh
Proportion (%)
AUDPC
Row spacing (cm)
Flowering to physiological maturity
LAI (m-2.m-2)
Spores intercepted/unit of LAI (M)
Surface wetness duration (days)
Canopy temperature (°C)
Infection rate (%)
Infection rate > 0 % (days)


Density Level
VeryLow
Low
Normal
High
VeryHigh
Proportion (%)
100
80
60
40
Shapes = total plant density levels
Colours = proportion of wheat
X axis = distance between rows
10
20
30
40
50
Row spacing (cm)

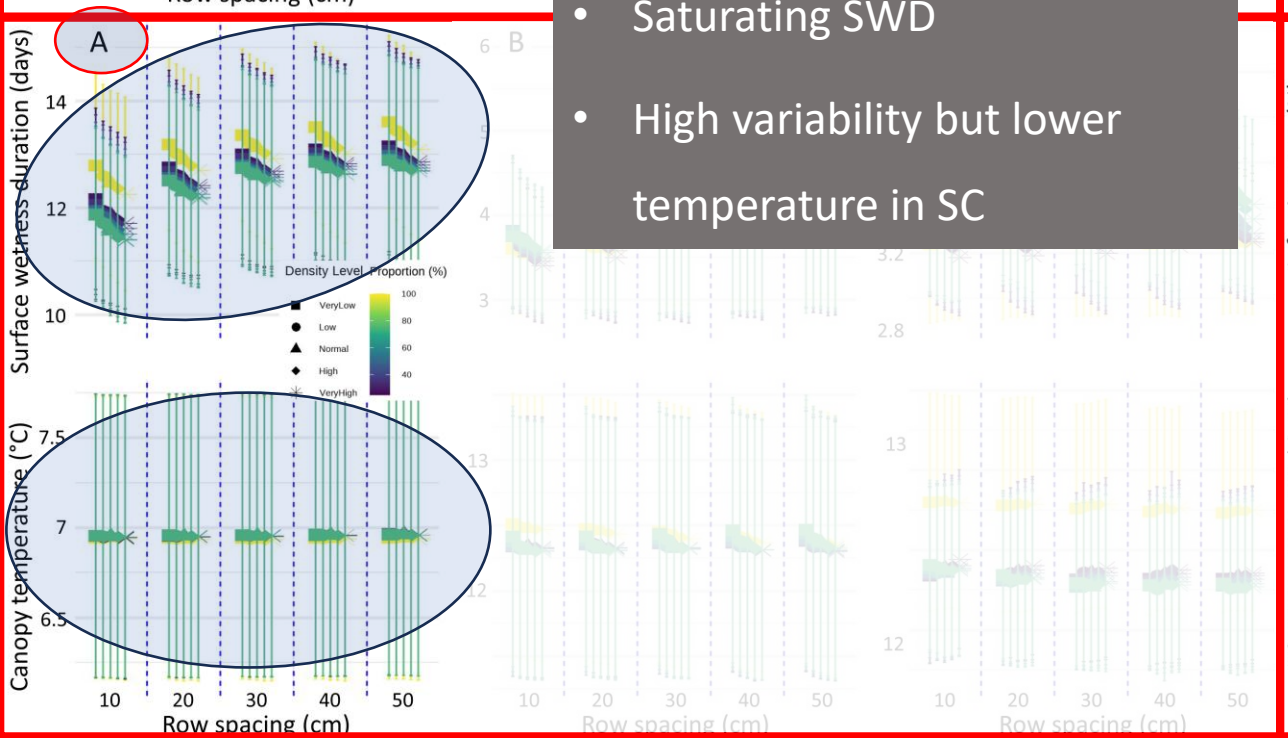

Max AUDPC
Max LAI
Cumul Spores/LAI
Mean SWD
Mean temp
Mean Inf rate
Days with inf
A
B
C
Density Level
VeryLow
Low
Normal
High
VeryHigh
Proportion (%)
100
80
60
40
Row spacing (cm)
10
20
30
40
50

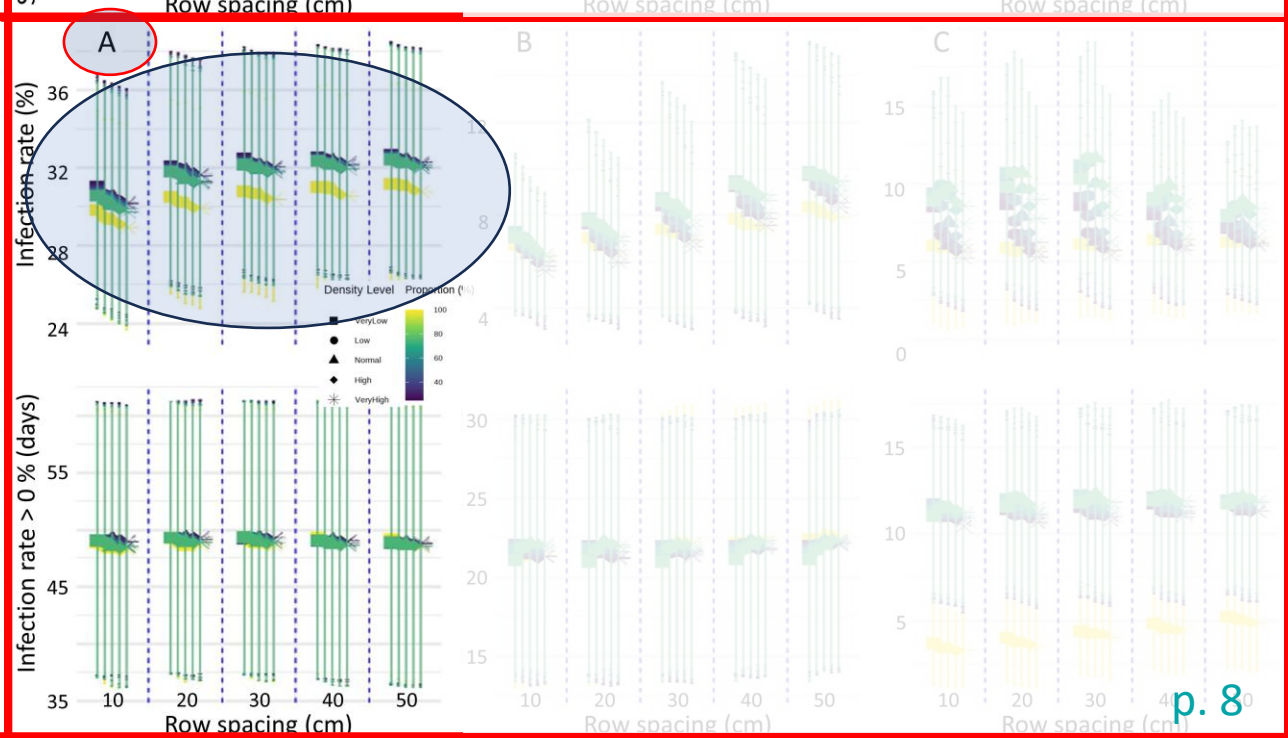


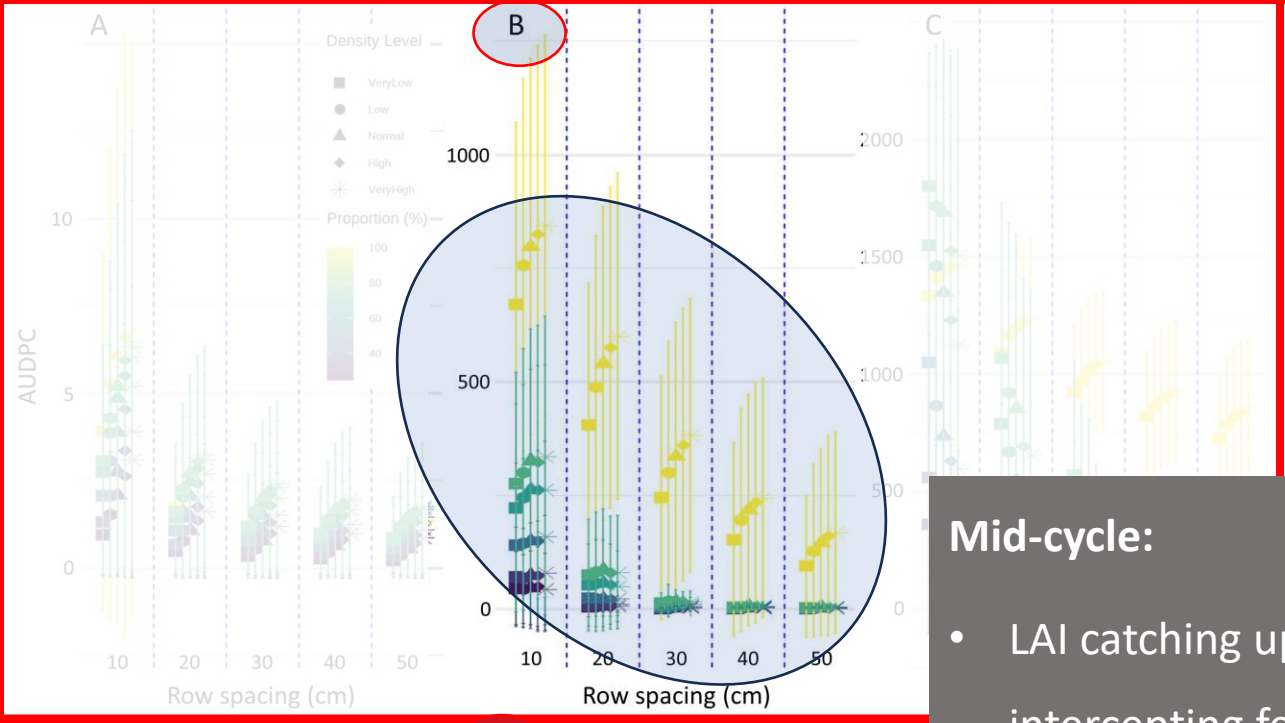


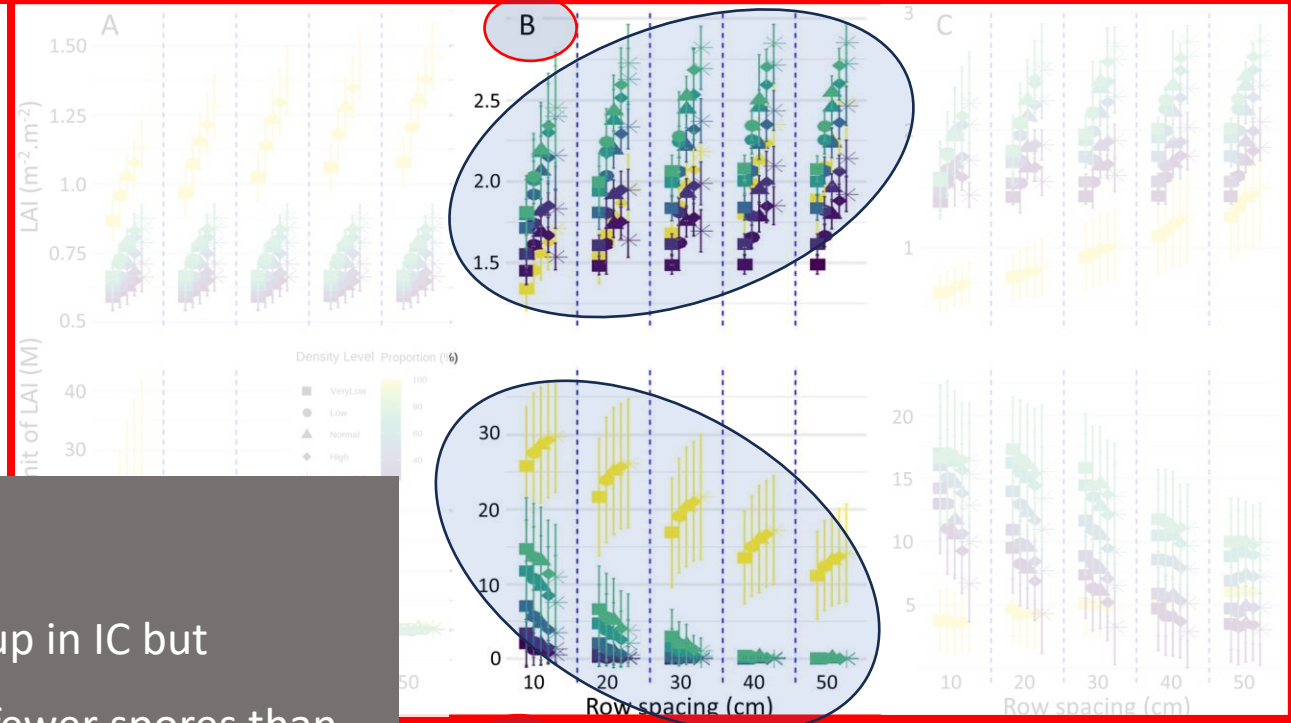
Early cycle:

- Low disease intensity/spore interception
- Reduced growth in IC
- Saturating SWD
- High variability but lower temperature in SC



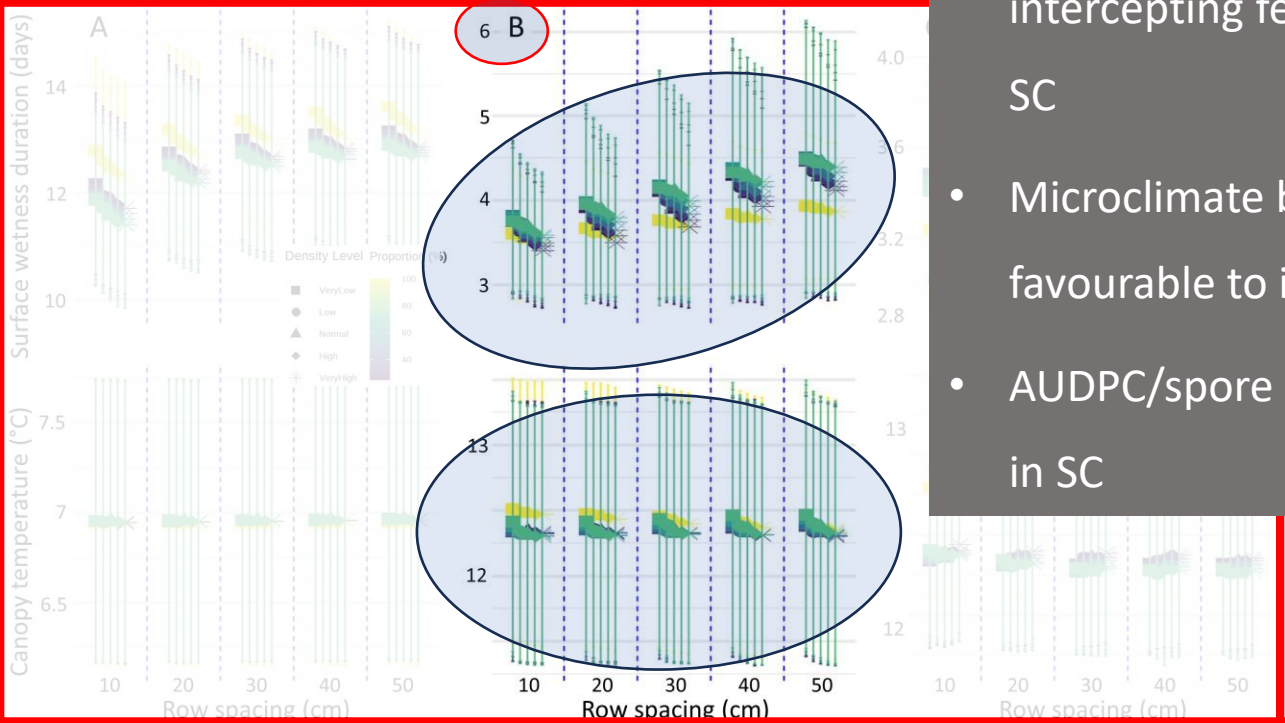


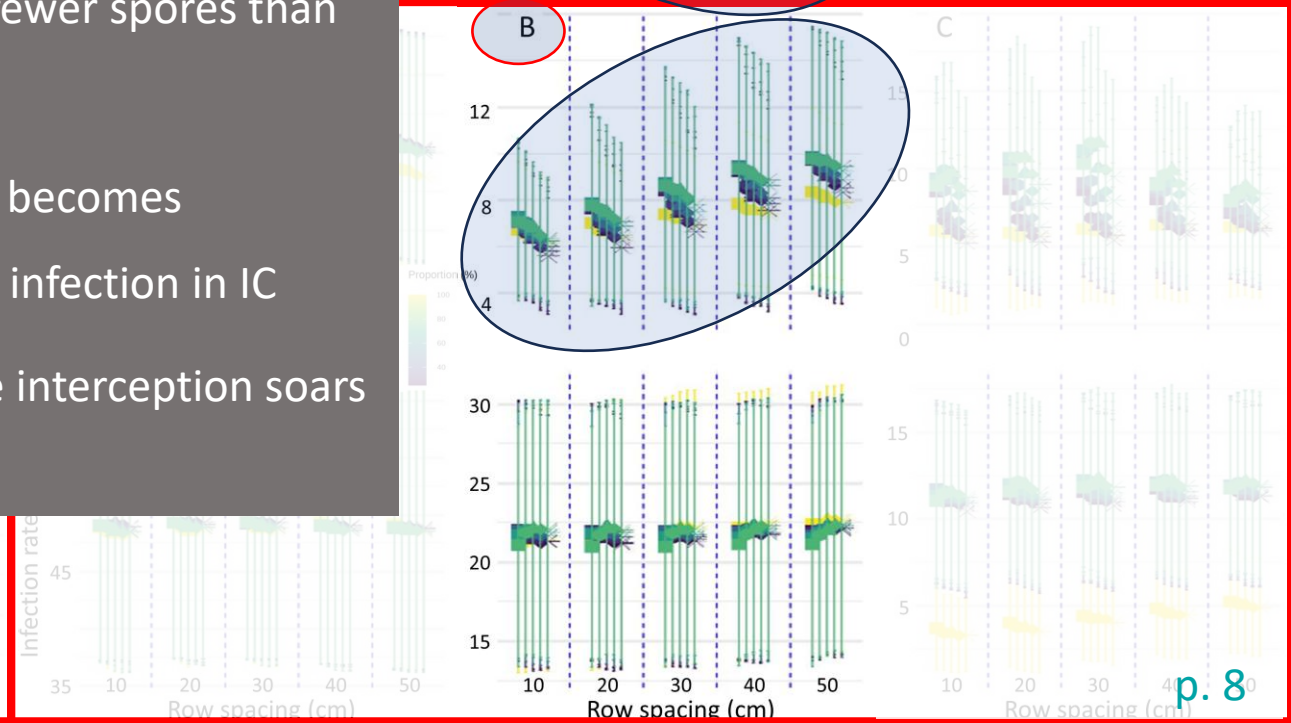


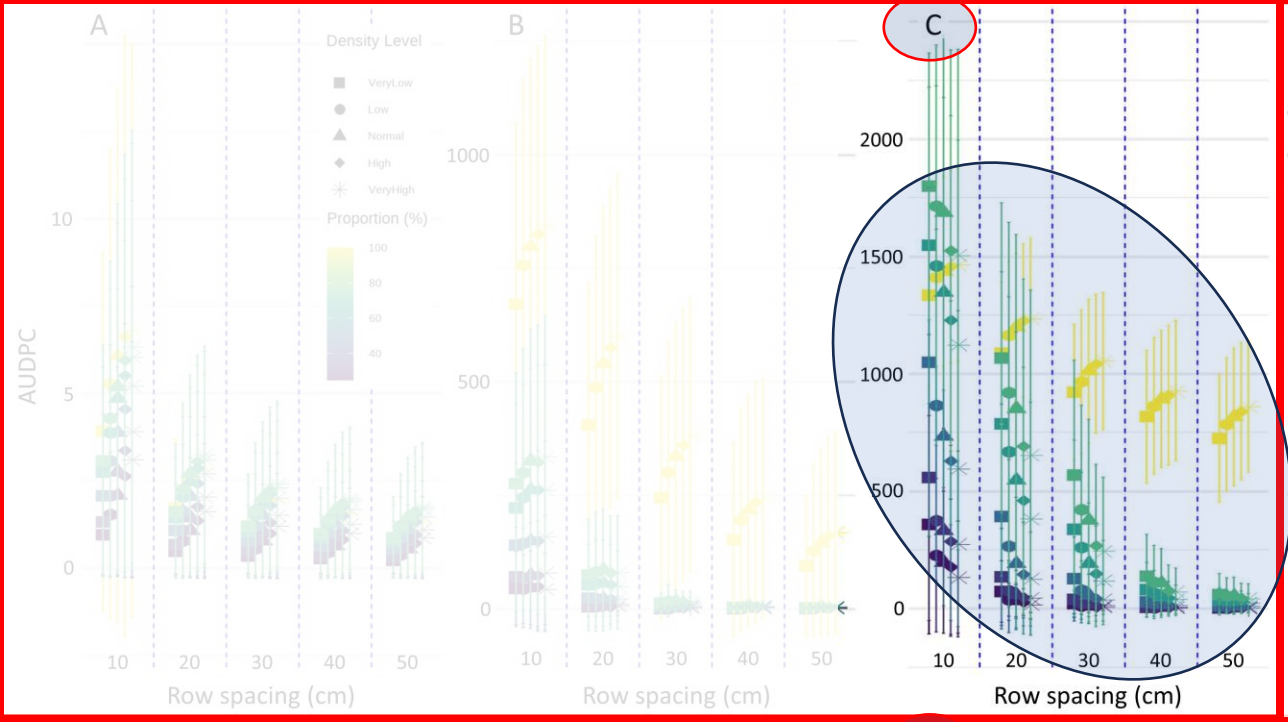


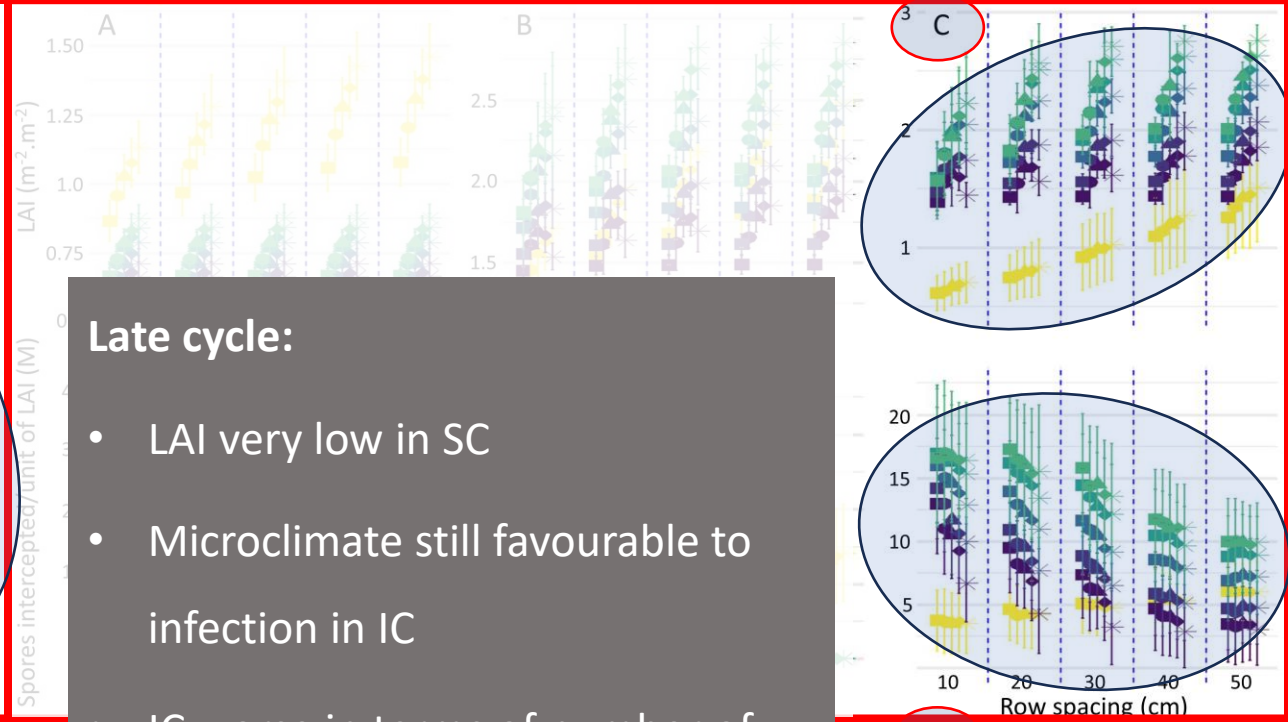
Mid-cycle:

- LAI catching up in IC but intercepting fewer spores than SC
- Microclimate becomes favourable to infection in IC
- AUDPC/spore interception soars in SC



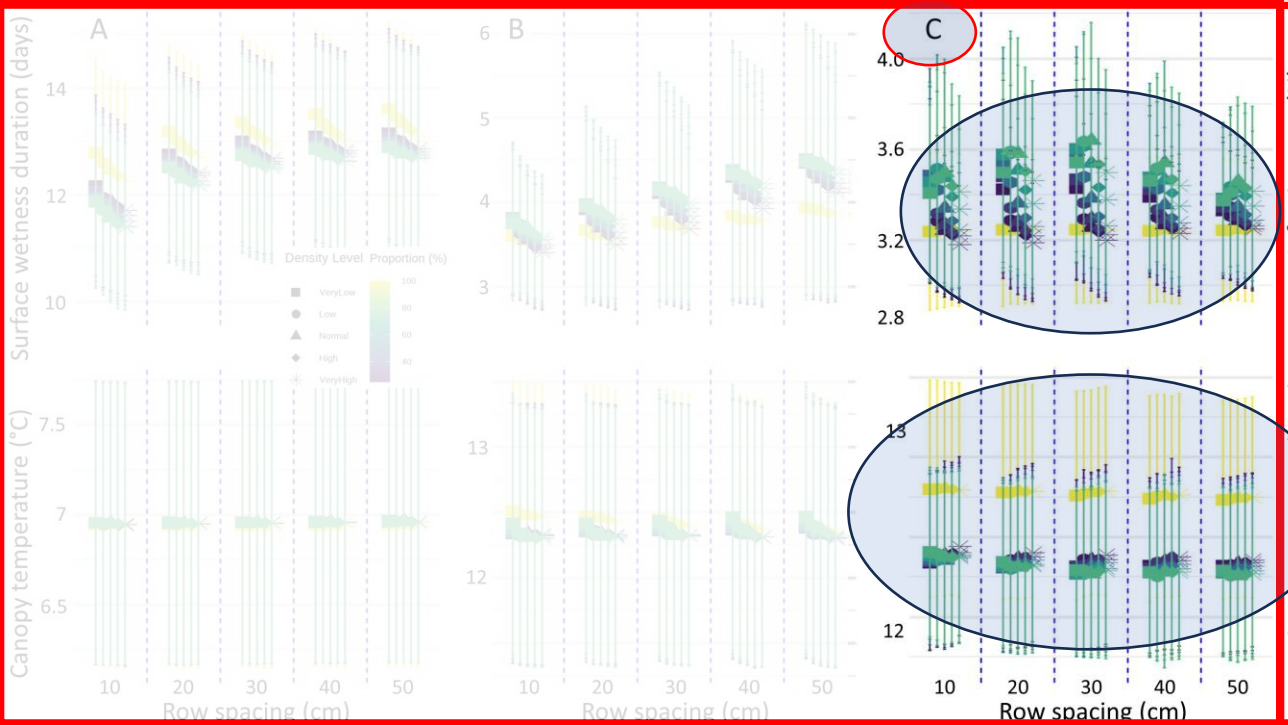


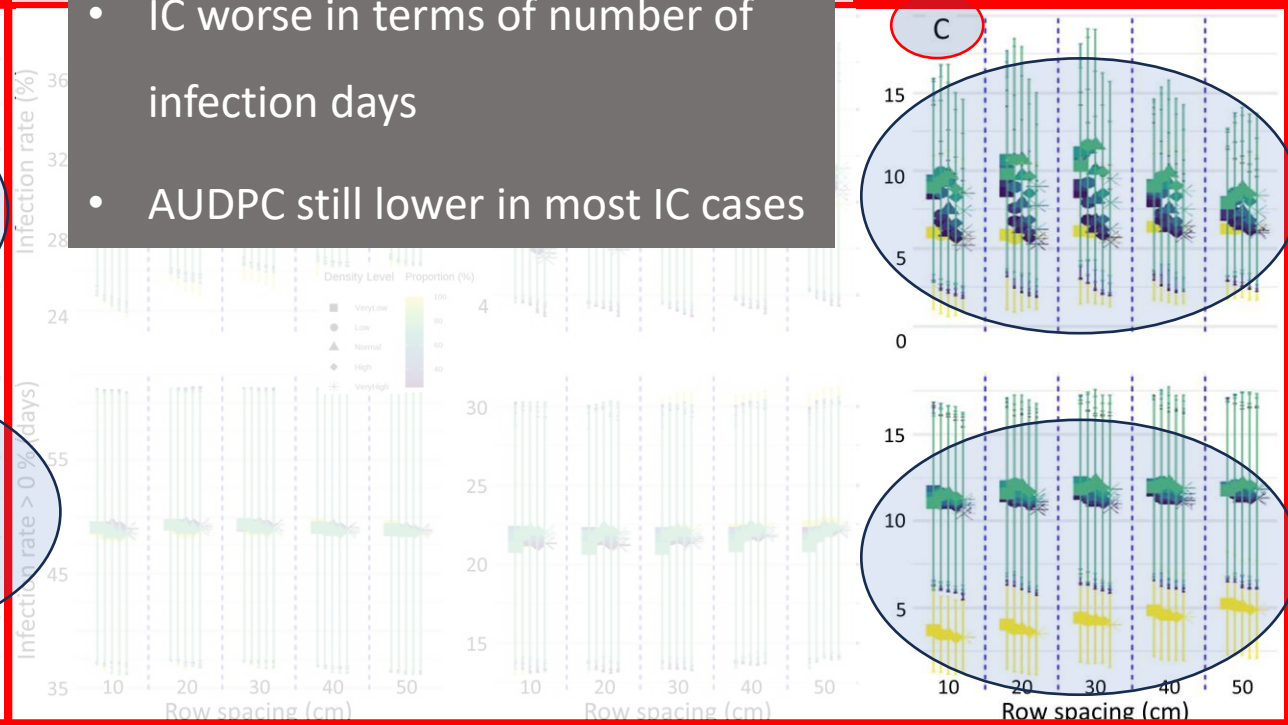




Late cycle:

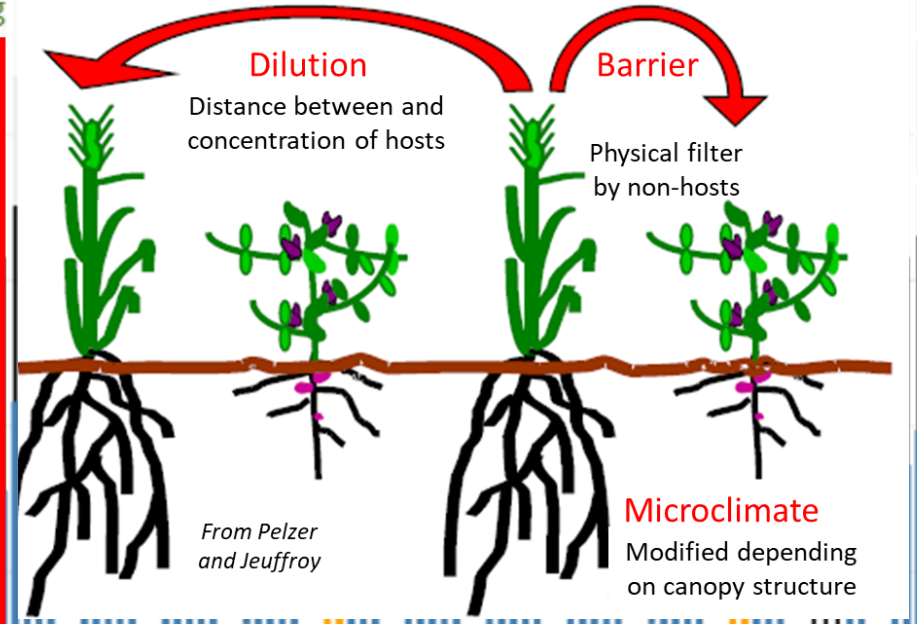
- LAI very low in SC
- Microclimate still favourable to infection in IC
- IC worse in terms of number of infection days
- AUDPC still lower in most IC cases





Wheat proportion (%) 25 33 50 66 75 100

Row spacing 10 20 30 40 50 10 20 30 40 50 10 20 30 40 50 10 20 30 40 50 10 20 30 40 50 10 20 30 40 50



Dilution effect alone

- Wheat as single crop
- Varying row spacing and total density

Dilution AND barrier effects

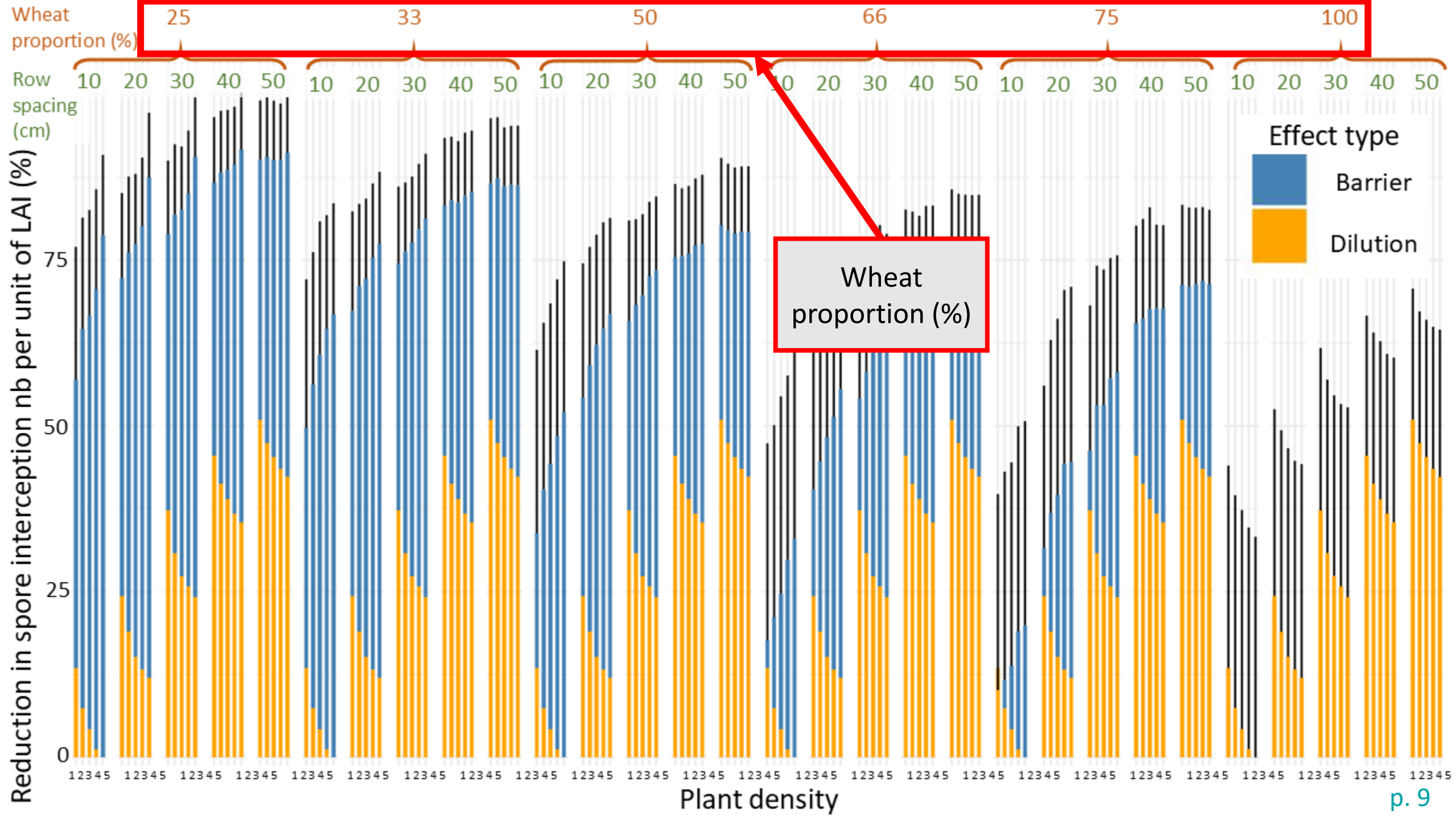
- Wheat – Pea system
- Varying row spacing, species proportion and total density

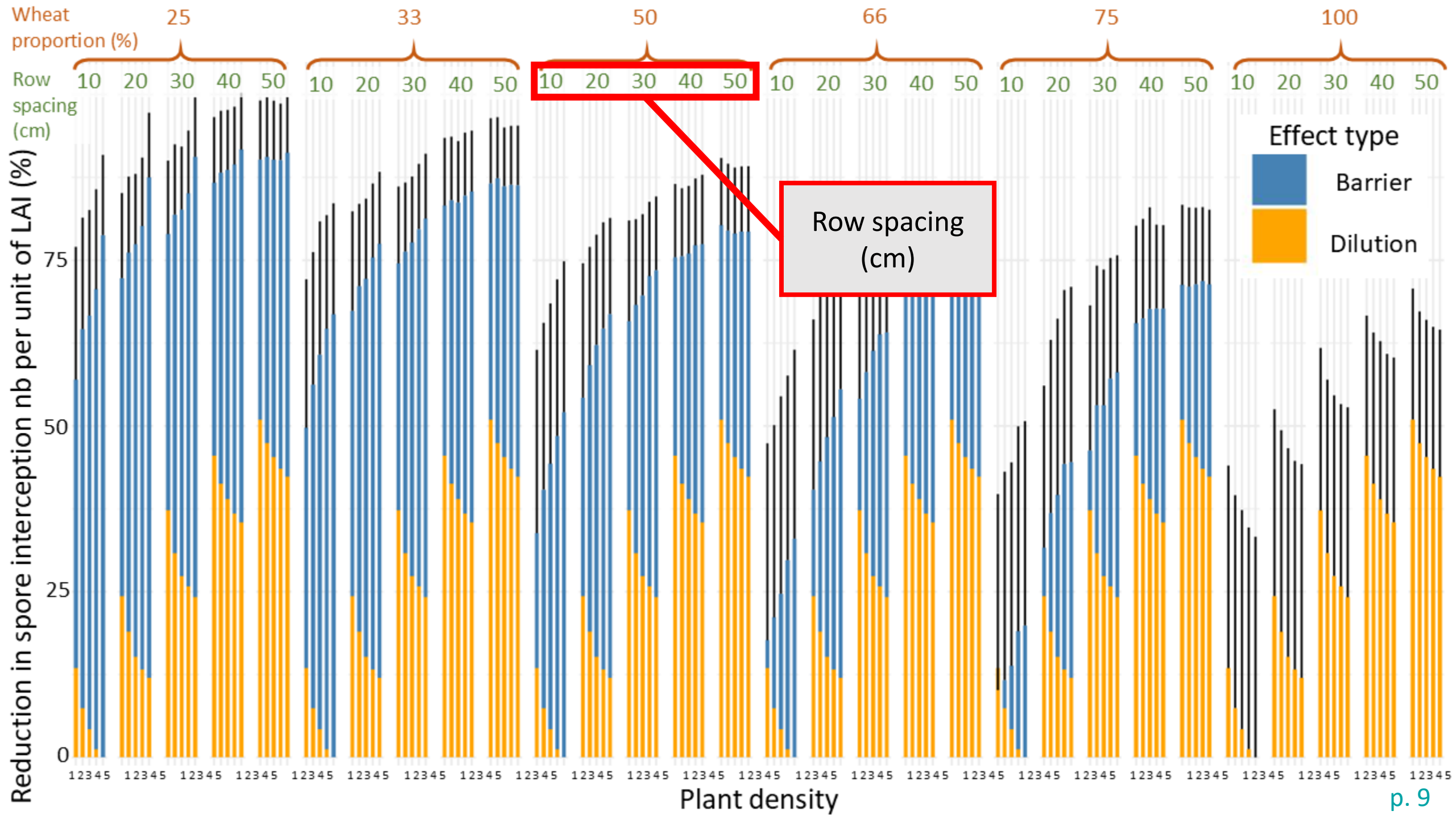
Effect type
Barrier
Dilution

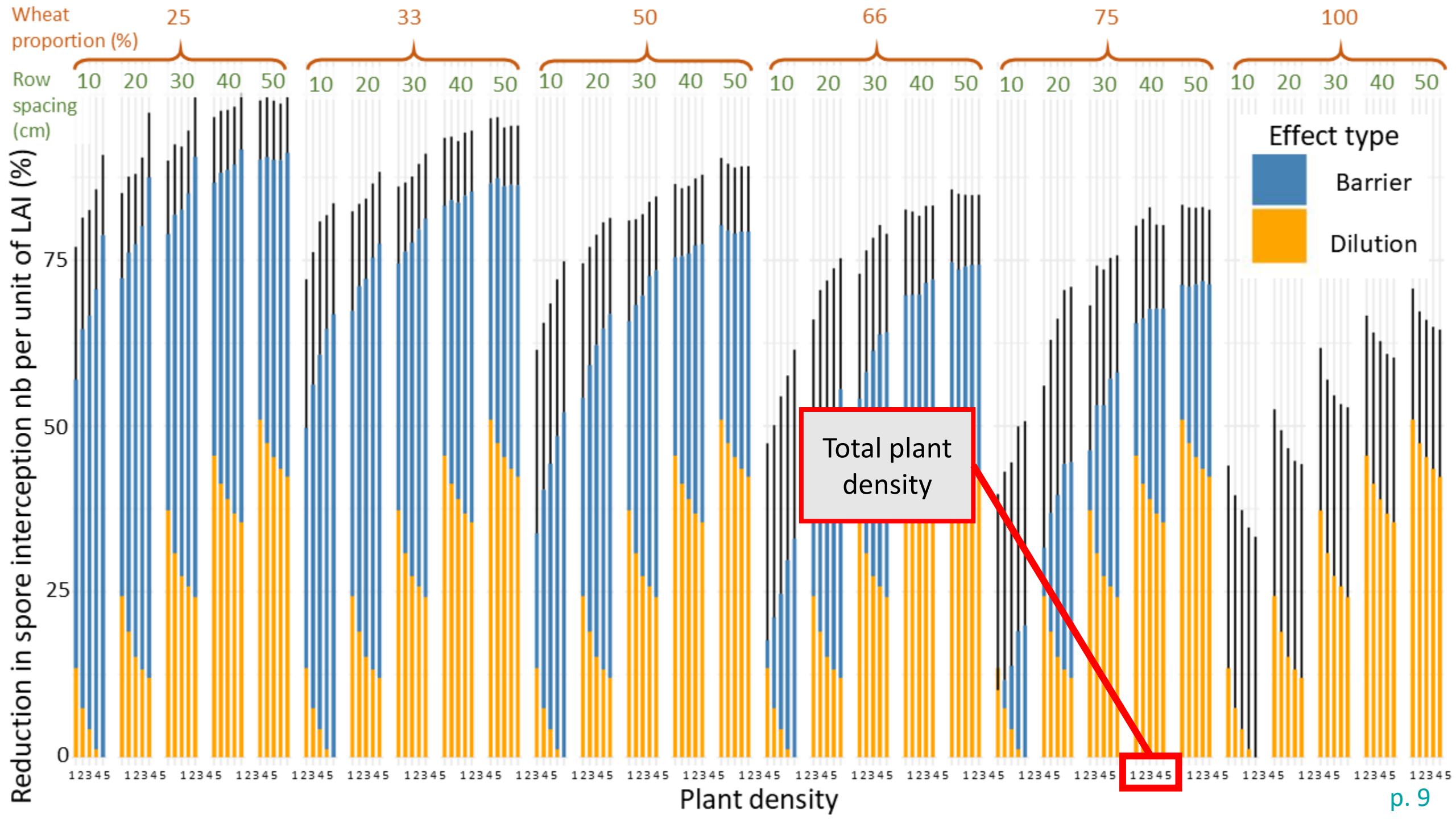
Reduction in spore interception nb per unit of LAI (%)

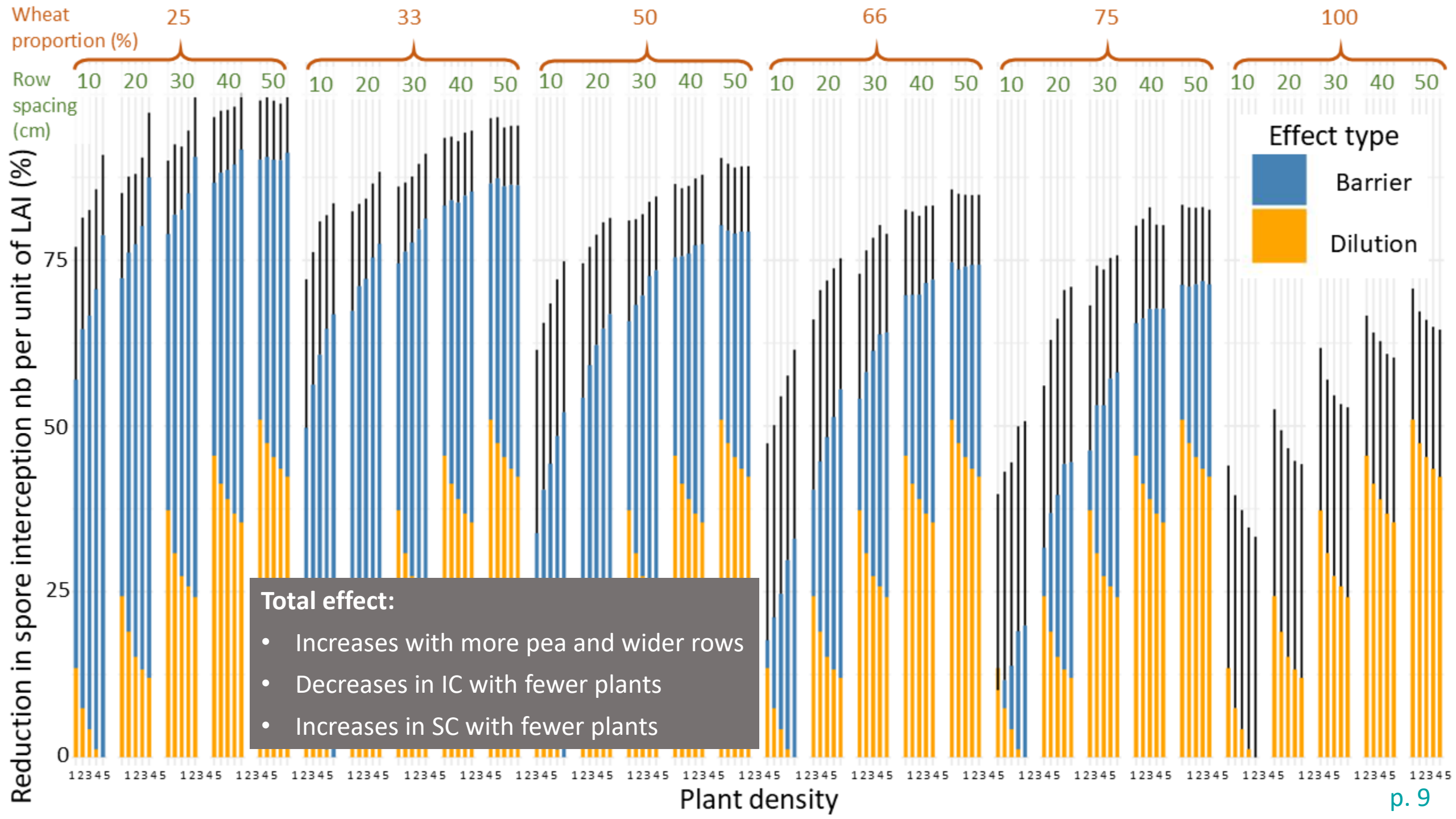
12345 12345

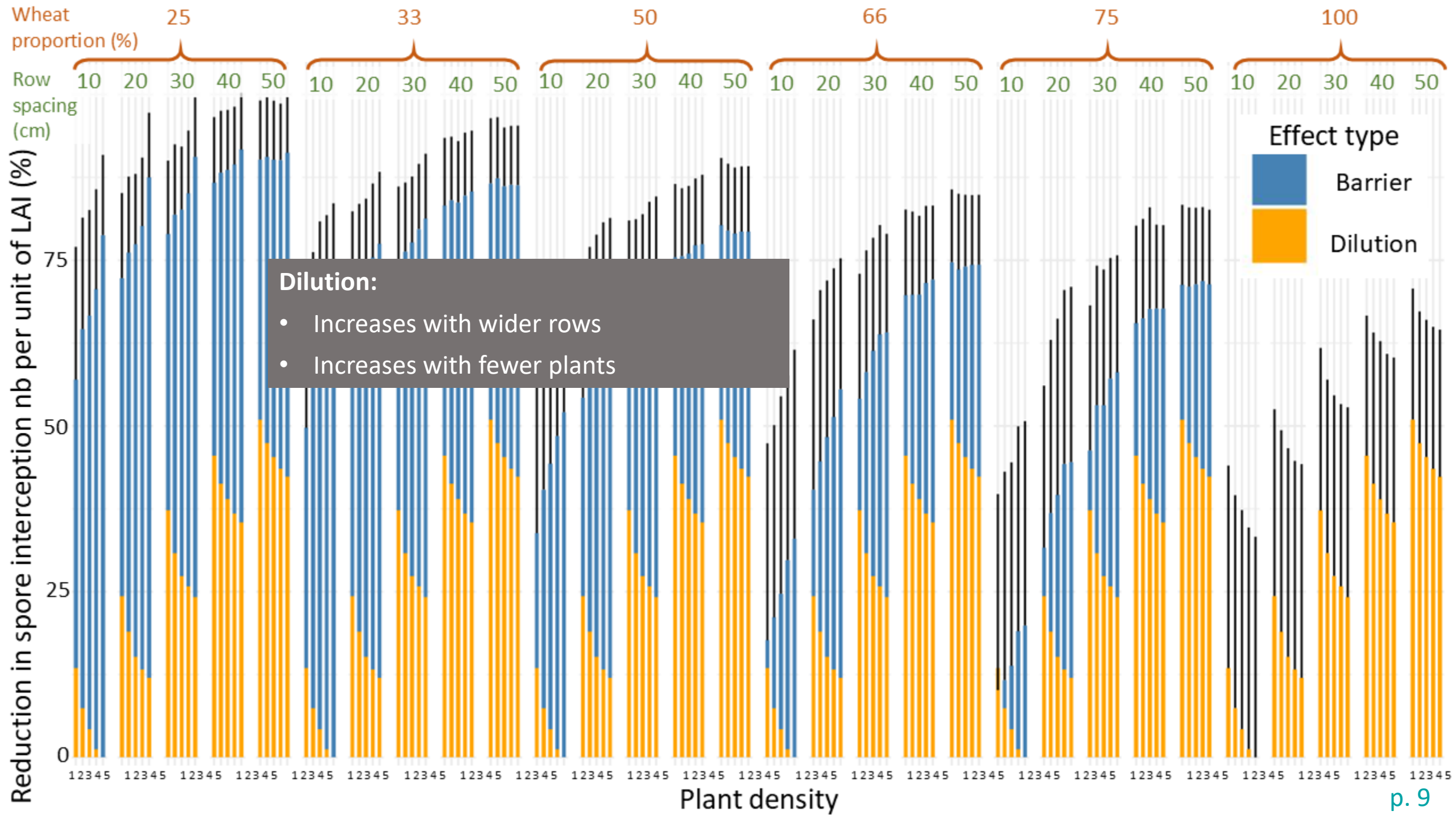
Plant density

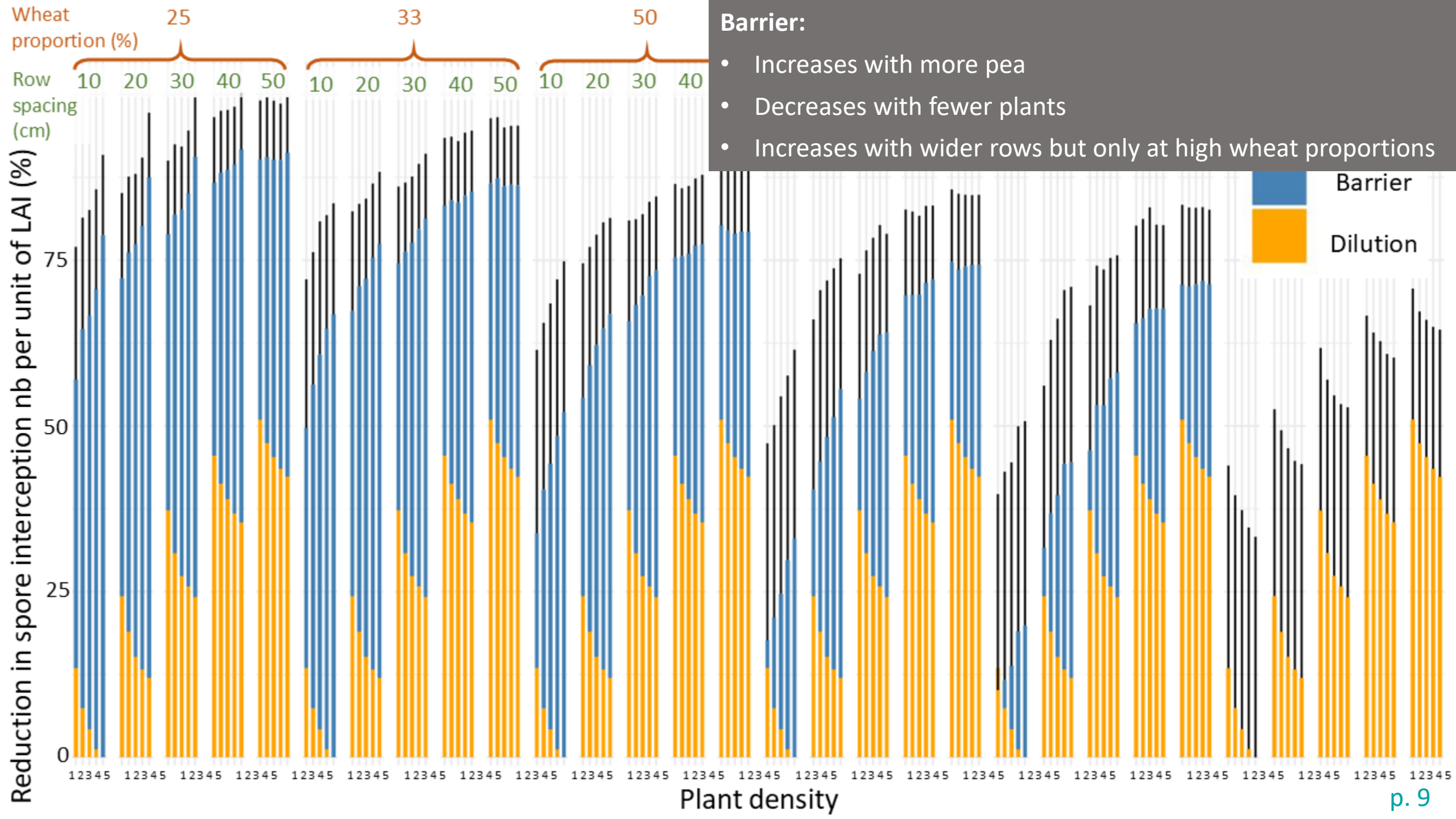

Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Effect type
Barrier
Dilution
Wheat proportion (%)
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
12345
Plant density


Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Effect type
Barrier
Dilution
Row spacing (cm)
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
1 2 3 4 5
Plant density


Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Effect type
Barrier
Dilution
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
Total plant density
12345
Plant density

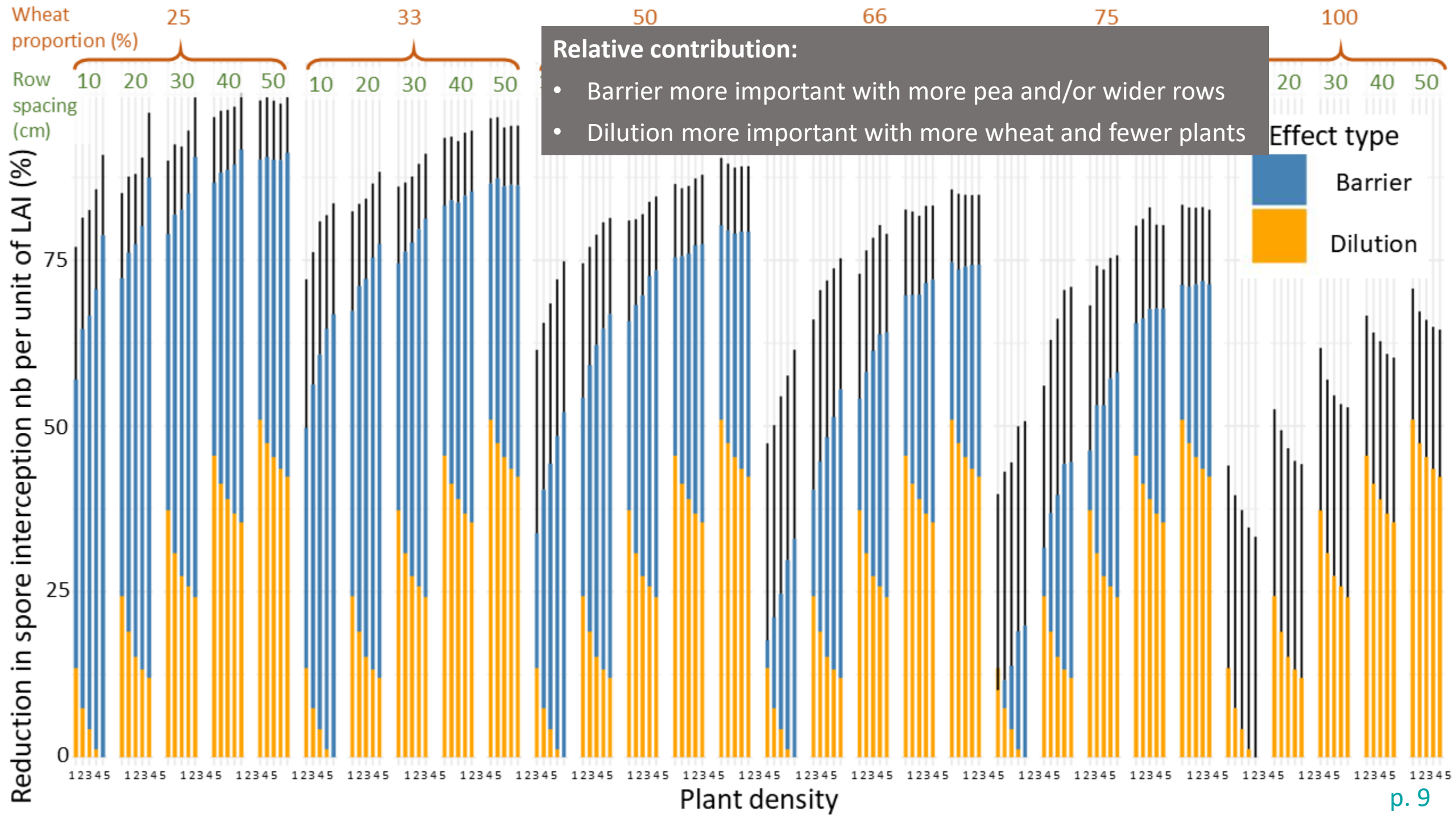

Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Effect type
Barrier
Dilution
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
12345
Plant density
Total effect:
• Increases with more pea and wider rows
• Decreases in IC with fewer plants
• Increases in SC with fewer plants


Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Effect type
Barrier
Dilution
Dilution:
• Increases with wider rows
• Increases with fewer plants
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
12345
Plant density



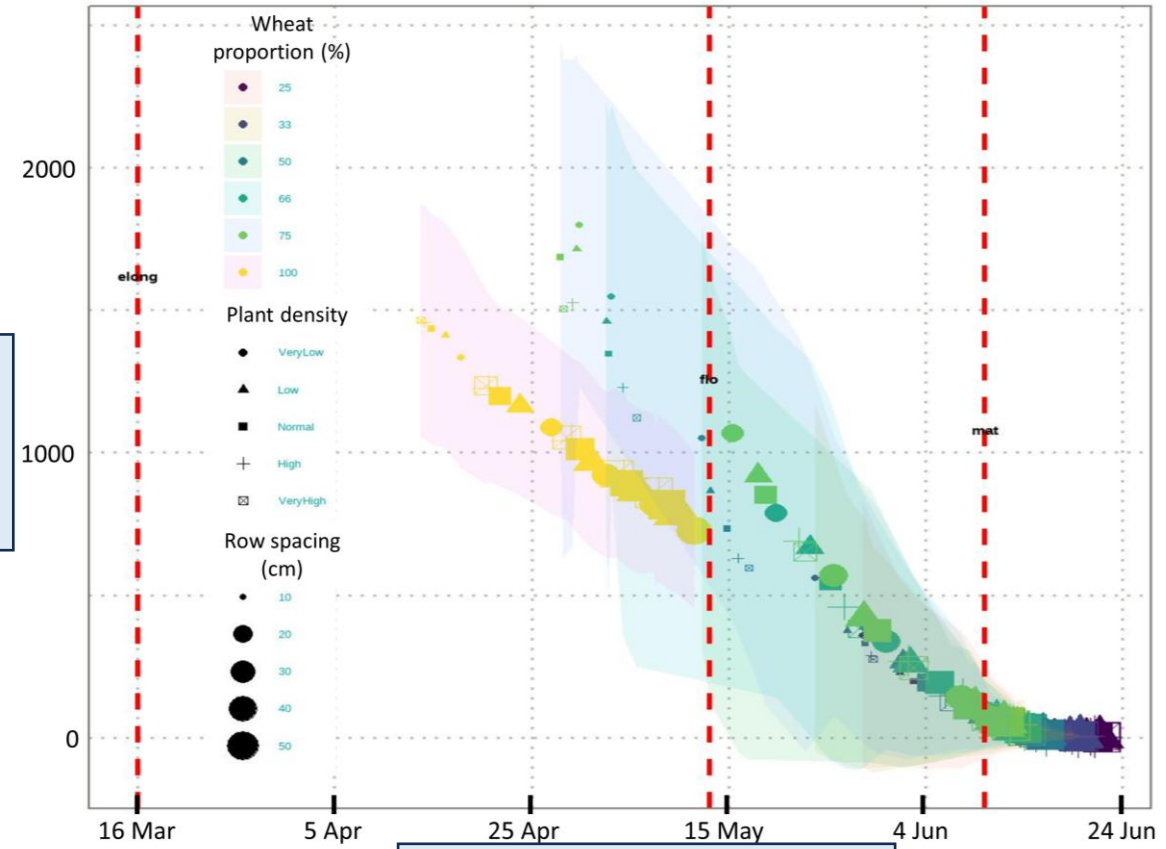
Barrier:

- Increases with more pea
- Decreases with fewer plants
- Increases with wider rows but only at high wheat proportions


Wheat proportion (%)
25
33
50
66
75
100
Row spacing (cm)
10 20 30 40 50
Relative contribution:
• Barrier more important with more pea and/or wider rows
• Dilution more important with more wheat and fewer plants
Effect type
Barrier
Dilution
Reduction in spore interception nb per unit of LAI (%)
0
25
50
75
12345
Plant density

Disease intensity

AUDPC



Date severity >= 5%

Disease precocity

- AUDPC = measure of disease intensity
- Date on which severity (% surface occupied by disease) reaches 5% = date where the epidemics is intense enough to start

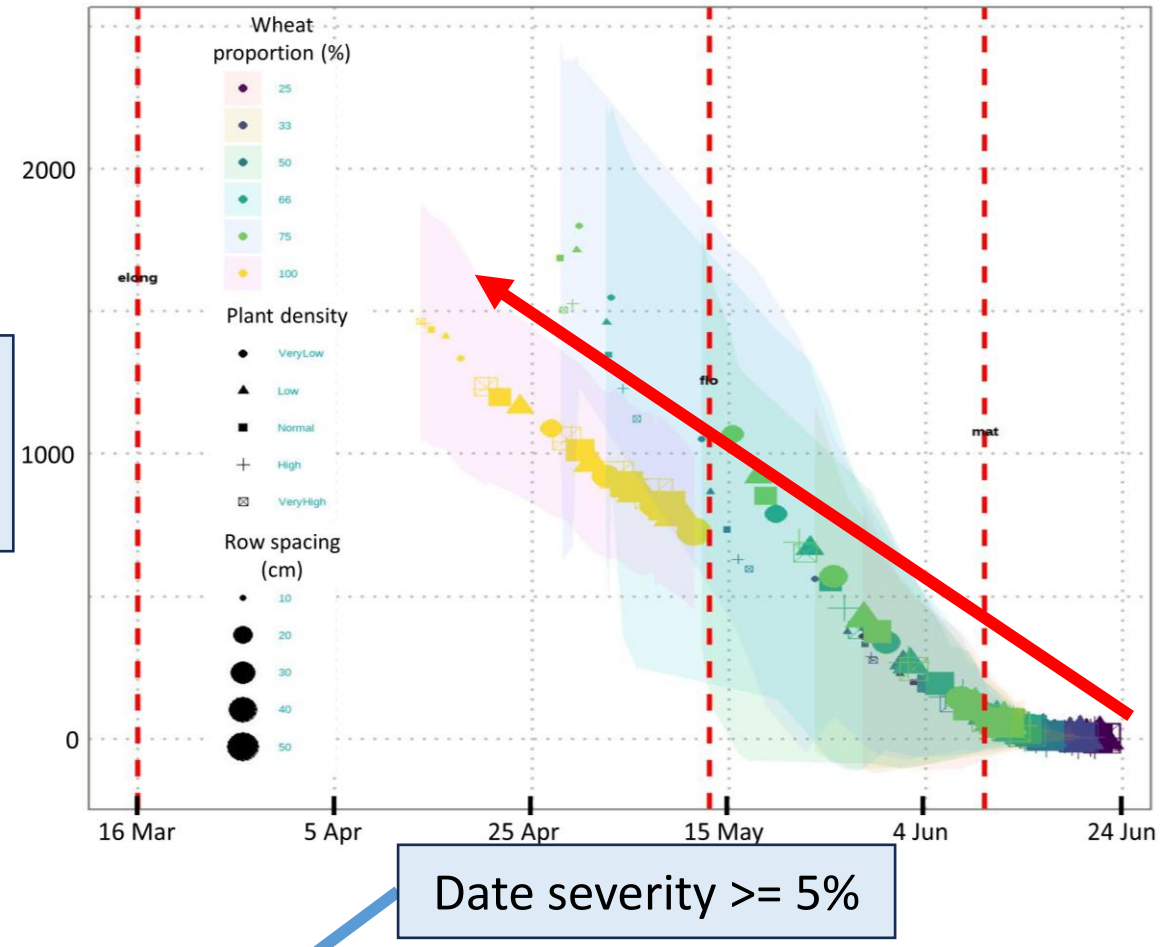
Shapes = total plant density levels

Colours = proportion of wheat

Size = distance between rows

Disease intensity

AUDPC



Date severity >= 5%

Disease precocity

- AUDPC = measure of disease intensity
- Date on which severity (% surface occupied by disease) reaches 5% = date where the epidemics is intense enough to start

➢ The earlier the epidemics starts, the more intense it becomes.

➢ Depends on spatial arrangement

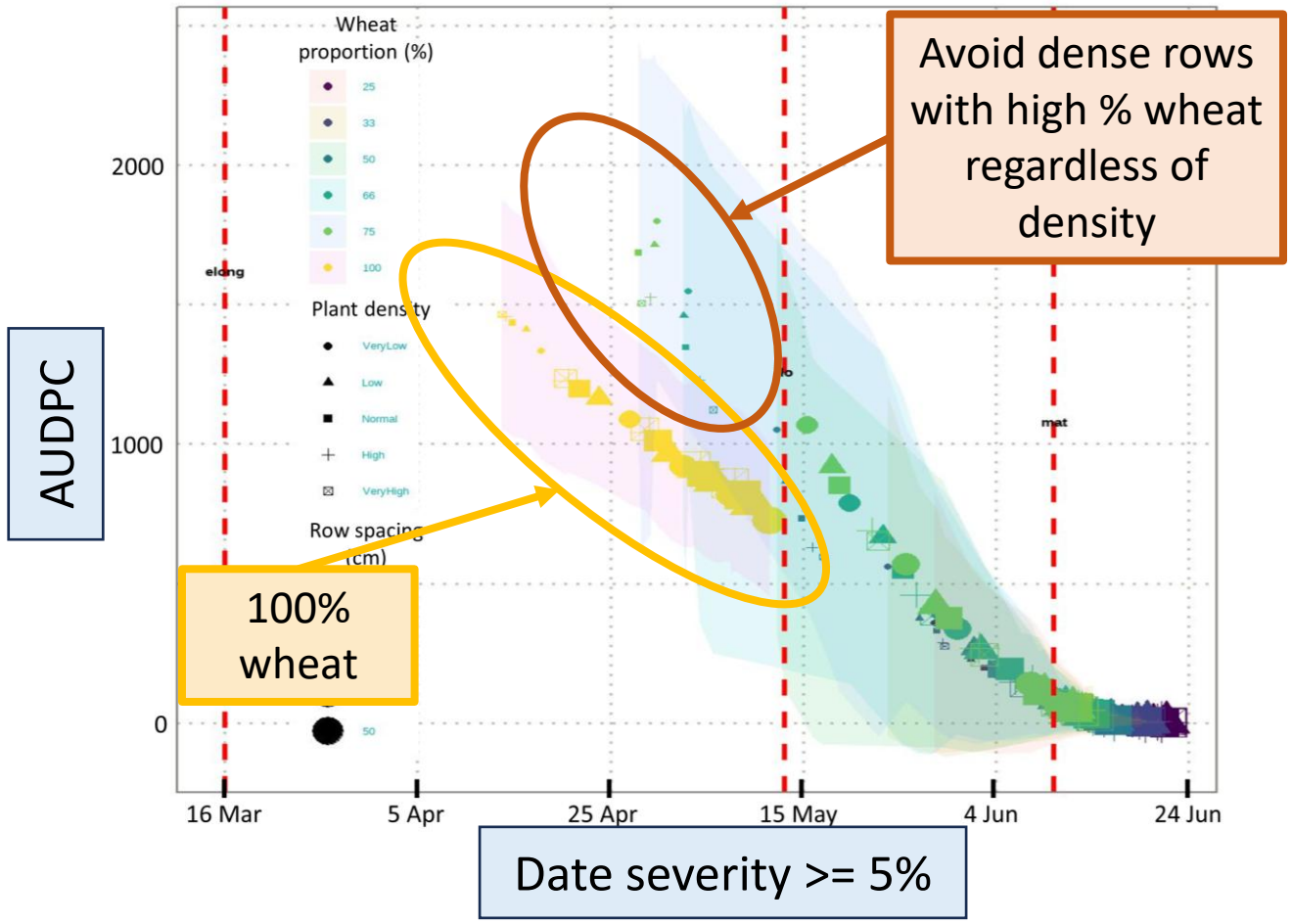
Shapes = total plant density levels

Colours = proportion of wheat

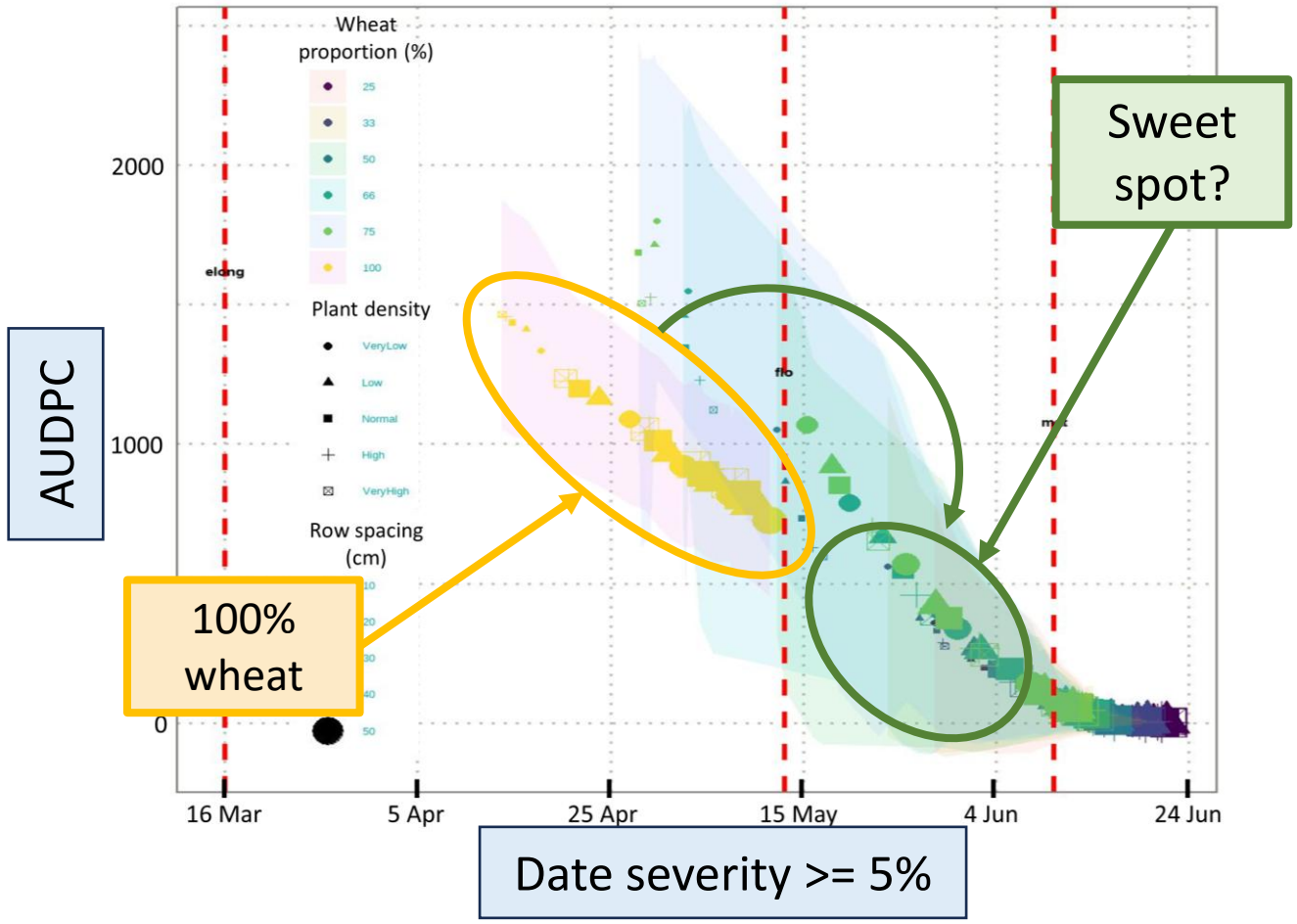
Size = distance between rows

INRAE

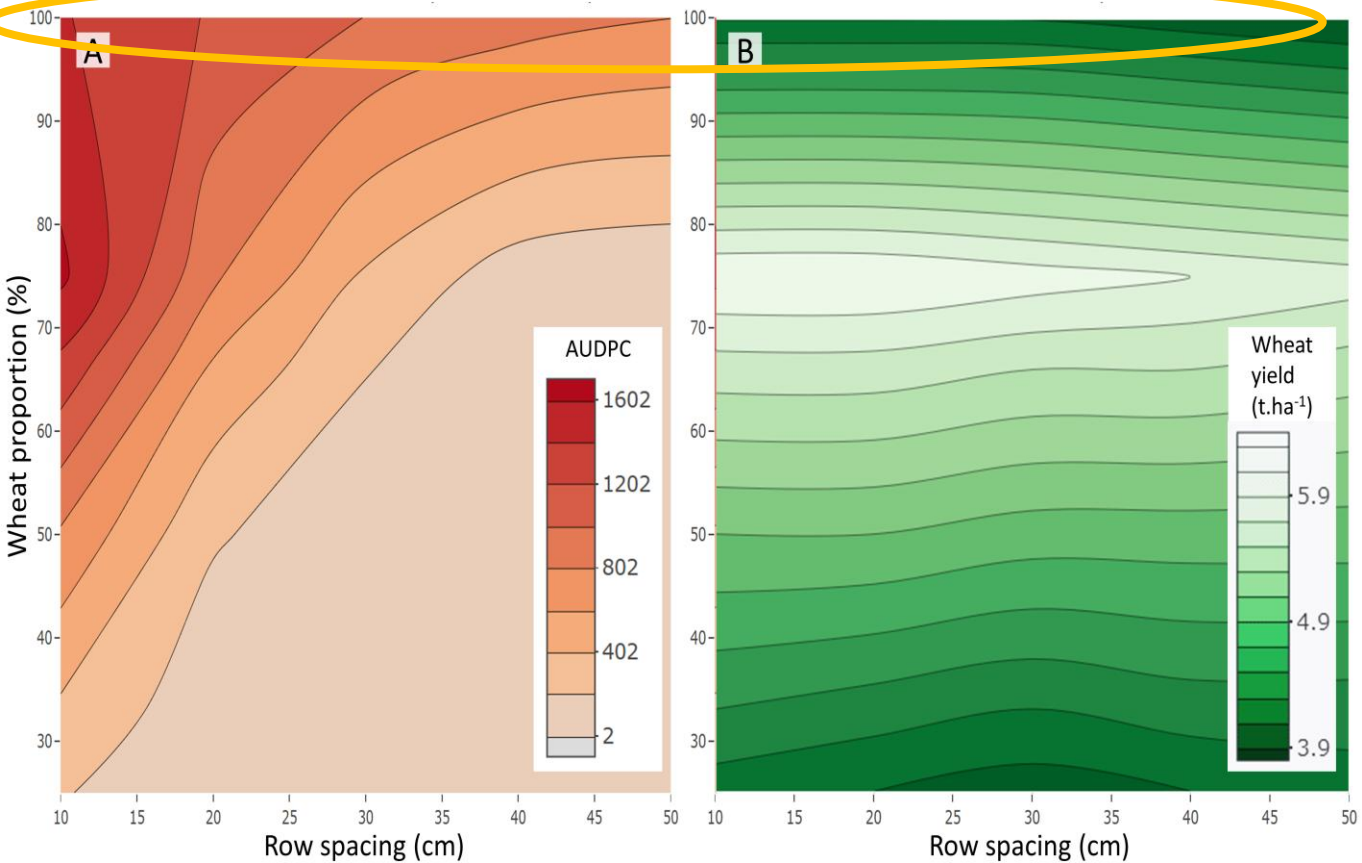
- Not all combinations are equally practical
- 100% wheat: epidemics starts before flowering + resulting in higher AUDPC
- Intercropping: worse than sole cropping when using close rows



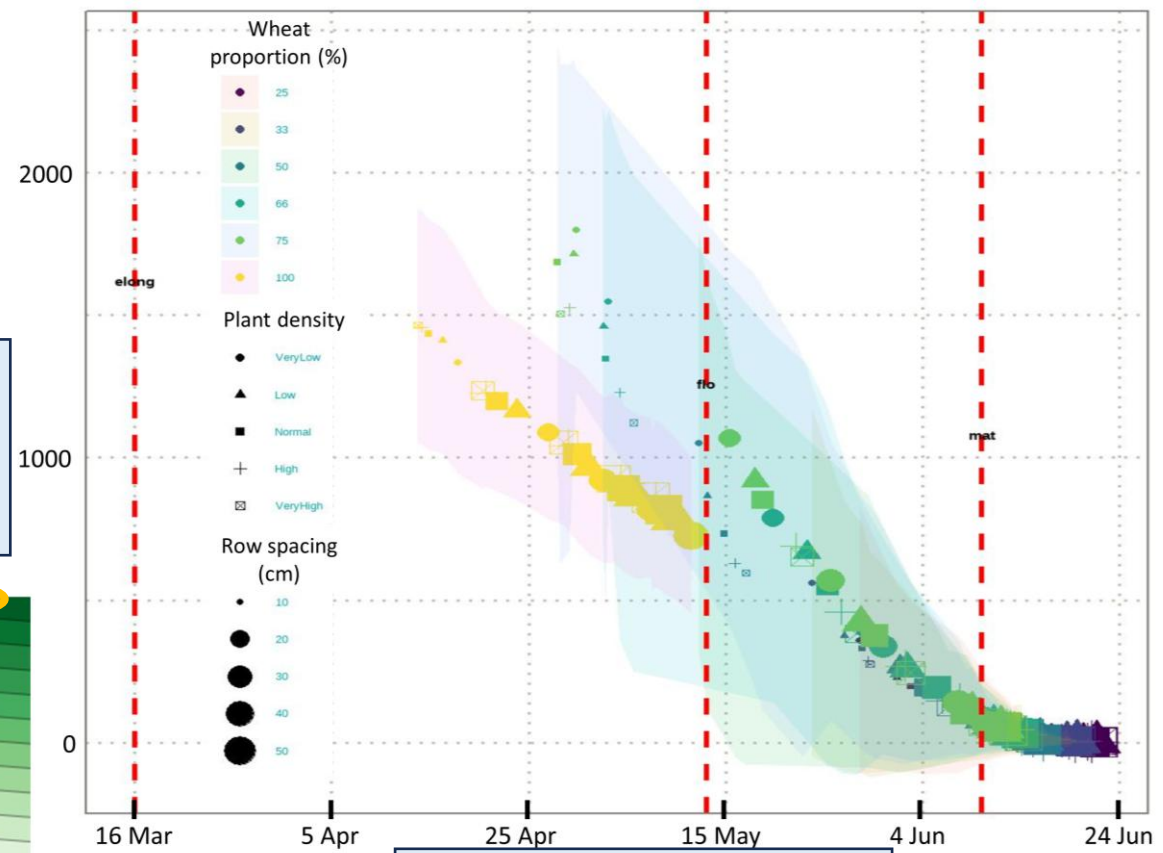
- 60–75% wheat + 25–40% pea with normal planting density and row spacing
- Benefits:
  - ~50% reduction in disease intensity
  - Epidemic delayed until AFTER flowering (grain fill protected)
  - Minimal disruption to current farming



100% wheat



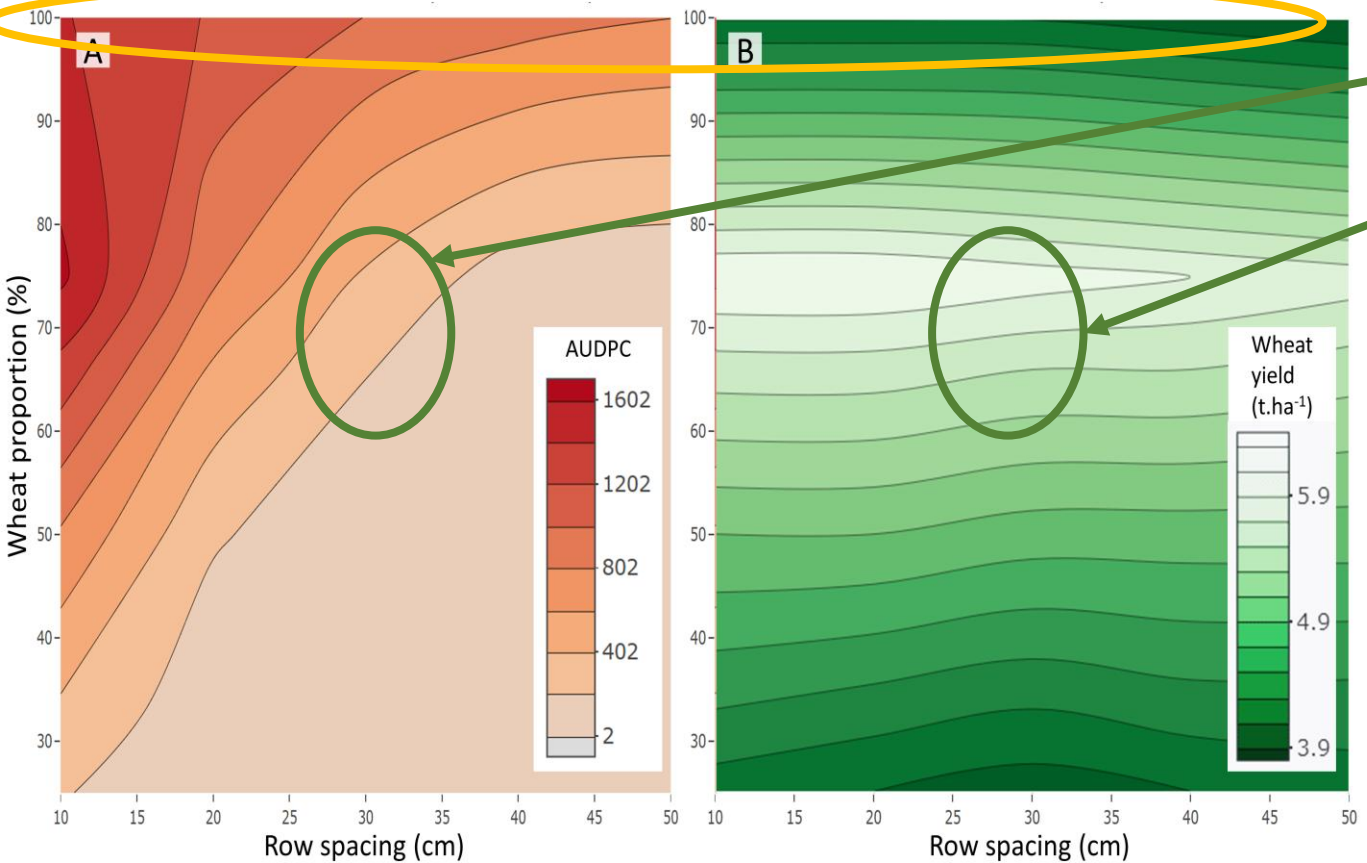
AUDPC



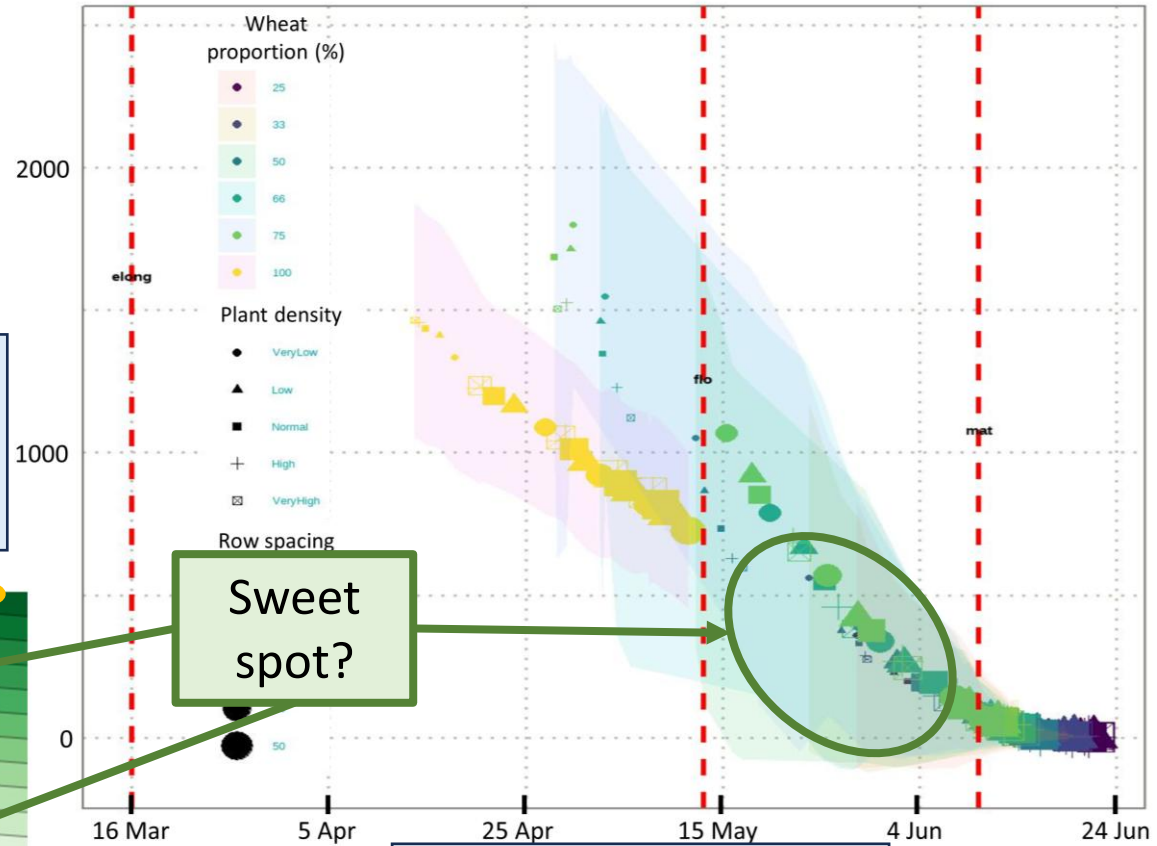
Date severity >= 5%

- Contour graph of AUDPC and yield
- Wheat proportion against row spacing for an average density

100% wheat



AUDPC



Sweet spot?

Date severity >= 5%

- Highlights the same “sweet spot”
- What is best for disease also maintains or improves yield

INRAE

Questions?

Read the paper here!