Which pea traits for agroecological weed management in pea–wheat intercrops

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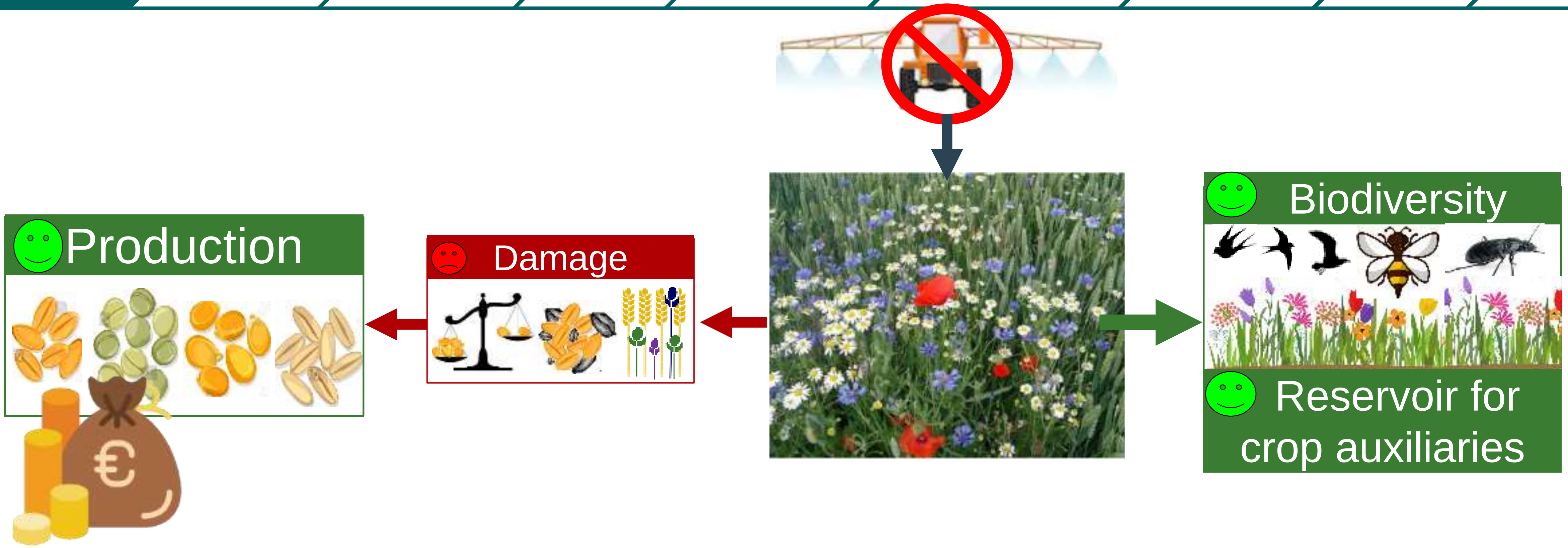
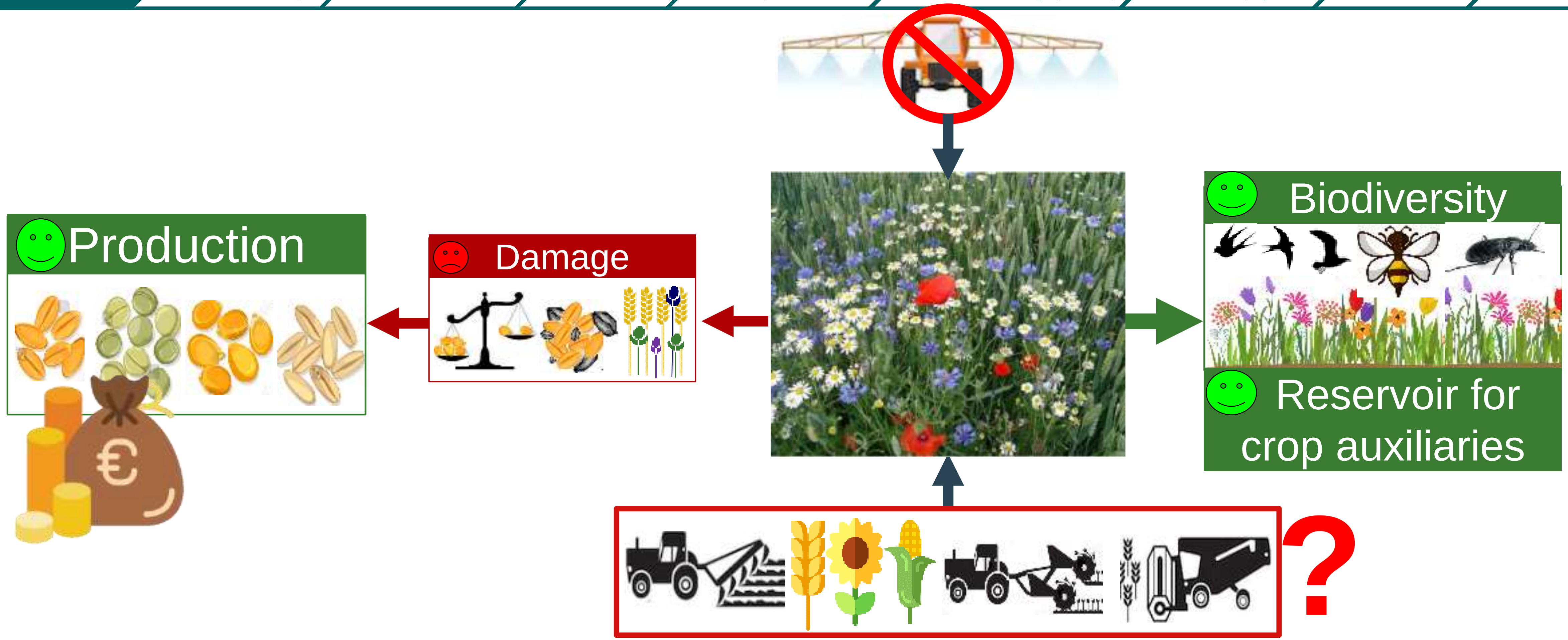
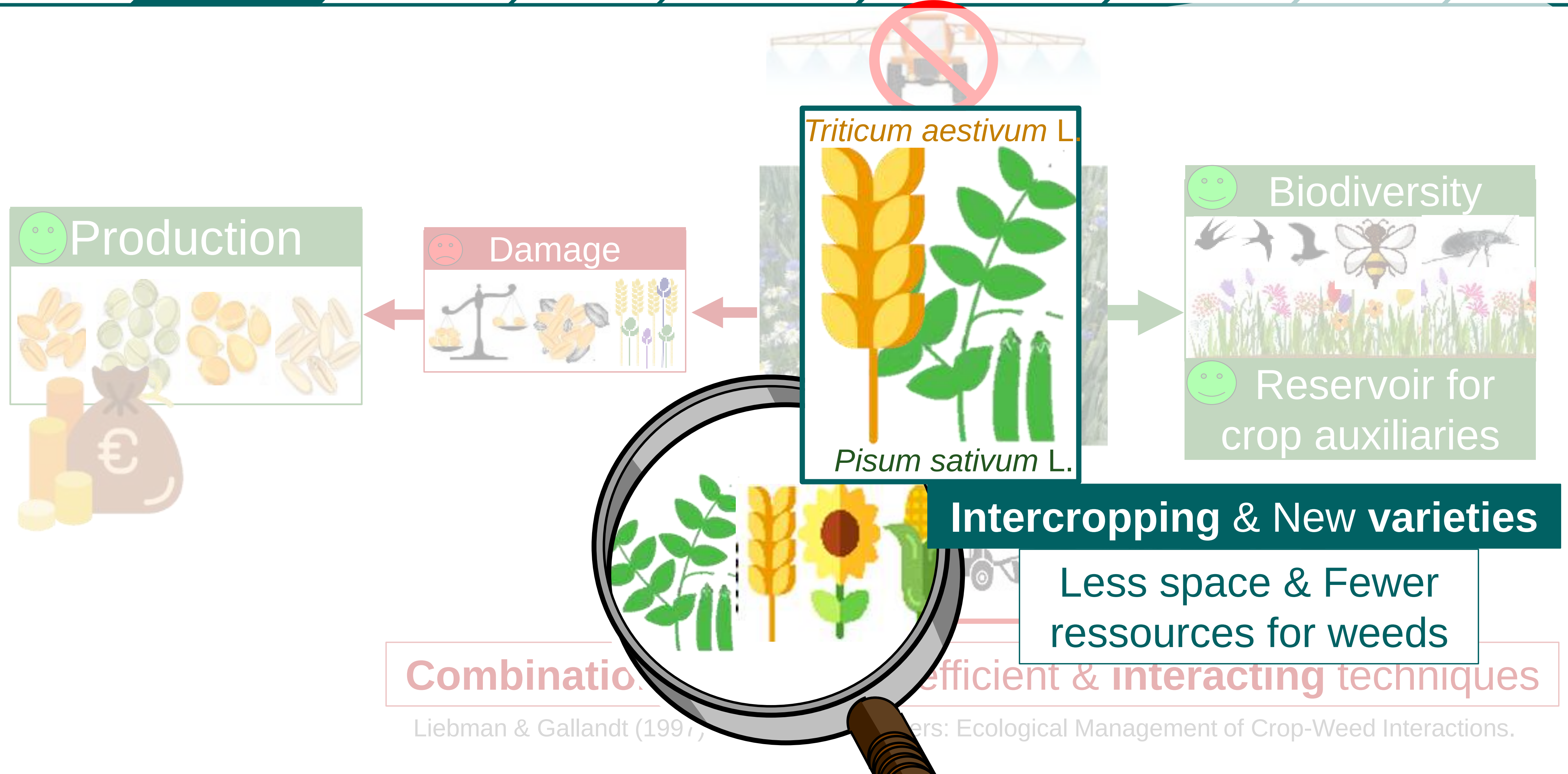

Production
Damage
Biodiversity
Reservoir for crop auxiliaries



Combinations of **partially** efficient & **interacting** techniques

Liebman & Gallandt (1997) Many Little Hammers: Ecological Management of Crop-Weed Interactions.


Production
Damage
Triticum aestivum L.
Pisum sativum L.
Biodiversity
Reservoir for crop auxiliaries
Intercropping & New **varieties**
Less space & Fewer ressources for weeds
Combinatio
fficient & interacting techniques
Liebman & Gallandt (199
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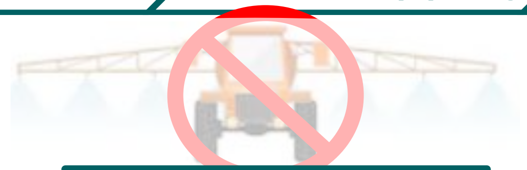
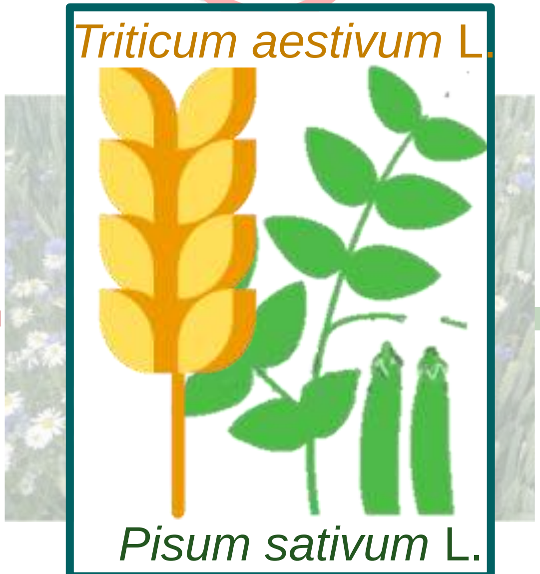


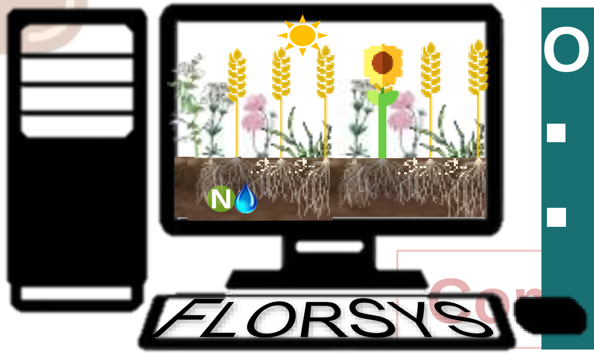


Production

Damage

Biodiversity

Reservoir for crop auxiliaries



Objective = Identify

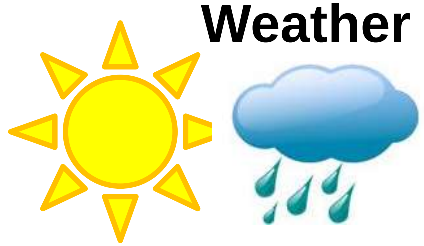
- Effect of intercropping vs sole crops
- Pea x Wheat **ideotypes** (ideal varieties)
- = f(production goal, intercrop management)

echniques

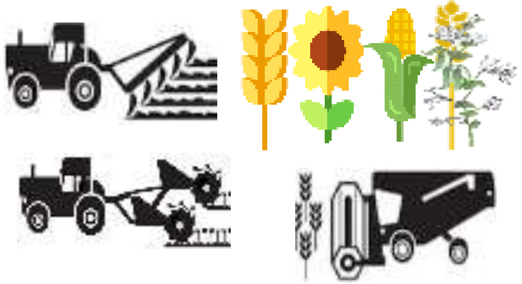
Management of Crop-Weed Interactions.

Many factors & interactions + Long term effects

Weather

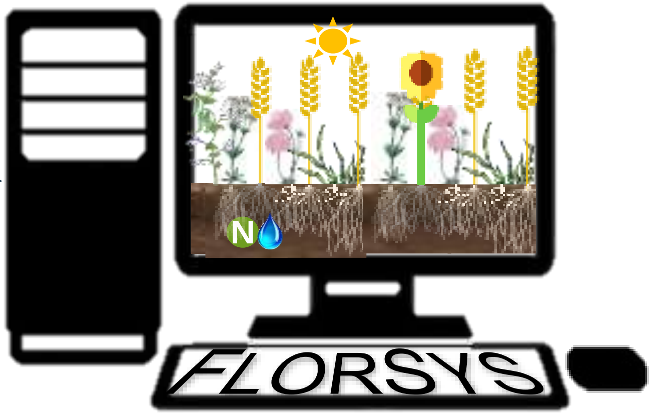


Cropping system



Soil characteristics

33 crop species
32 weed species



Detailed inputs → Biophysical processes
Daily time-step – multiannual
3D individual-based - multispecies

Competition for …

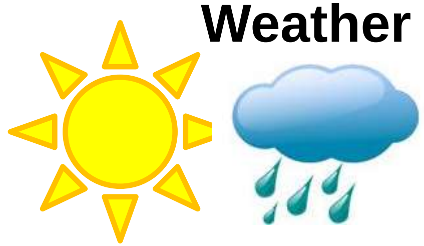
…Water during germination/emergence

…Light during post-emergence growth

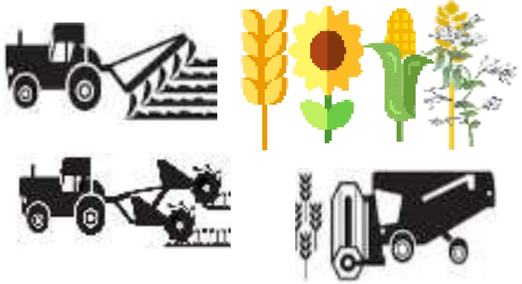
(temperate arable cropping systems)

Colbach et al (2014) Eur J Agron, Colbach et al (2021) Field Crops Research, Gardarin et al (2012) Ecol Modelling, Mézière et al (2015) Ecological Indicators, Munier-Jolain et al (2013) Ecol Modelling, Pointurier et al (2021) Ecol Modelling

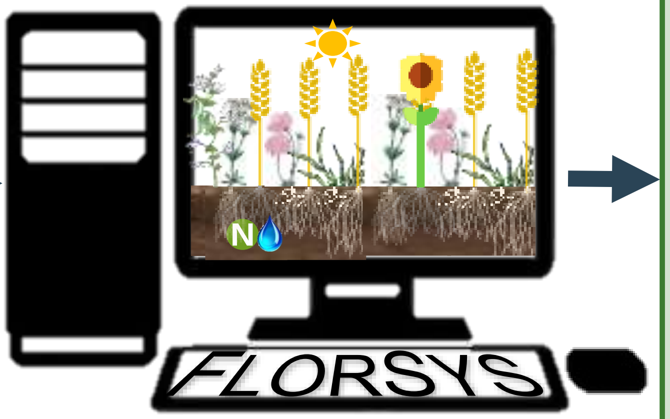
Weather



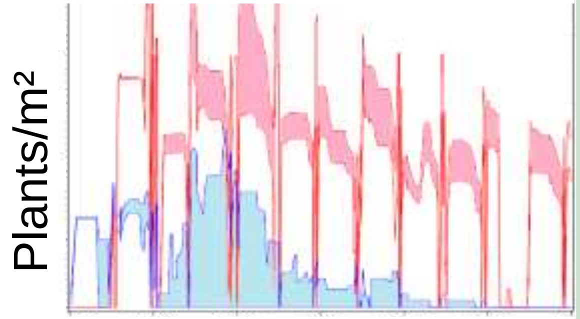
Cropping system



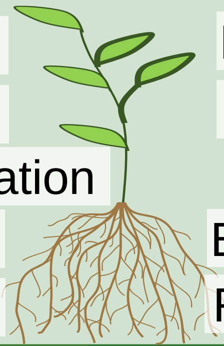
Soil characteristics



For each state variable



For each plant & day



Weed harmfulness

Biodiversity

Indicator 1	Indicator 2	Indicator 3	…
0	0	9	
6	4	9	
10	5	0	
9	5	10	
3	7	4	
7	0	1	
8	5	7	
7	6	9	
2	3	4	
3	3	5	
3	4	1	
8	5	8	

Understand

Compare

Detailed inputs → Biophysical processes
Daily time-step – multiannual
3D individual-based - multispecies → Daily 3D outputs → Indicators

Colbach et al (2014) Eur J Agron, Colbach et al (2021) Field Crops Research, Gardarin et al (2012) Ecol Modelling, Mézière et al (2015) Ecological Indicators, Munier-Jolain et al (2013) Ecol Modelling, Pointurier et al (2021) Ecol Modelling

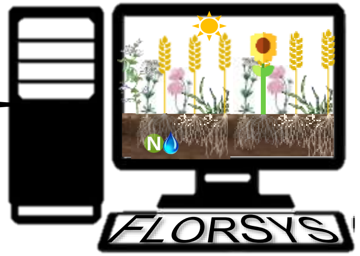
Actual varieties

Variety	Seasonality	Leaf morphology
886/1	Winter-Hr	Afila
China	Winter-Hr	Leafy
DCG0449	Winter-Hr	Leafy
Enduro	Winter-hr	Afila
Isard	Winter-hr	Afila
Cameor	Spring	Leafy
Kayanne	Spring	Afila

Colbach et al (2022) Frontiers Plant Sci

Caphorn	Winter
Cézanne	Winter
Orvantis	Winter

Colbach et al (2020) Eur J Agron



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Colbach et al (2022) Frontiers Plant Sci

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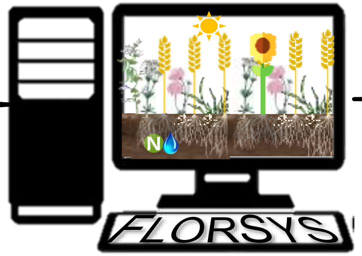

Virtual varieties

↗ Diversity of varieties in simulation

- Draw random value inside [min, max] for each parameter with LHS plan
- Respect correlations among parameters established on existing varieties

5 winter pea varieties
5 spring pea varieties

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10 winter wheat varieties

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Simulation plan

1. Create contrasting cropping systems

- 3600 cropping systems with LHS plan
  (≠ rotations, organic vs conventional, no-till vs tillage, diverse vs poor floras …)
  - Randomly choose crops, varieties, management techniques
  - Respect agronomic constraints

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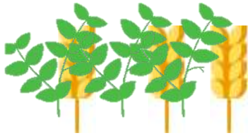
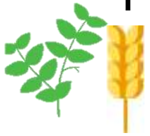
Simulation plan

1. Create contrasting cropping systems

- 3600 cropping systems with LHS plan
  (≠ rotations, organic vs conventional, no-till vs tillage, diverse vs poor floras …)

2. Include pea–wheat intercrops

- Random choice of pea and wheat varieties among actual & virtual varieties
- 1/3 substitutive + 1/3 additive + 1/3 incomplete designs

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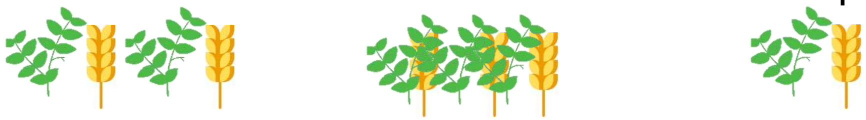

3. Include pea & wheat sole crops

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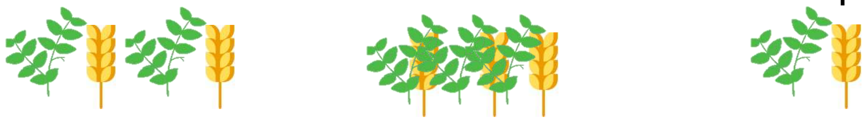

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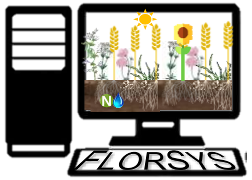
4. Simulate with weeds



Colbach et al (in revision) Field Crops Res

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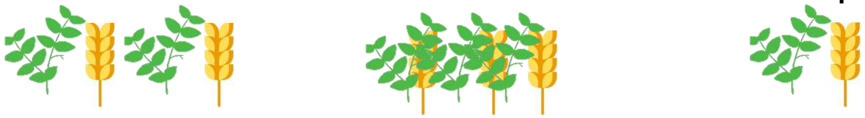

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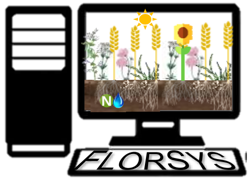

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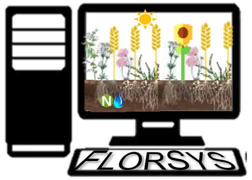
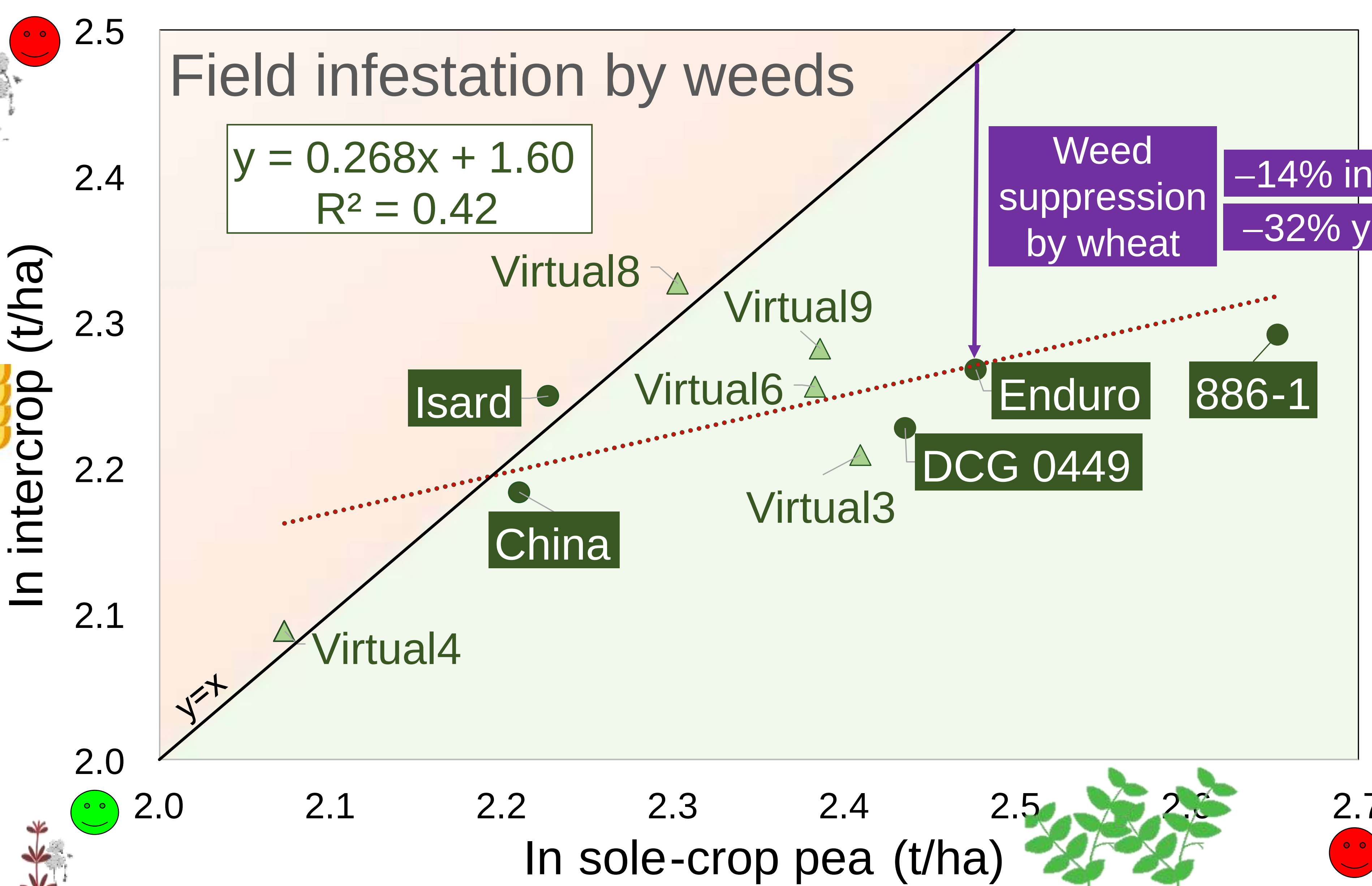


5. Simulate without weeds

- 12 years
- 5 weather repetitions



Anova: weed biomass = f(variety, cropping system, weather repetition, etc)

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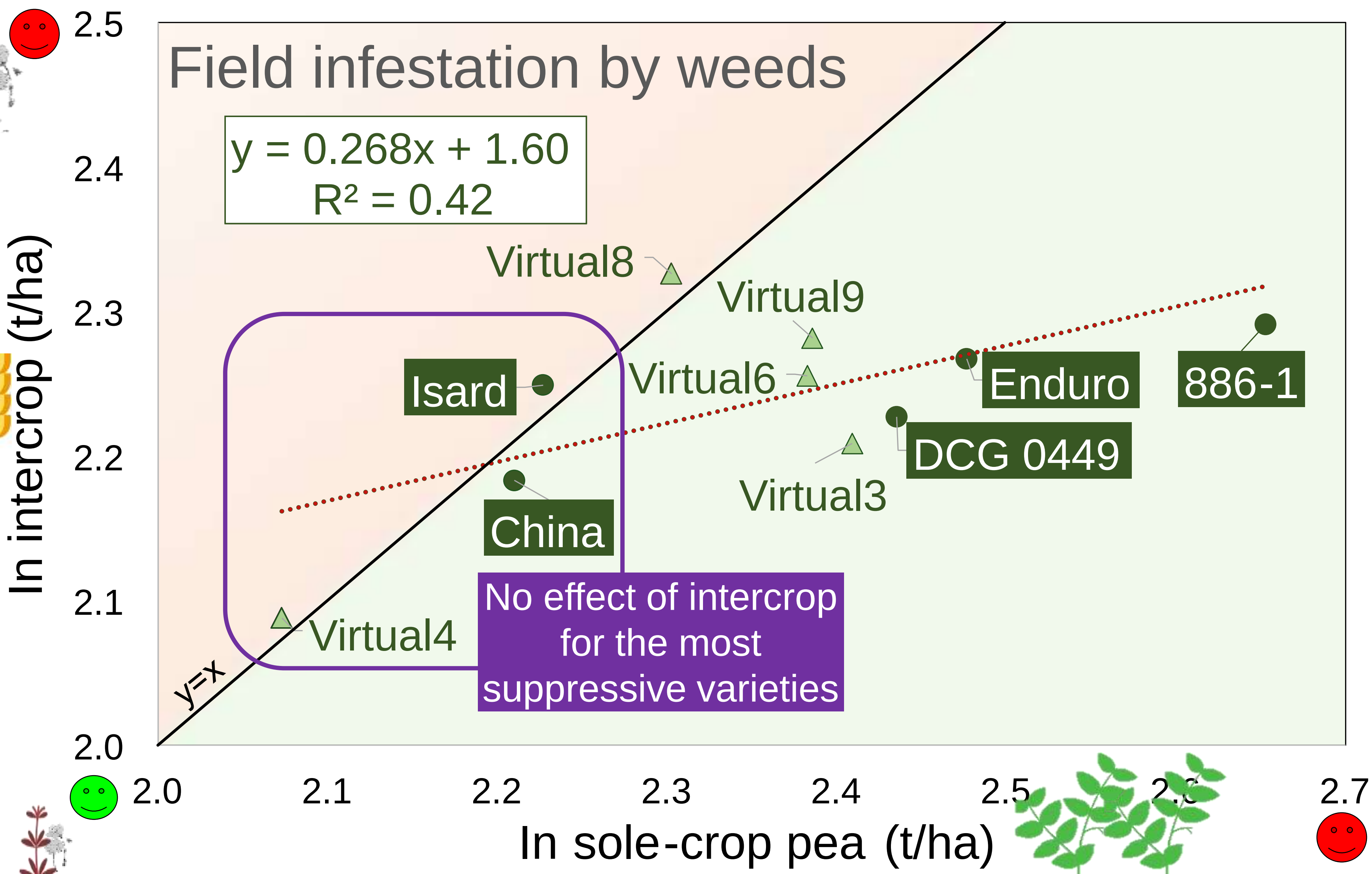

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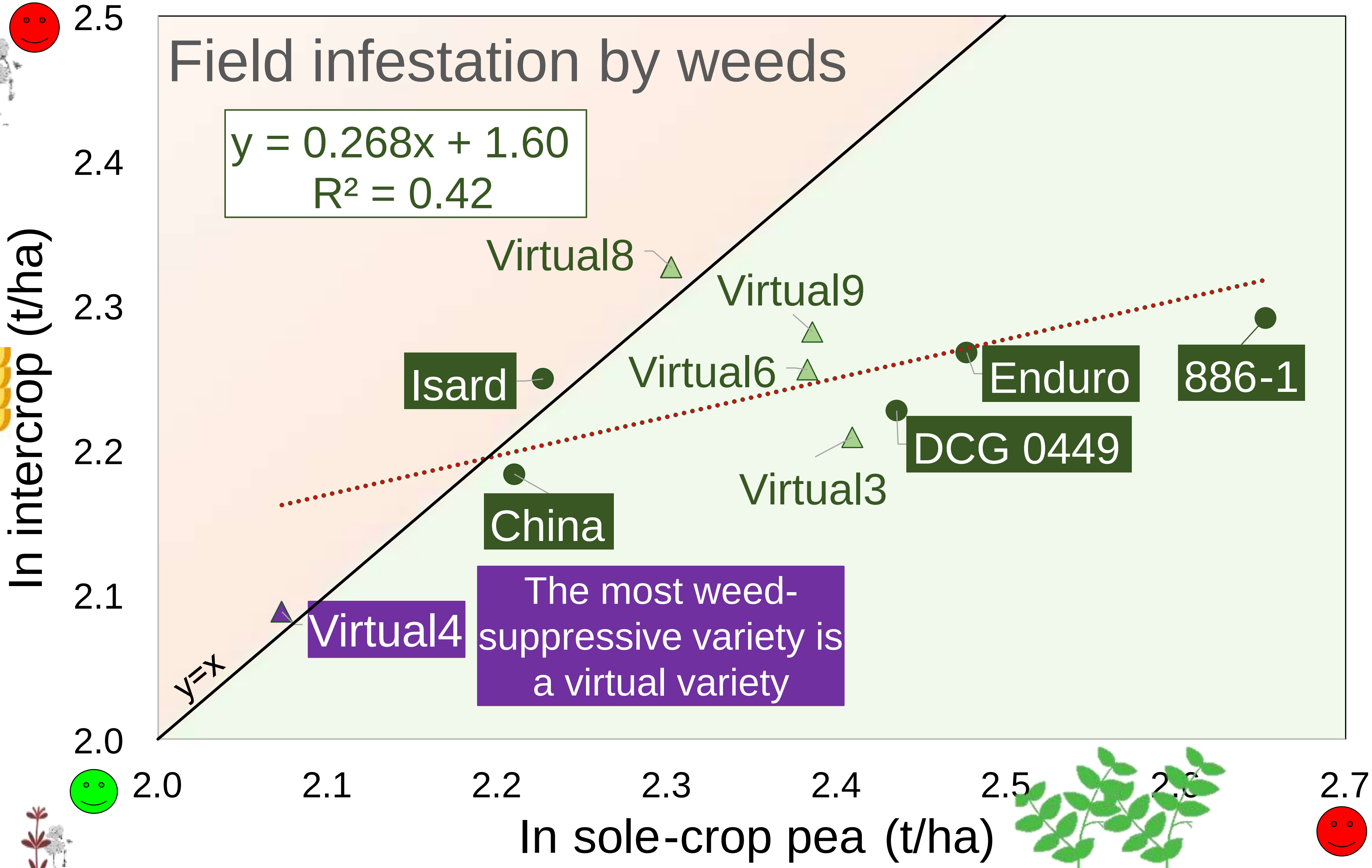

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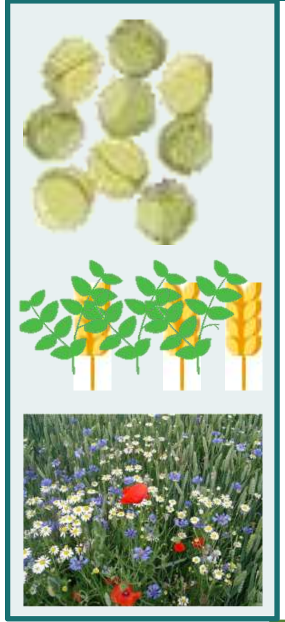
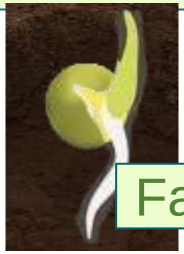
The best pea–wheat combination in additive designs

Key beneficial ≠ with existing varieties



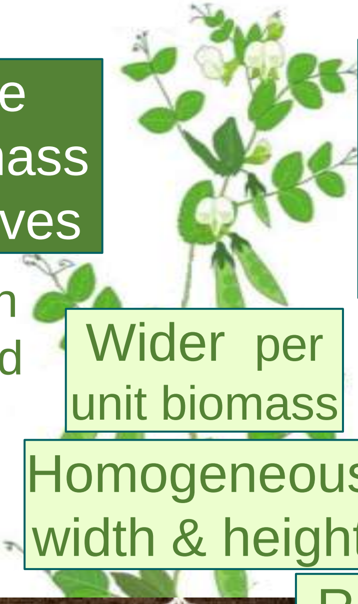
Pea Ideotype a1



Faster

Faster
Homogeneous

Precede weeds



More %biomass for leaves

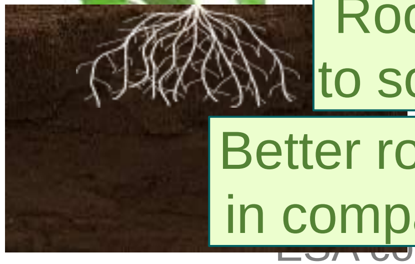
Leaves at top of plants

Intercept more light above weeds & wheat

Reproduction
When shaded

Wider per unit biomass

Homogeneous width & height



Roots closer to soil surface

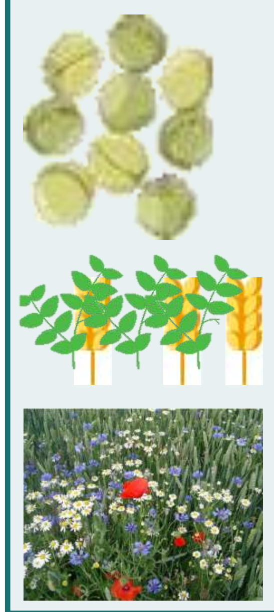
Better root growth in compacted soil

Leave less water for weed

Classification and Regression Trees

Colbach et al (in revision) Field Crops Res

The best pea–wheat combination in additive designs



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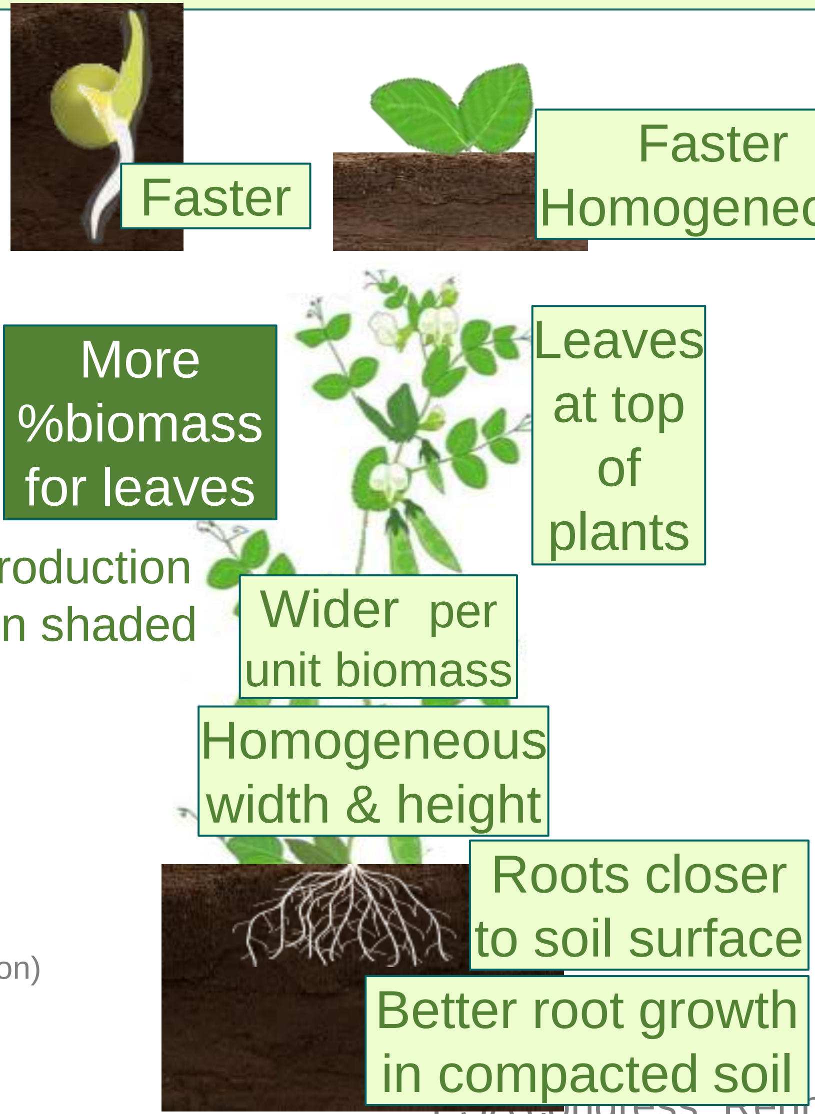


Faster

Faster Homogeneous

More %biomass for leaves

Leaves at top of plants

Reproduction When shaded

Wider per unit biomass

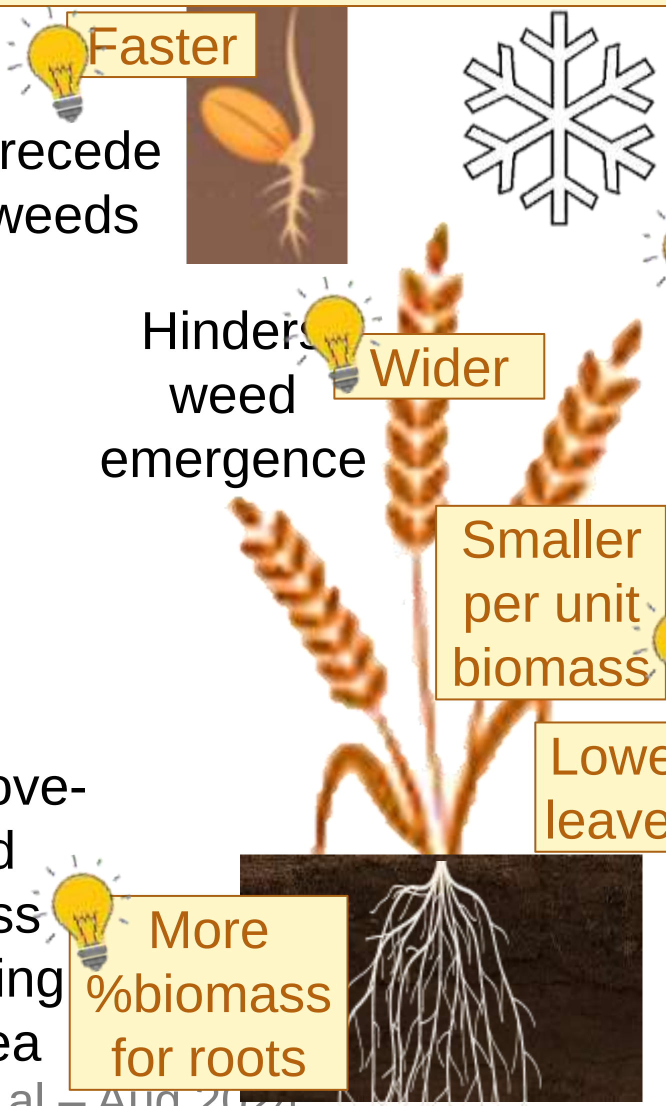
Homogeneous width & height

Roots closer to soil surface

Better root growth in compacted soil

Key beneficial ≠ with existing varieties

Wheat Ideotype a1*



Faster

Precede weeds

Less frost sensitive

More competition for weeds

Hinders weed emergence

Wider

Smaller per unit biomass

Leaves more light for pea

Lower leaves

Less above-gound biomass competing with pea

More %biomass for roots

Classification and Regression Trees

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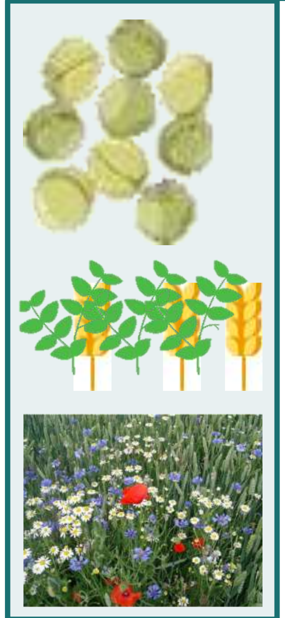
The best pea–wheat combination in additive designs

Key beneficial ≠ with existing varieties



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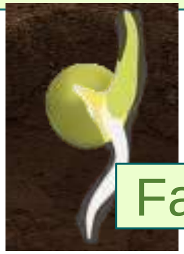
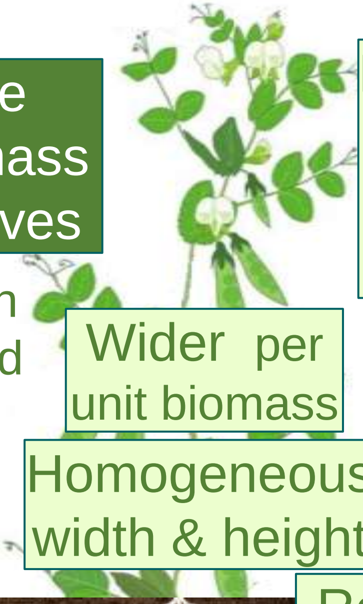


Faster

Faster
Homogeneous



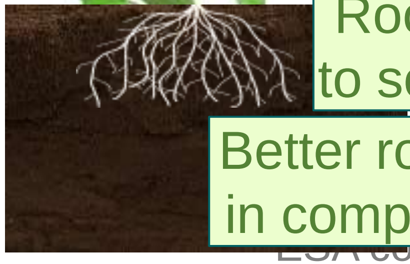
More %biomass for leaves

Leaves at top of plants

Reproduction When shaded

Wider per unit biomass

Homogeneous width & height



Roots closer to soil surface

Better root growth in compacted soil

Wheat Ideotype a1*

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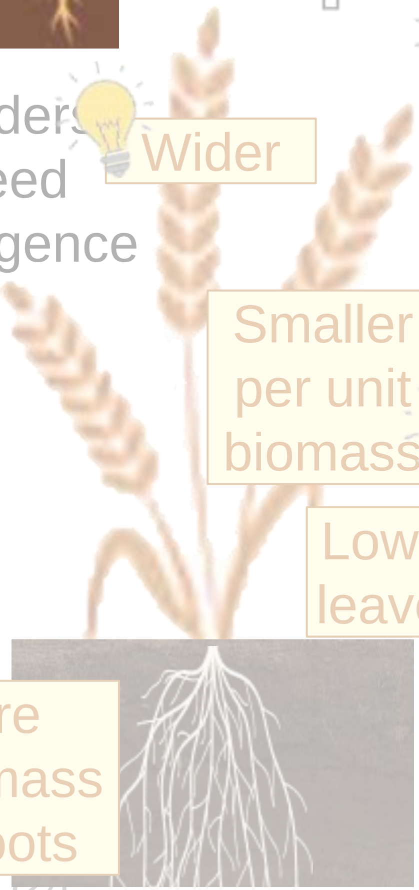

Smaller per unit biomass

Leaves more light for pea

Lower leaves

Less above-gound biomass competing with pea

More %biomass for roots

Classification and Regression Trees

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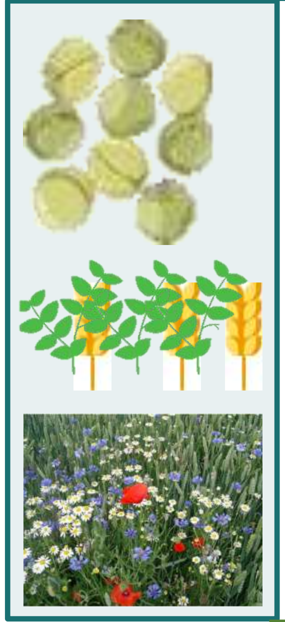
The best pea–wheat combination in additive designs

Key beneficial ≠ with existing varieties



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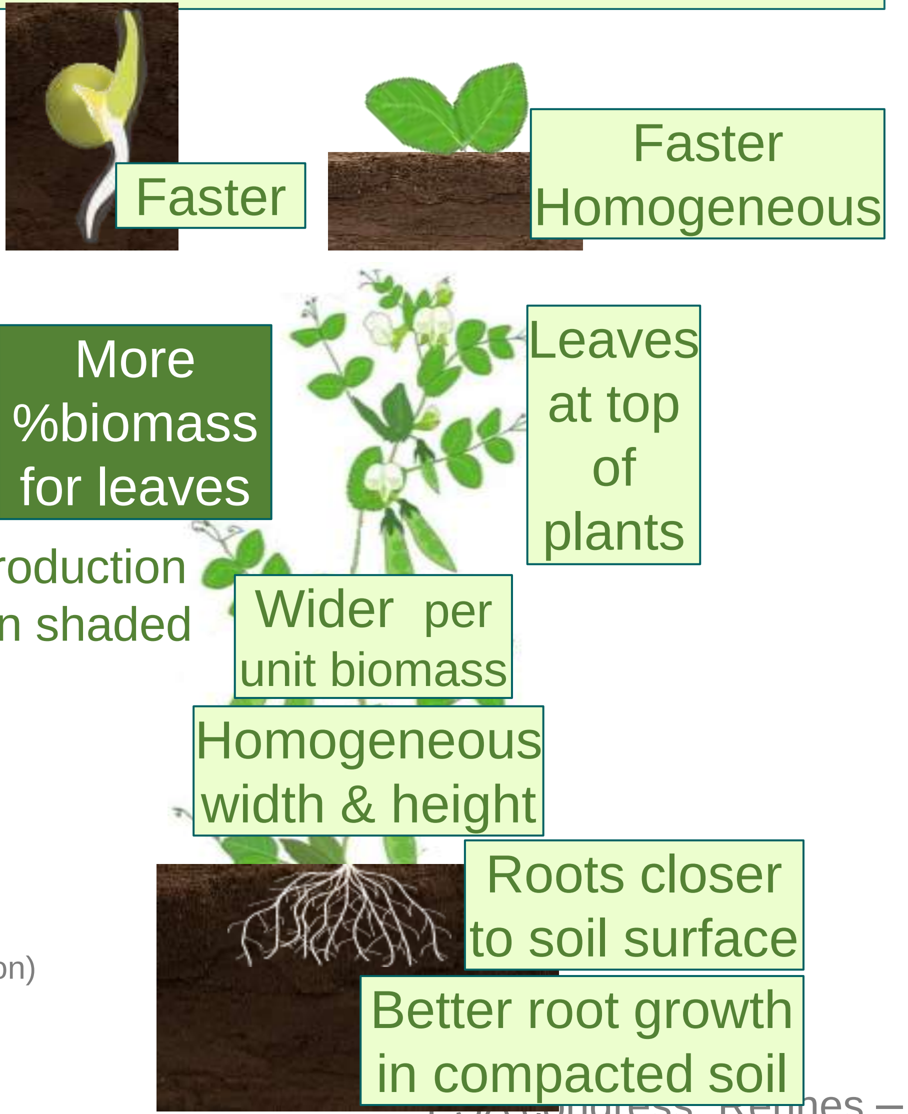

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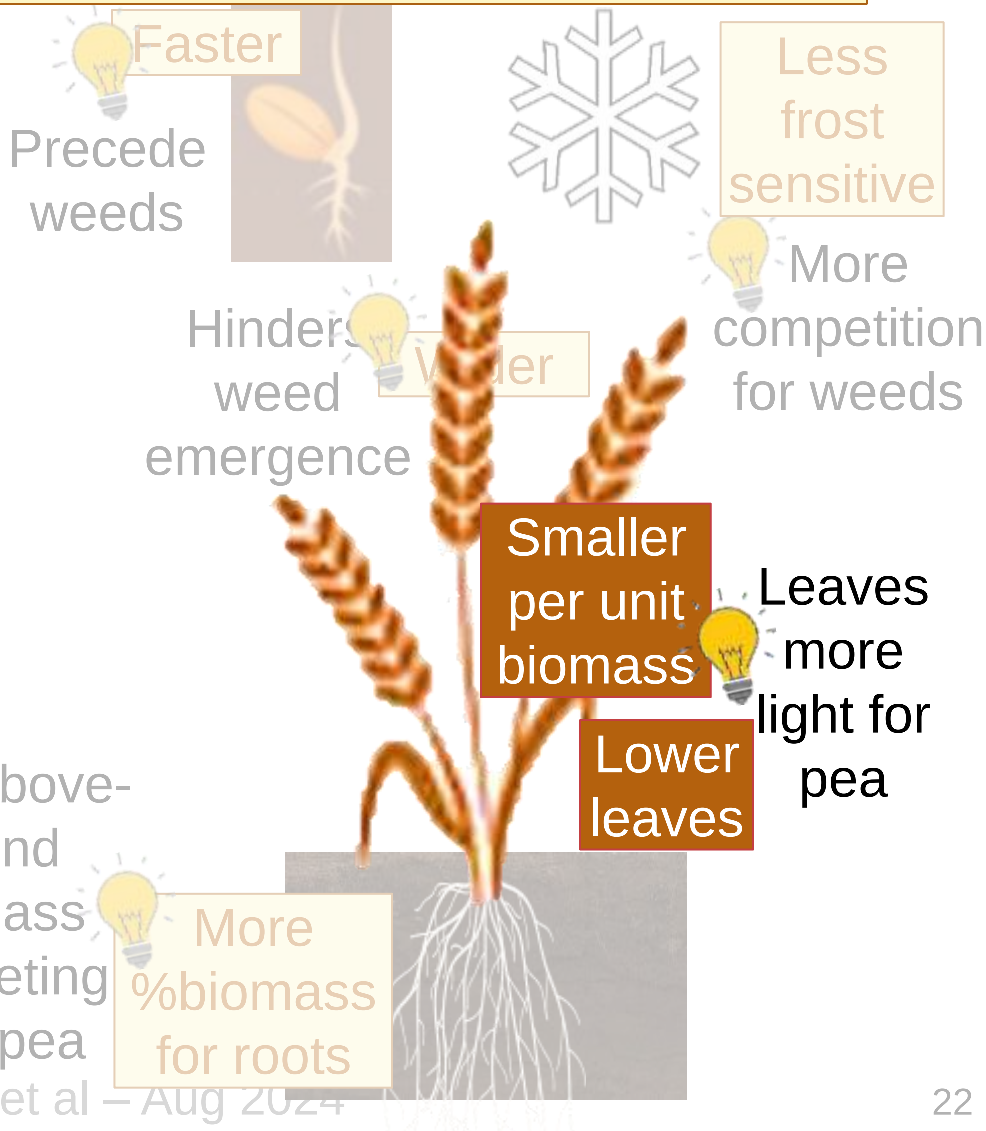

Classification and Regression Trees

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Pea x wheat trait combinations = f(intercropping design, production goal)

Intercropping design = **Additive**

Pea traits

ombinations of beneficial PEA characteristics			a1
Seed dormancy			
Germination onset			Similar
Pre-emergent root growth speed (lower drought risk)			Faster
Pre-emergent seedling loss due to seed depth			Similar
Pre-emergent seedling loss due to soil compaction			Similar
Post-emergent growth			Faster
Inter-plant heterogeneity in post-emergent leaf area			Smaller
Maximum plant height			Smaller
Plant height homogeneity		reproduction	Better
Plant width homogeneity		vegetative	Better
Plant width per biomass		vegetative	Narrower
		reproduction	Wider
%biomass allocated to leaves		emergence	Less
		reproduction	**More**
Leaf area distribution along plant height		emergence	Lower
		vegetative	Higher
Shading response	Plant height per biomass	emergence	Smaller
	Plant width per biomass	reproduction	Wider
	% biomass allocated to leaves	vegetative	More
		reproduction	More
	Leaf area per leaf biomass	reproduction	Smaller
	Leaf area distribution along plant height	vegetative	Higher
		reproduction	Lower
Root-system width (maximum)			Similar
Root biomass distribution			Shallow
Root growth in compacted soil			Better
Frost sensitivity		reproduction	
Photosynthesis in warm conditions			Worse

Wheat traits

ombinations of beneficial WHEAT characteristics		a1*
Emergence of shallow seeds		Faster
Maximum pre-emergent shoot length		
Seedling mortality in broadcast seeds		Less
Post-emergent growth		
Leaf area at emergence		
Maximum plant width		Wider
Plant height per biomass	reproduction	Smaller
Leaf area distribution along plant height	reproduction	Lower
Biomass allocation to roots		More
Root-system growth		
Root biomass distribution		Similar
Light conversion efficiency		
Photosynthesis efficiency in cool conditions		
Frost sensitivity	emergence	Better
Frost sensitivity	reproduction	

Classification and Regression Trees

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Pea x wheat trait combinations = f(intercropping design, production goal)

Intercropping design = Additive

Pea traits

ombinations of beneficial PEA characteristics			a1	a2
Seed dormancy				
Germination onset			Similar	
Pre-emergent root growth speed (lower drought risk)			Faster	Faster
Pre-emergent seedling loss due to seed depth			Similar	
Pre-emergent seedling loss due to soil compaction			Similar	
Post-emergent growth			Faster	Slower
Inter-plant heterogeneity in post-emergent leaf area			Smaller	**Smaller**
Maximum plant height			Smaller	Taller
Plant height homogeneity		reproduction	Better	
Plant width homogeneity		vegetative	Better	
Plant width per biomass		vegetative	Narrower	
		reproduction	Wider	**Wider**
%biomass allocated to leaves		emergence	Less	**Less**
		reproduction	**More**	**More**
Leaf area distribution along plant height		emergence	Lower	Higher
		vegetative	Higher	Higher
Shading response	Plant height per biomass	emergence	Smaller	Taller
	Plant width per biomass	reproduction	Wider	Narrower
	% biomass allocated to leaves	vegetative	More	
		reproduction	More	Less
	Leaf area per leaf biomass	reproduction	Smaller	
	Leaf area distribution along plant height	vegetative	Higher	Lower
		reproduction	Lower	**Lower**
Root-system width (maximum)			Similar	
Root biomass distribution			Shallow	Deeper
Root growth in compacted soil			Better	Worse
Frost sensitivity		reproduction		
Photosynthesis in warm conditions			Worse	Better

Wheat traits

ombinations of beneficial WHEAT characteristics		a1*	a2 *
Emergence of shallow seeds		Faster	Faster
Maximum pre-emergent shoot length			
Seedling mortality in broadcast seeds		Less	
Post-emergent growth			Slower
Leaf area at emergence			
Maximum plant width		Wider	Wider
Plant height per biomass	reproduction	Smaller	
Leaf area distribution along plant height	reproduction	Lower	Higher
Biomass allocation to roots		More	
Root-system growth			Faster
Root biomass distribution		Similar	Similar
Light conversion efficiency			Worse
Photosynthesis efficiency in cool conditions			Worse
Frost sensitivity	emergence	Better	Better
Frost sensitivity	reproduction		

Classification and Regression Trees

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Pea x wheat trait combinations = f(intercropping design, production goal)


Intercropping design = Additive (a1, a2) | Substitutive (s1, s2) | Incomplete (i1, i2)

Pea traits

Combinations of beneficial PEA characteristics			a1	a2	s1	s2	i1	i2
Seed dormancy								
Germination onset			Similar			Earlier		
Pre-emergent root growth speed (lower drought risk)			Faster	Faster	Faster	Slower	Slower	
Pre-emergent seedling loss due to seed depth			Similar			Less		
Pre-emergent seedling loss due to soil compaction			Similar			More		
Post-emergent growth			Faster	Slower		Faster		
Inter-plant heterogeneity in post-emergent leaf area			Smaller	**Smaller**	Smaller	Larger		
Maximum plant height			Smaller	Taller		Similar	Smaller	
Plant height homogeneity		reproduction	Better			Worse		
Plant width homogeneity		vegetative	Better		Better	Worse		
Plant width per biomass		vegetative	Narrower			Large		
Plant width per biomass		reproduction	Wider	**Wider**	Wider	Narrower	Similar	
%biomass allocated to leaves		emergence	Less	**Less**	**Less**	More	Similar	
%biomass allocated to leaves		reproduction	**More**	**More**	**More**	Similar	Similar	
Leaf area distribution along plant height		emergence	Lower	Higher	Higher	Higher	Lower	
Leaf area distribution along plant height		vegetative	Higher	Higher	Higher	Lower	Lower	
Shading response	Plant height per biomass	emergence	Smaller	Taller	Smaller	Taller	Smaller	
Shading response	Plant width per biomass	reproduction	Wider	Narrower	Narrower	Narrower	Wider	Narrower
Shading response	% biomass allocated to leaves	vegetative	More		More	Less		
Shading response	% biomass allocated to leaves	reproduction	More	Less	**Less**	Less	More	
Shading response	Leaf area per leaf biomass	reproduction	Smaller		Smaller	Larger		
Shading response	Leaf area distribution along plant height	vegetative	Higher	Lower		Lower	Higher	
Shading response	Leaf area distribution along plant height	reproduction	Lower	**Lower**	Lower	Higher	Higher	
Root-system width (maximum)			Similar			Wider		
Root biomass distribution			Shallow	Deeper		Deeper	Shallow	
Root growth in compacted soil			Better	Worse		Worse	Better	
Frost sensitivity		reproduction				Lower		
Photosynthesis in warm conditions			Worse	Better	Better	Similar	Worse	

Wheat traits

Combinations of beneficial WHEAT characteristics		a1*	a2 *	s1 *	s2 *	i1 *	i2 *
Emergence of shallow seeds		Faster	Faster	Faster	Faster		Faster
Maximum pre-emergent shoot length					Smaller		
Seedling mortality in broadcast seeds		Less					Less
Post-emergent growth			Slower				
Leaf area at emergence					Larger		
Maximum plant width		Wider	Wider		Wider		
Plant height per biomass	reproduction	Smaller		Taller			Taller
Leaf area distribution along plant height	reproduction	Lower	Higher				
Biomass allocation to roots		More					More
Root-system growth			Faster				Similar
Root biomass distribution		Similar	Similar				
Light conversion efficiency			Worse				Worse
Photosynthesis efficiency in cool conditions			Worse		Similar		Worse
Frost sensitivity	emergence	Better	Better				Better
Frost sensitivity	reproduction				Worse		Worse

Classification and Regression Trees

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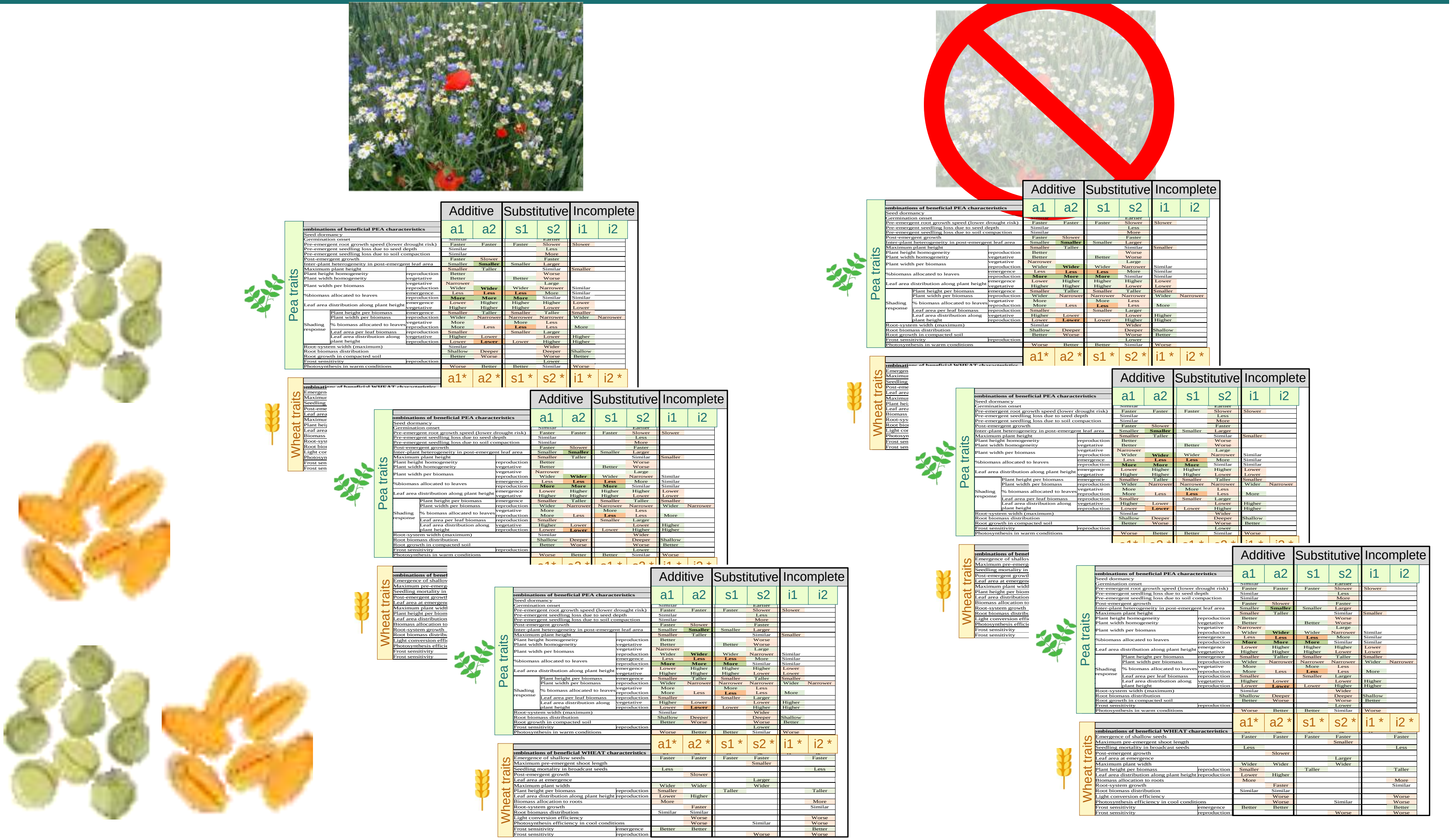
Pea x wheat trait combinations = f(intercropping design, production goal)



Classification and Regression Trees

Colbach et al (in revision) Field Crops Res

- Implications for weed management
  - Weed suppression: Virtual > actual pea varieties → Current pea varieties disregard weed control
  - Pea ideotypes = f(intercropping design, intercropped wheat variety, production goal)
  - Intercrop management = f(production goal)
- Basis for decision support system
  - Identification of key pea x wheat traits
    for yield potential, weed tolerant & weed suppression → Breeders
  - Decision trees for choosing pea x wheat variety types /management
    = f(goal, cropping system) → Farmers

- **Perspectives**
  - Simulate situations with N & water stress & climate change
  - Link complicated FLORSYS parameters
    to variables easily measured in variety trials

Thank you for your attention – Merci beaucoup!

The most important references

Colbach et al (**2021**) The FLORSYS crop-weed canopy model, a tool to investigate and promote agroecological weed management. Field Crops Res 261, 108006, doi: 10.1016/j.fcr.2020.108006

Colbach et al (**2022**) Tracking ideal varieties and cropping techniques for agroecological weed management: a simulation-based study on pea. Frontiers Plant Sci 13:809056, doi.org\10.3389/fpls.2022.809056

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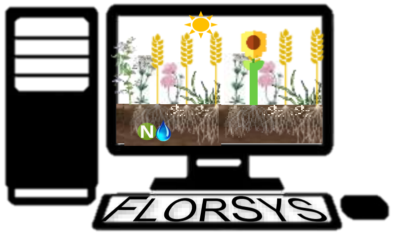

Pea x wheat trait combinations = f(intercropping design, production goal)

Classification and Regression Trees

Colbach et al (in revision) Field Crops Res

Which management = f(intercropping design, production goal)?

Potential yield	Weedy yield	Weed suppression

Management techniques

Intercrop management technique	Unit	Simulated variation Min	Simulated variation Max	Potential yield P	Potential yield W	Weedy yield or weed tolerance P	Weedy yield or weed tolerance W	Weed suppression	Why?
Tillage									
Superficial tillage operations	Number per year	0	10			+			Empties weed seed bank by triggering germination during summer fallow ("false seed bed"), kills weed plants before sowing
Tillage after 1 Nov	Number per year	0	10				+		More weed destruction and late sowing (seed sowing date)
Time from last tillage to crop sowing	days	0	147			–	–	–	Leaves more time for weeds to reinfest the field after the last tillage operation cleaned out all weeds
Crop residue shredding operations	ops / year	0	4			+	+		Destroys weeds during summer fallow
Sowing									
Sowing date		01 Oct	30 Nov				+		Leaves more time for false seed bed techniques; shortens the time during which weeds can grow inside the crop
Proportion of pea rows in intercrop	rows/ rows	0.20	0.80		–				Pea plants occupy more space in field and leave less for companion wheat
Interrow width	cm	4	52		–	–	–		More competition between plants inside a given row, more light missed by crops
Crop species are sown in separate rows	yes (1) or no (0)	0	1	+	–				Pea suffers more from interspecies competition but wheat plants suffer more from intraspecies competition
Total sowing density vs sole crops	seeds / seeds	0.06	4.89	+	+				More pea and wheat plants in field, intercepting more light and leaving less space and resources for weeds
Pea sowing density vs pure pea	seeds·m²/ seeds·m²	0.03	3.23	+	+			+	More pea plants and leaf area to produce pea biomass and shade weeds (but not on wheat)
Wheat sowing density vs pure wheat	seeds·m²/ seeds·m²	0.02	2.50	–	+	+			More wheat plants and leaf area to produce wheat biomass and shade weeds and companion pea
Other									
Multi-entry herbicides	Number per year	0	4			+	+		Destroys weed plants (and more efficiently than herbicides entering only via either leaves, roots or meristem)
Anti-monocot herbicides	Number per year	0	4				+		Fewer monocot weeds survive and compete with the crop
Anti-dicot herbicides	Number per year	0	4				+		Fewer dicot weeds survive and compete with the crop

Tillage

Sowing date

Interrow width

Sowing densities

…

INRAE