Multi-service cover crops: towards a new paradigm for biocontrol and soil fertility enhancement

Antoine Couëdel, Éric Justes, Lionel Alletto, John Kirkegaard

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Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTERE
DE L'AGRICULTURE
DE L'AGROALIMENTAIRE
ET DE LA FORET

avec la contribution financière du compte d'affectation spéciale «Développement agricole et rural»

La Région Occitanie Pyrénées - Méditerranée

Presentation outline

1- Overview of multi-service cover crops

2- Cover crops mixtures : levels of services provided

3- Revisiting the biocontrol potential

Annual crop rotation

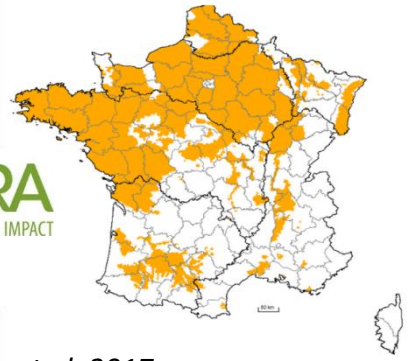
Summer Autumn Winter Spring



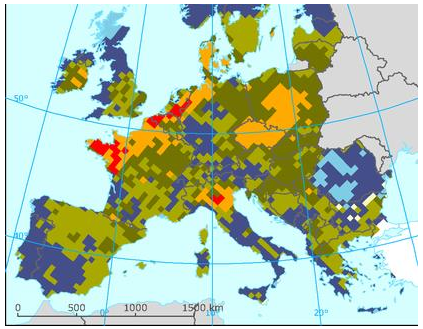
Cash crop (n) | = Cover Crops | Cash crop (n +1)

Erosion, Nutrient leaching,
Pathogens, Weeds

e.g: Nitrate directive in the EU and N leaching



Justes et al. 2017



Thorup Kristensen et al. 2003
Garcia Gonzalez et al. 2018

e.g: Wind erosion in the US great plains

Blanco-Canqui et al. 2015

Annual crop rotation

Summer Autumn Winter Spring

Catch crops Biofumigants

Cover crops Green manures

Cash crop (n) | = Multiservice Cover Crops | Cash crop (n +1)

Multi-effects (Services and Disservices)

Physical soil properties
- Erosion
- Soil structure

Greenhouse gases
- C storage

Water balance
- Preemption
- Drainage

Nutrients cycle
- Leaching
- Mineralisation
- Organisation
- Preemption

Living organisms
- Weeds
- Pathogens
- Beneficials

Trade-off to evaluate

Justes et al. 2017

Annual crop rotation

Summer | Autumn | Winter | Spring

Catch crops | Biofumigants

Cover crops | Green manures

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Multi-effects (Services and Disservices)

Presentation's frame

Physical soil properties
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Greenhouse gases
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Water balance
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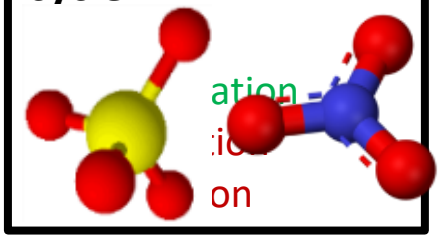
Nutrients cycle



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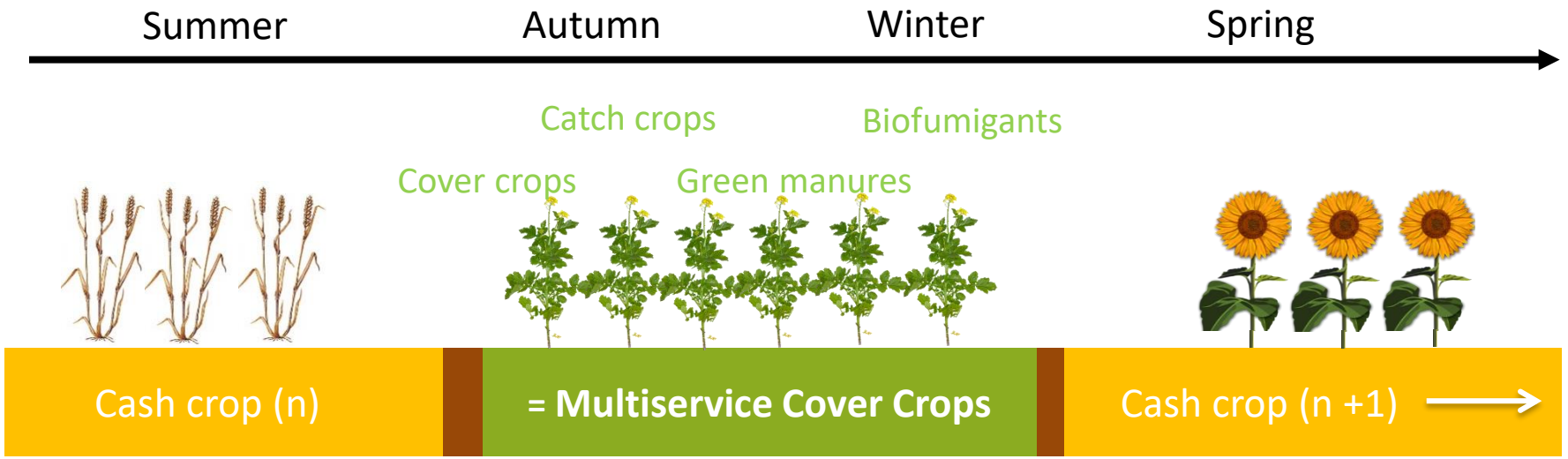


Which species ?

Justes et al. 2017

Presentation's frame Cover crop families

Brassicaceae or Crucifers

White mustard

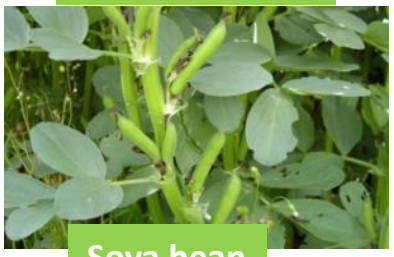
Ethiopian mustard

Turnip

Fabaceae or Legumes

Egyptian clover

Common vetch



Soya bean

Pea

Poaceae or grasses

Oat

Sorghum

Other families

Buckwheat

Phacelia

Nyger

Legumes or Fabaceae

N Catch crop Service	S Catch crop Service
-25 % to -60% of leaching *(Justes et al. 2012; Tribouillois et al. 2016)*	**Medium acquisition by cash crops** = 20 to 50 kg S/ha *(Studer 1984)*

Legumes or Fabaceae

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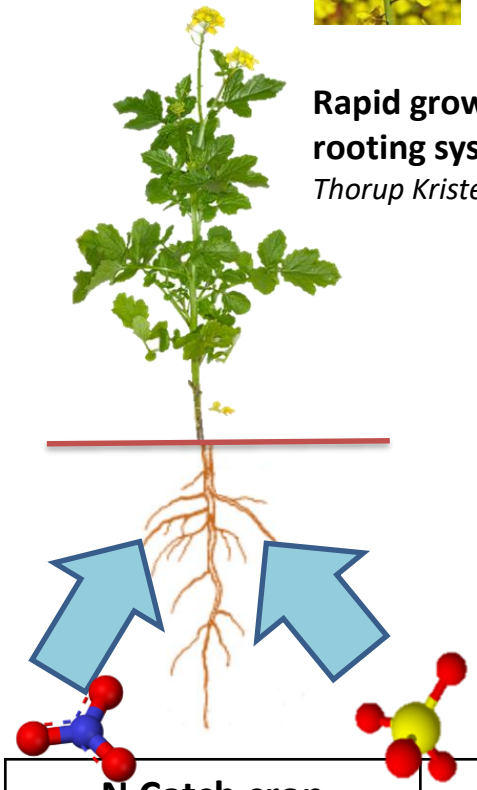
Crucifers or Brassicaceae



Rapid growth, dense and deep rooting system

Thorup Kristensen et al. (2001, 2003)

N Catch crop Service	S Catch crop Service
-50 to -75 % of leaching *(Justes et al. 2012)*	**Strong acquisition by cash crops** 60 to 80 kg S/ha *(Studer 1984)*

Crucifers or Brassicaceae

Rapid growth, dense and deep rooting system

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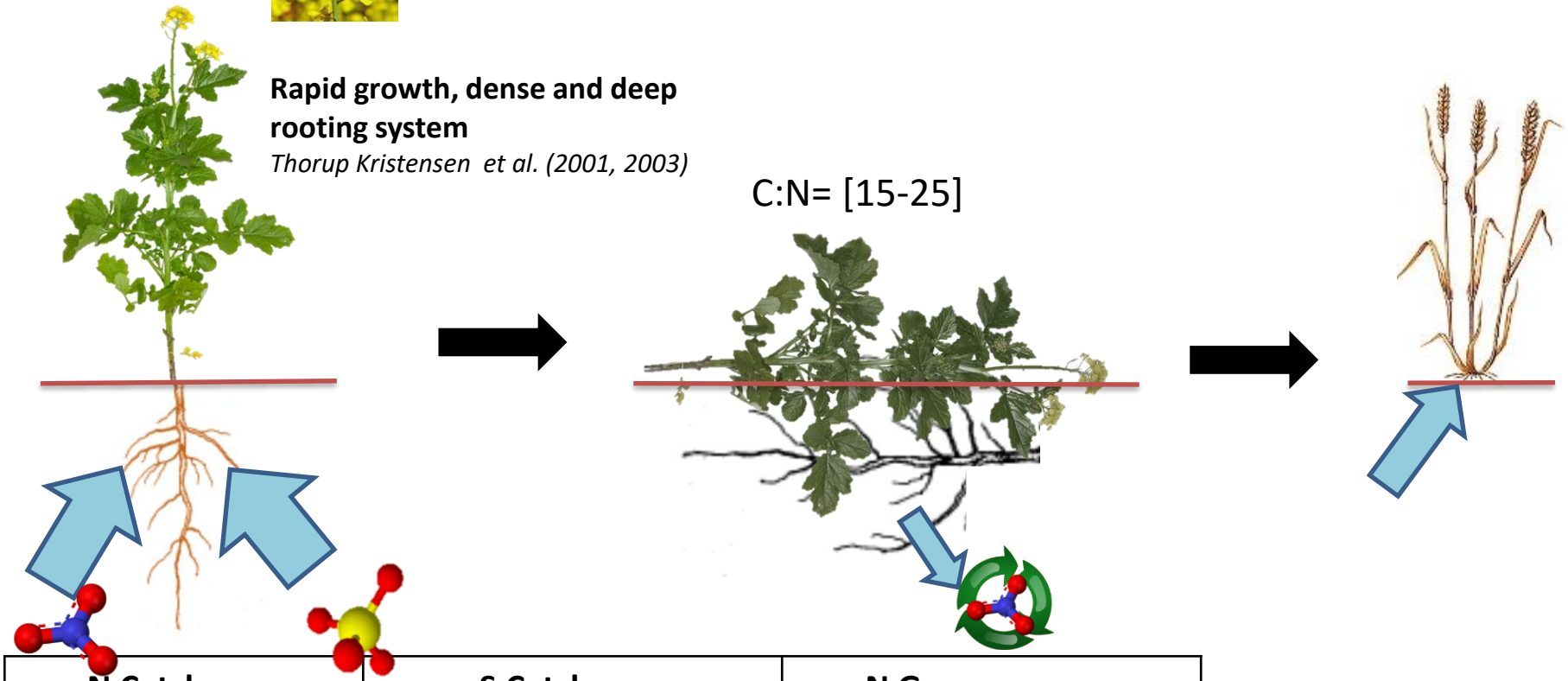
C:N= [15-25]



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Crucifers or Brassicaceae

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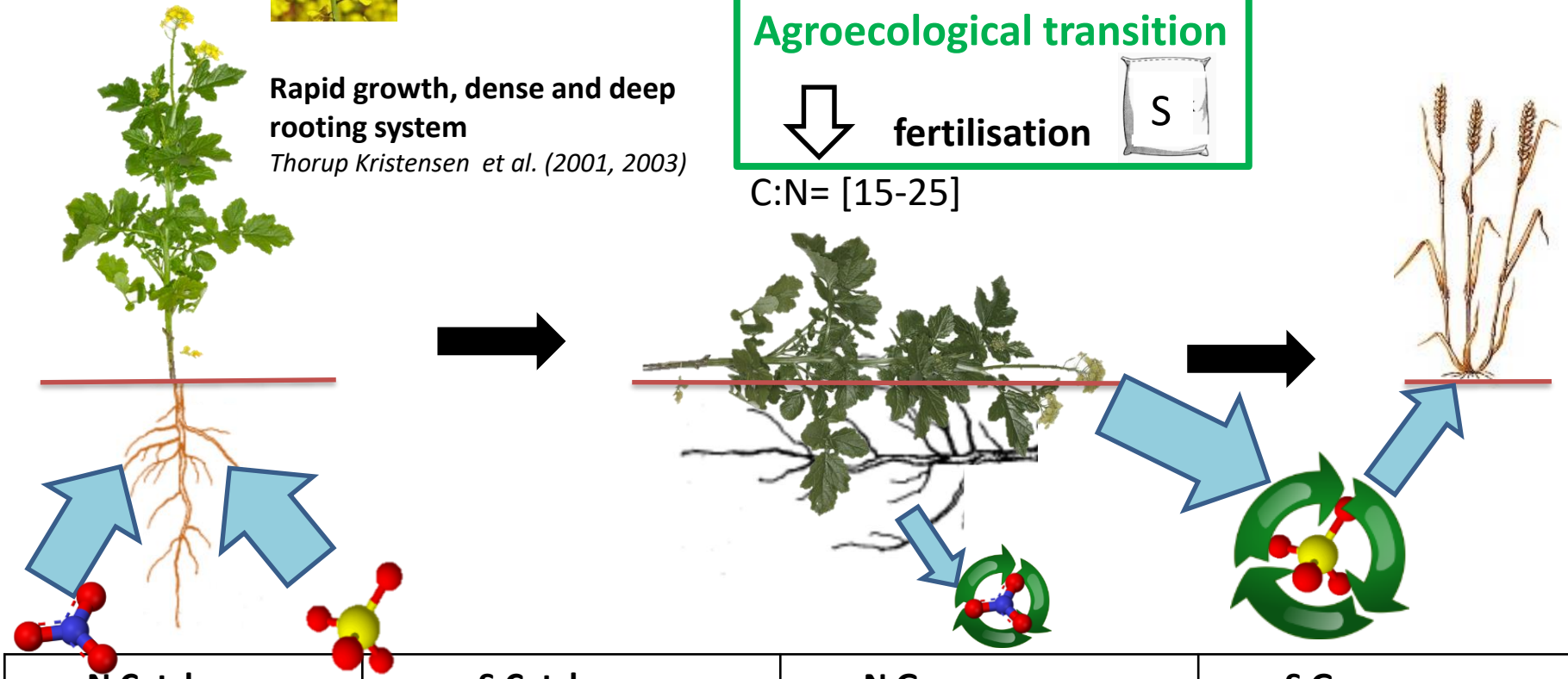
Agroecological transition

⇩ **fertilisation** S

C:N= [15-25]



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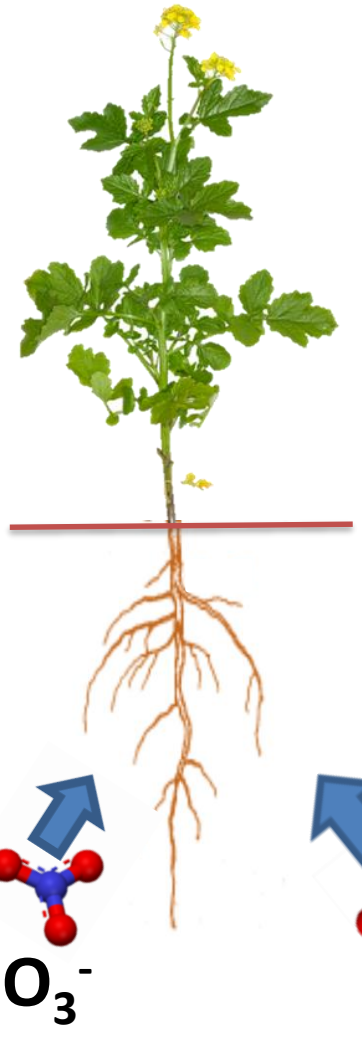
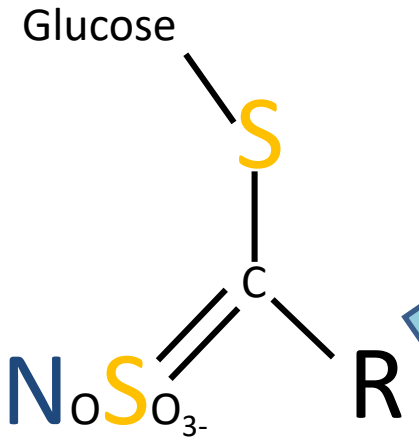
Glucosinolates?



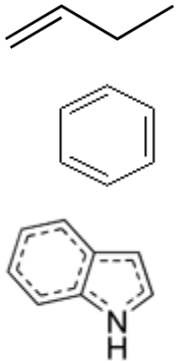


Glucosinolate

Secondary metabolites

8 amino acids

140 GSL identified



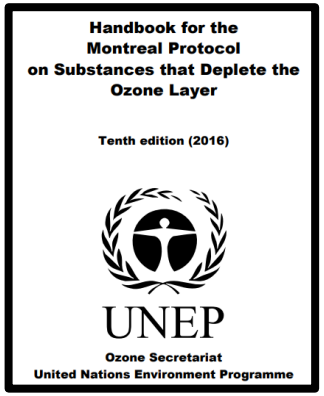
Aliphatic

Aromatic

Indolic

Fahey et al. 2001; Agerbirk and Olsen 2012

Use of glucosinolates?



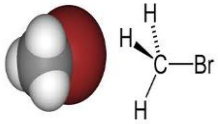
Agroecological transition

⇩ **PESTICIDES**

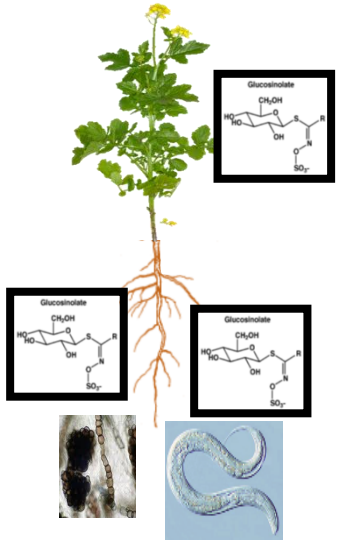
Biocontrol

Fumigation (until 1987)

Methyl Bromide
Dazomet
…



Allelopathy

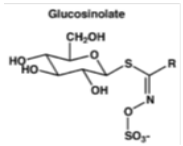
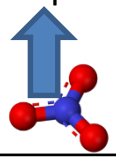
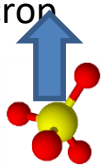
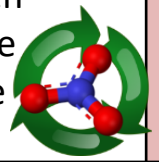


Bio-Fumigation

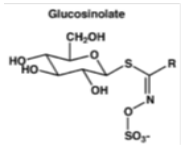
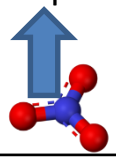
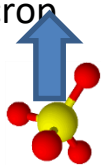
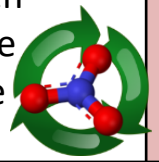
GLUCOSINOLATE

Matthiessen and Kirkegaard (2006)

Multiservice approach

	Crucifers
GSL 	+++
N Catch crop Service 	+++
S Catch crop Service 	+++
N Green manure Service 	-
S Green manure Service 	+++

Multiservice approach

	Crucifers	Legumes
GSL 	+++	/
N Catch crop Service 	+++	+
S Catch crop Service 	+++	+
N Green manure Service 	-	+++
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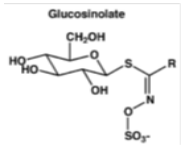
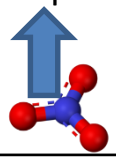
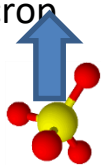
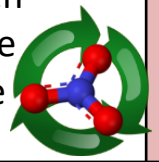
Multiservice approach

	Crucifers	Legumes	Crucifers + Legumes
GSL 	+++	/	??
N Catch crop Service 	+++	+	??
S Catch crop Service 	+++	+	??
N Green manure Service 	-	+++	??
S Green manure Service 	+++	-	??

Presentation outline

1- Overview of multi-service cover crops

2- Cover crops mixtures : levels of services provided

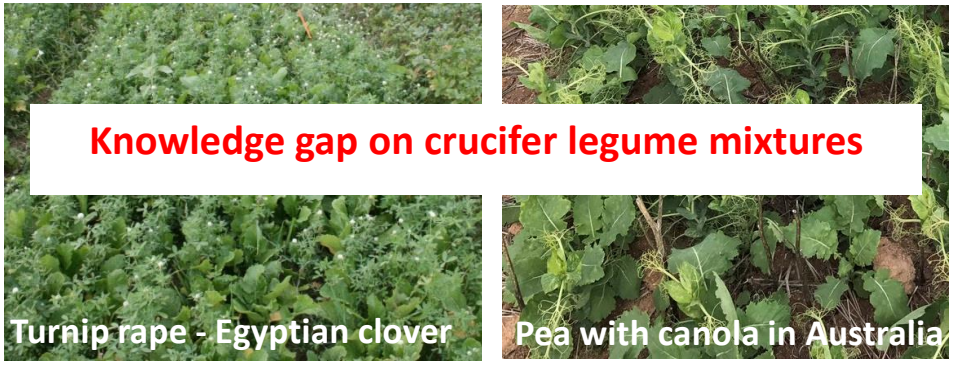
3- Revisiting the biocontrol potential

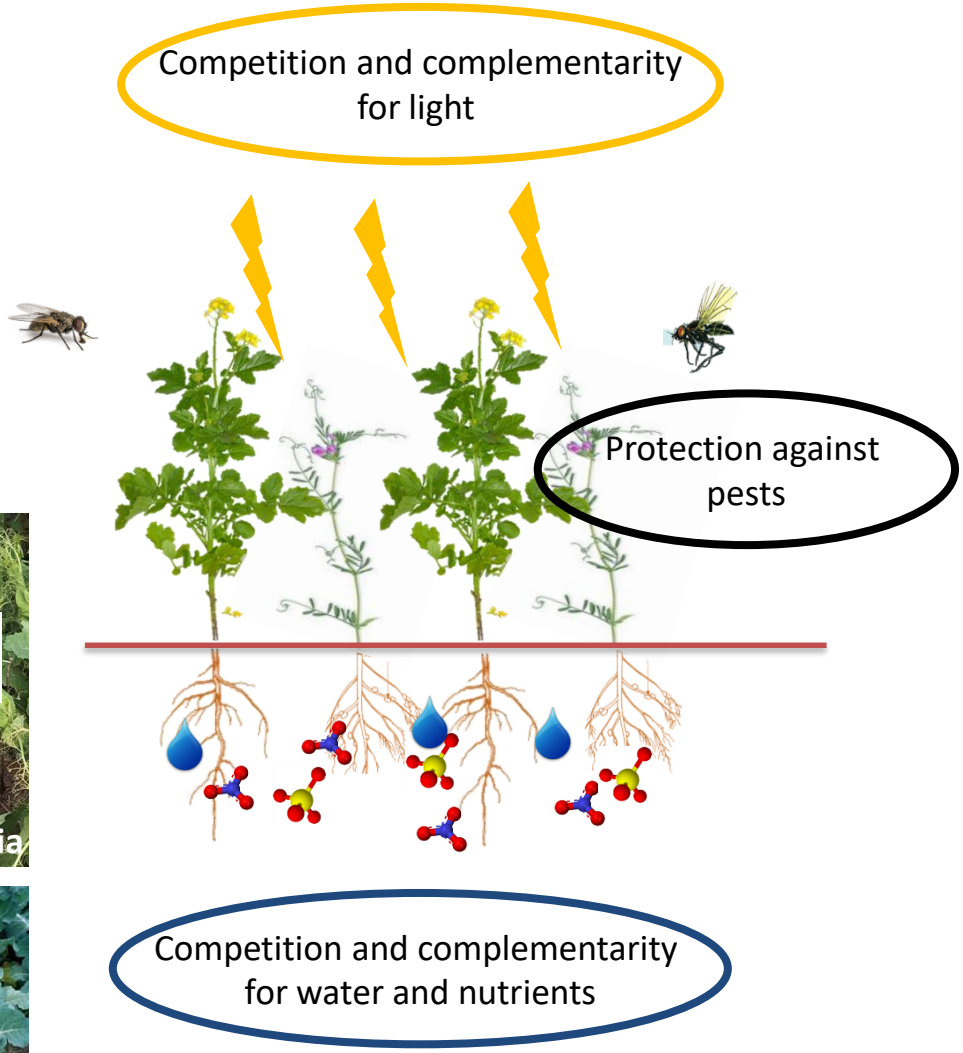
What can we expect from crop mixtures?

- **Increased biomass production :**
  - Cash crops *(Bedoussac et al., 2015)*
  - Cover crops *(Wendling et al., 2017)*

- **Mutualised ecosystem services** *(Tribouillois et al., 2016)*

- **Increased pest protection**
  - Weeds *(Corre-Hellou et al., 2011)*
  - Insects *(Andow et al., 1991)*





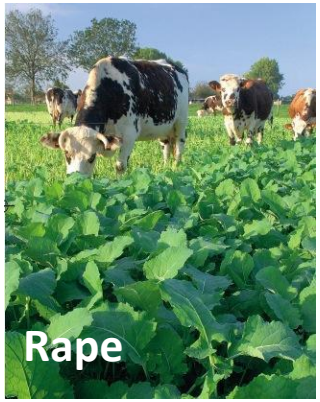
A wide range of species mixtures (substitutives: 50%-50%)

Mustards

White

Indian

Ethiopian



DIVERSITY: Species and cultivars

- **Shoot and root architecture**
- **Development**
- **Frost resistance**
- **Glucosinolate types**

Species	*Cultivars*
Rape	*Mosa* *Ringo*
White mustard	*Abraham* *Architect*
Indian mustard	*Brons* *Etamine*
Ethiopian mustard	*Capucino* *Carbon* *Utopia*
Turnip	*Samson*
Turnip rape	*Chicon* *Hector*
Radish	*Arena* *Nemaflex* *Terranova*
Rocket	*Trio*

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DIVERSITY: Species and cultivars

- **Shoot and root architecture**
- **Development**
- **Frost resistance**
- **Seed size**

Species	*Cultivars*
Egyptian clover	*Tabor*
Purple vetch	*Titane*
Common vetch	*Spido*
	Nacre
	Ardente
Hairy Vetch	*Massa*
	Savane
Crimson clover	*Cegalo*
Soya bean	*Merlin*
Faba bean	*Divine*
Pea	*Ascension*
Lupin	*Arabella*

Clovers

Vetches (common, hairy, purple)

A wide range of species mixtures (substitutives: 50%-50%)

Mustards

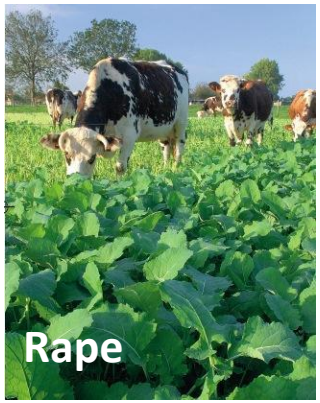
White

Indian

Ethiopian

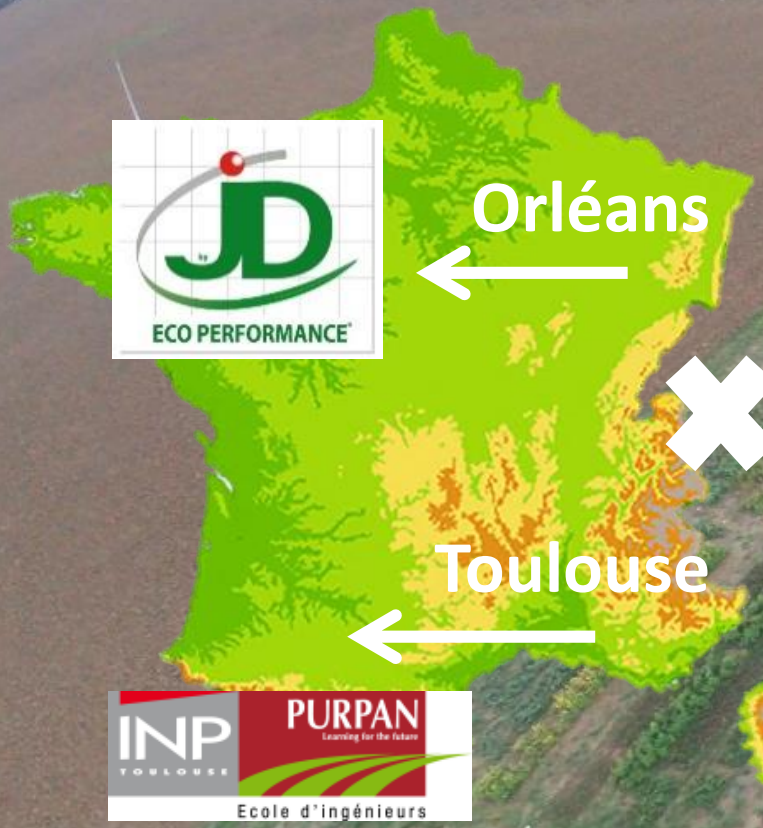
Clovers

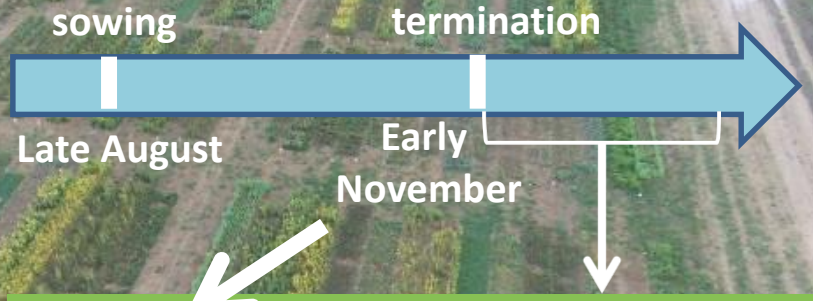
Vetches (common, hairy, purple)



Lupin

Field trials

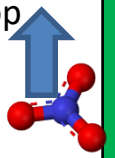
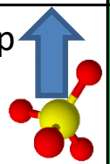




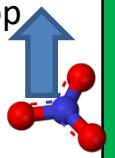
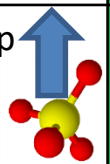
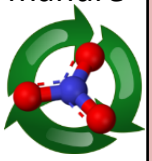
Measured
- Biomass
- Nutrient content
- Soil mineral nitrogen

Simulated
- N and S mineralised

Multiservice approach

	Pure crucifers	Pure legumes	Crucifers + Legumes
N Catch crop Service 	**100%** -51% to -70% soil mineral N	**66%** -37% to -43% soil mineral N	**98%** -48% to -70% soil mineral N
S catch crop Service 	**100%** 10 to 15 kg S/ha	**30%** 4 to 5 kg S/ha	**99%** 10 to 14 kg S/ha

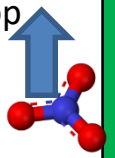
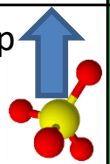
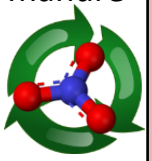
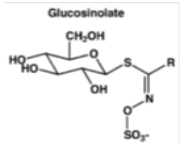
Multiservice approach

	Pure crucifers	Pure legumes	Crucifers + Legumes
N Catch crop Service 	**100%** -51% to -70% soil mineral N	**66%** -37% to -43% soil mineral N	**98%** -48% to -70% soil mineral N
S catch crop Service 	**100%** 10 to 15 kg S/ha	**30%** 4 to 5 kg S/ha	**99%** 10 to 14 kg S/ha
N Green manure Service 	**18%** 1 to 10 kg N/ha released	**100%** 35 to 54 kg N/ha released	**63%** 18 to 30 kg N/ha released
S Green manure Service 	**100%** 6 to 8 kg S/ha released	**23%** 1 to 2 kg S/ha released	**85%** 5 to 6 kg S/ha released

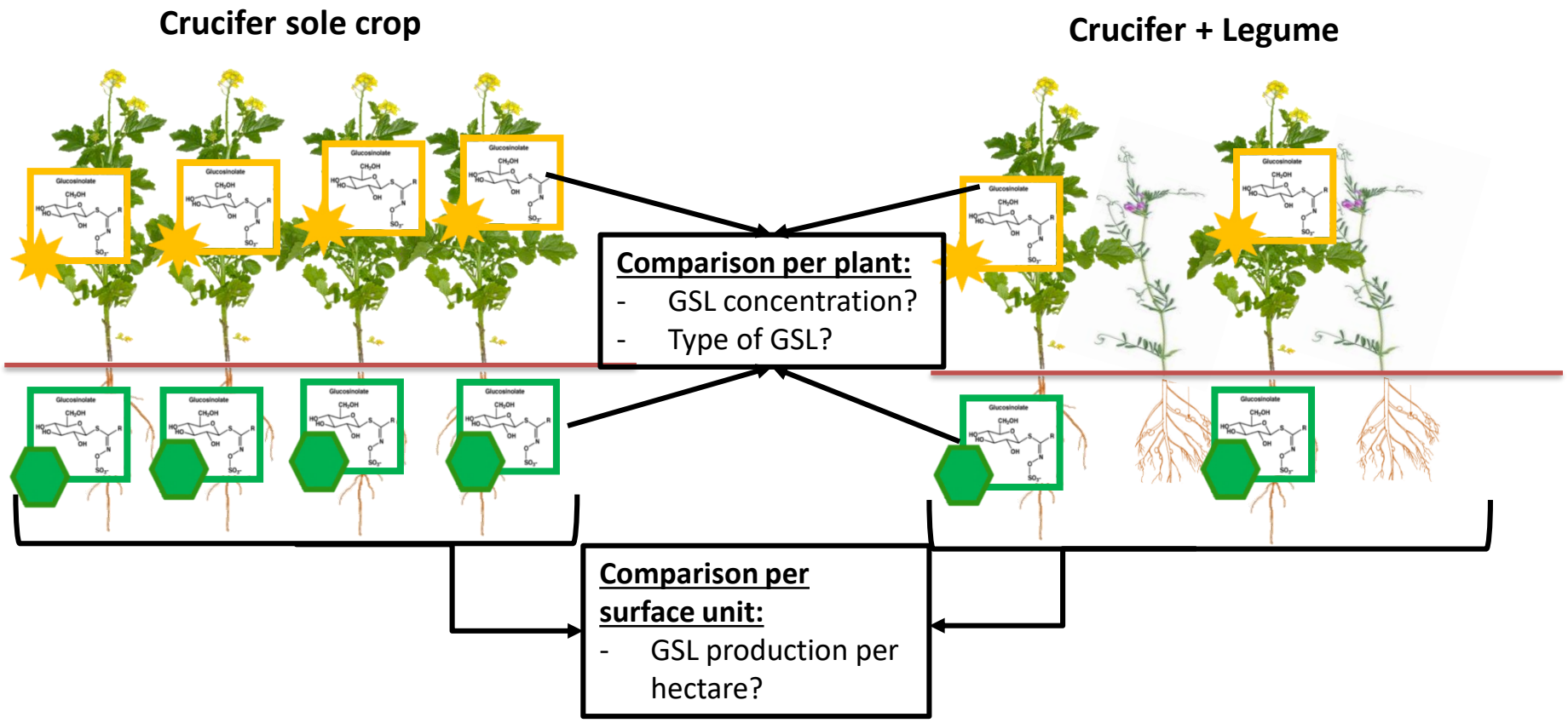
Couëdel et al. 2018a. Cover crop crucifer-legume mixtures provide effective nitrate catch crop and nitrogen green manure ecosystem services. Agric. Ecosyst. Environ. 254, 50–59

Couëdel et al. 2018b. Crucifer-legume cover crop mixtures provide effective sulphate catch crop and sulphur green manure services. Plant Soil. 426, 61–76

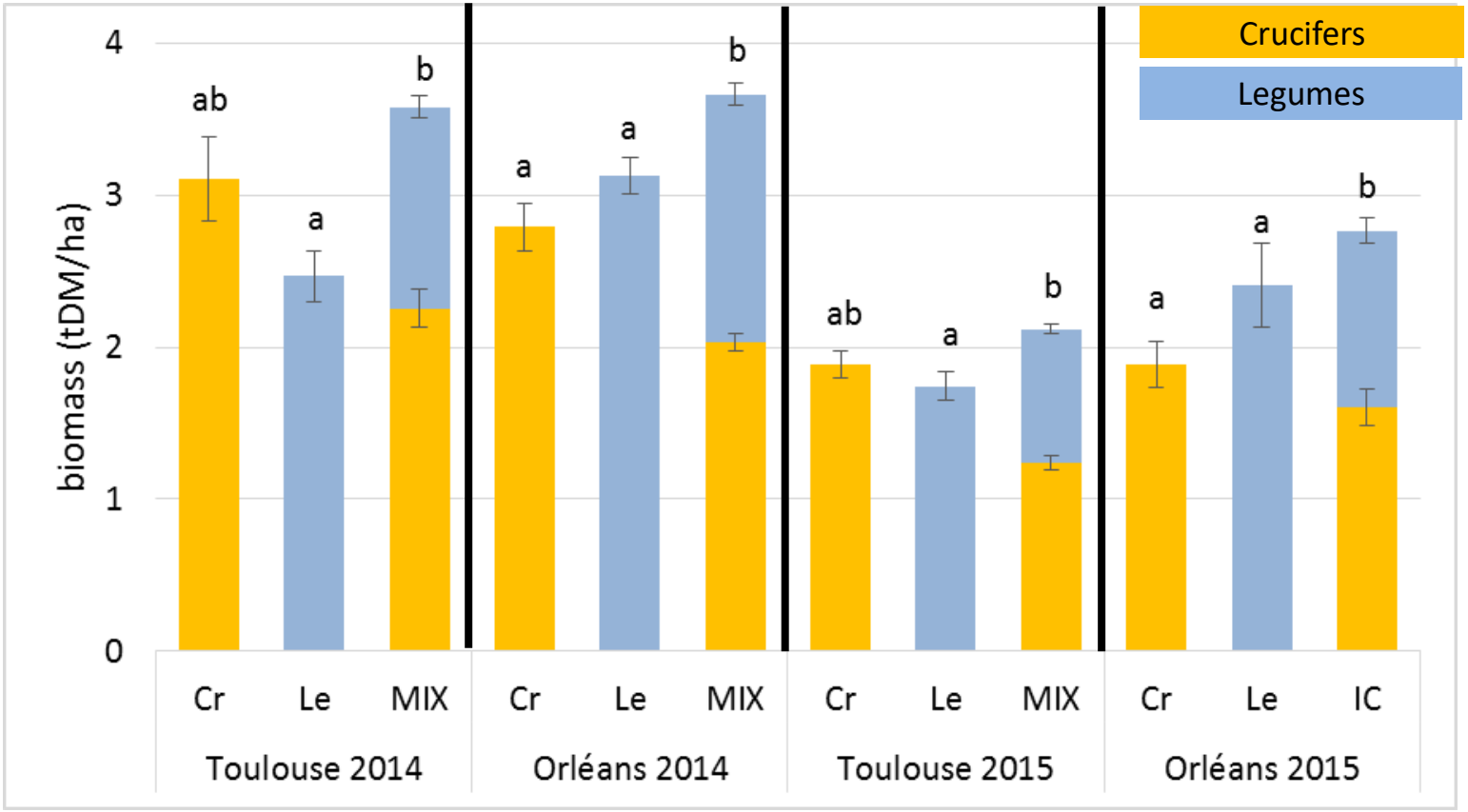
Multiservice approach

	Pure crucifers	Pure legumes	Crucifers + Legumes
N Catch crop Service 	**100%** -51% to -70% soil mineral N	**66%** -37% to -43% soil mineral N	**98%** -48% to -70% soil mineral N
S catch crop Service 	**100%** 10 to 15 kg S/ha	**30%** 4 to 5 kg S/ha	**99%** 10 to 14 kg S/ha
N Green manure Service 	**18%** 1 to 10 kg N/ha released	**100%** 35 to 54 kg N/ha released	**63%** 18 to 30 kg N/ha released
S Green manure Service 	**100%** 6 to 8 kg S/ha released	**23%** 1 to 2 kg S/ha released	**85%** 5 to 6 kg S/ha released
Glucosinolates 	**??**	**/**	**??**

Impact of mixtures on glucosinolate production



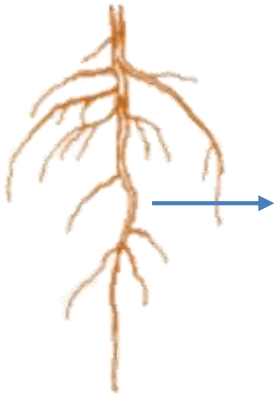
Biomass production of cover crops

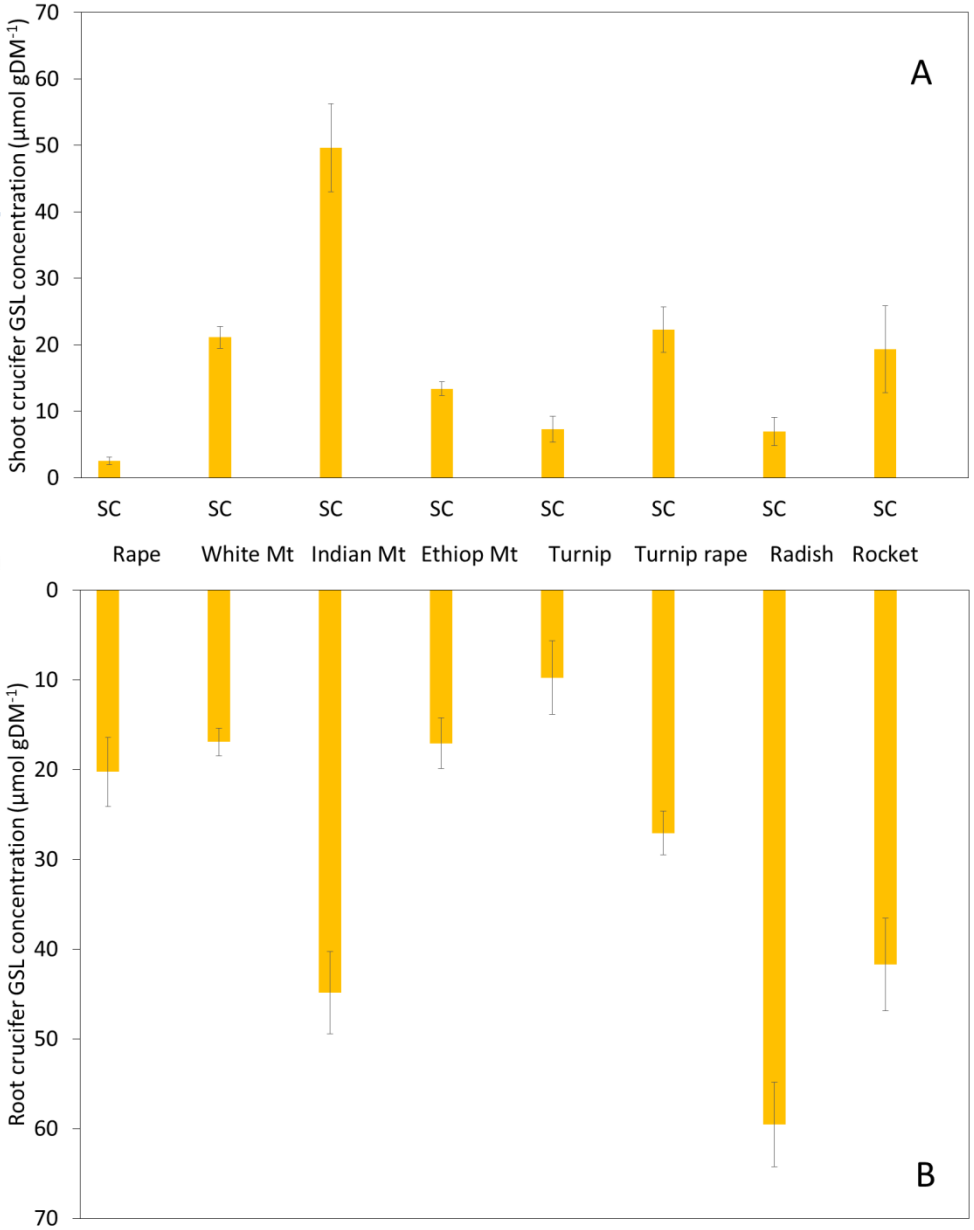


Higher biomass in mixtures compared to sole cover crops:

- Crucifers benefited from mixtures (75% of their sole cover crop biomass)
- Legumes not penalised (50% of their sole cover crop biomass)
- No incompatibility between species

Crucifer glucosinolate profile?





GSL concentration:

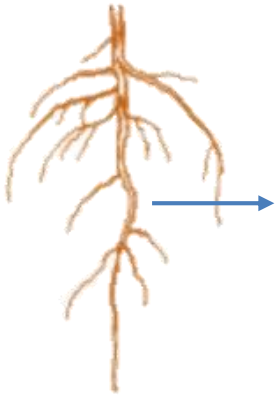
- no cultivar differences

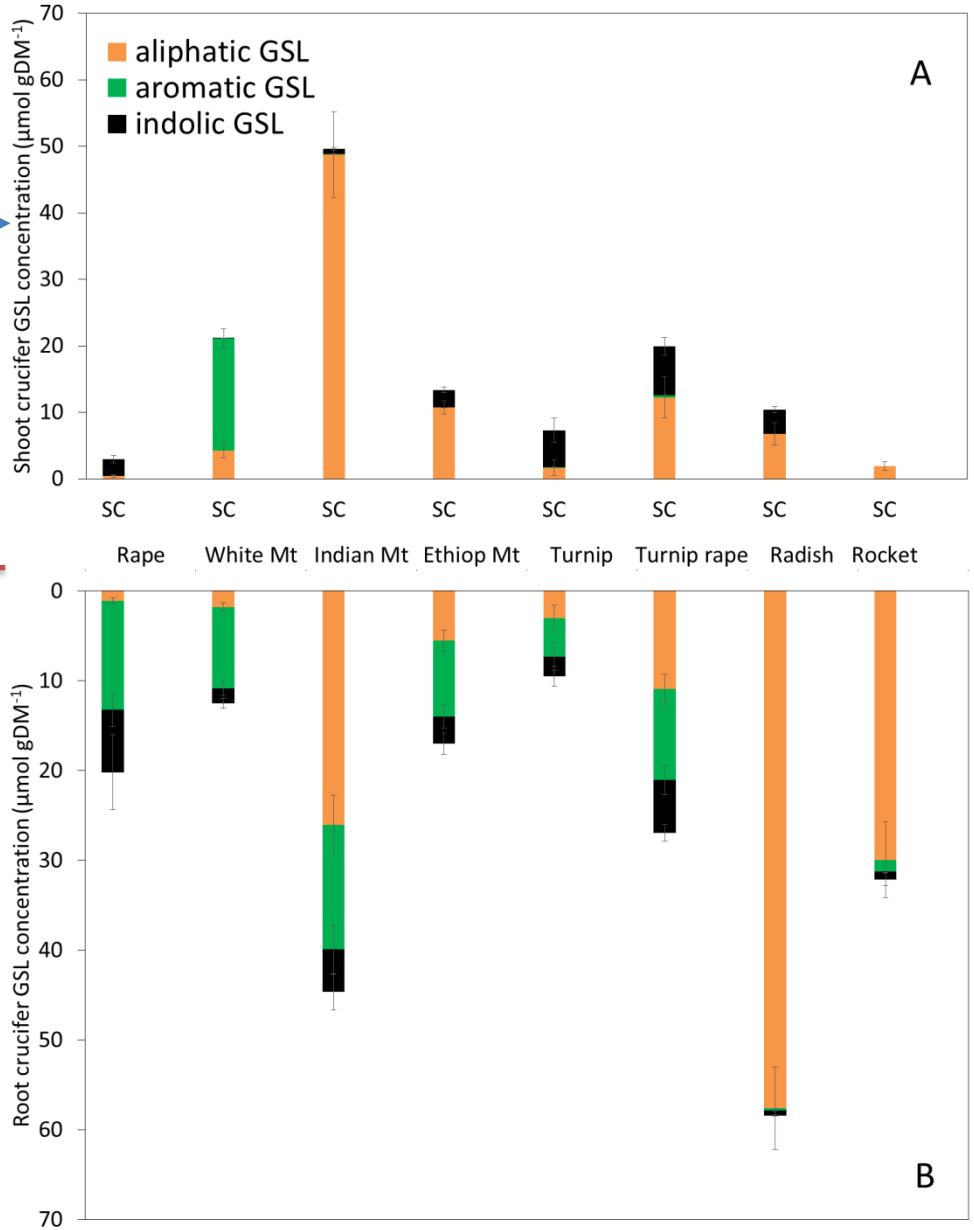
- Inter species differences

- Root and shoot differences

Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Crucifer glucosinolate profile?





Type of GSL:

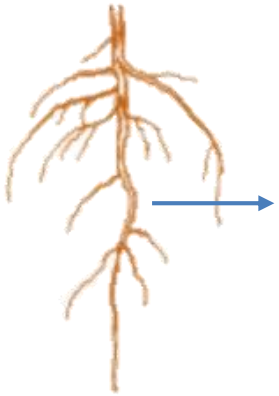
- no cultivar differences

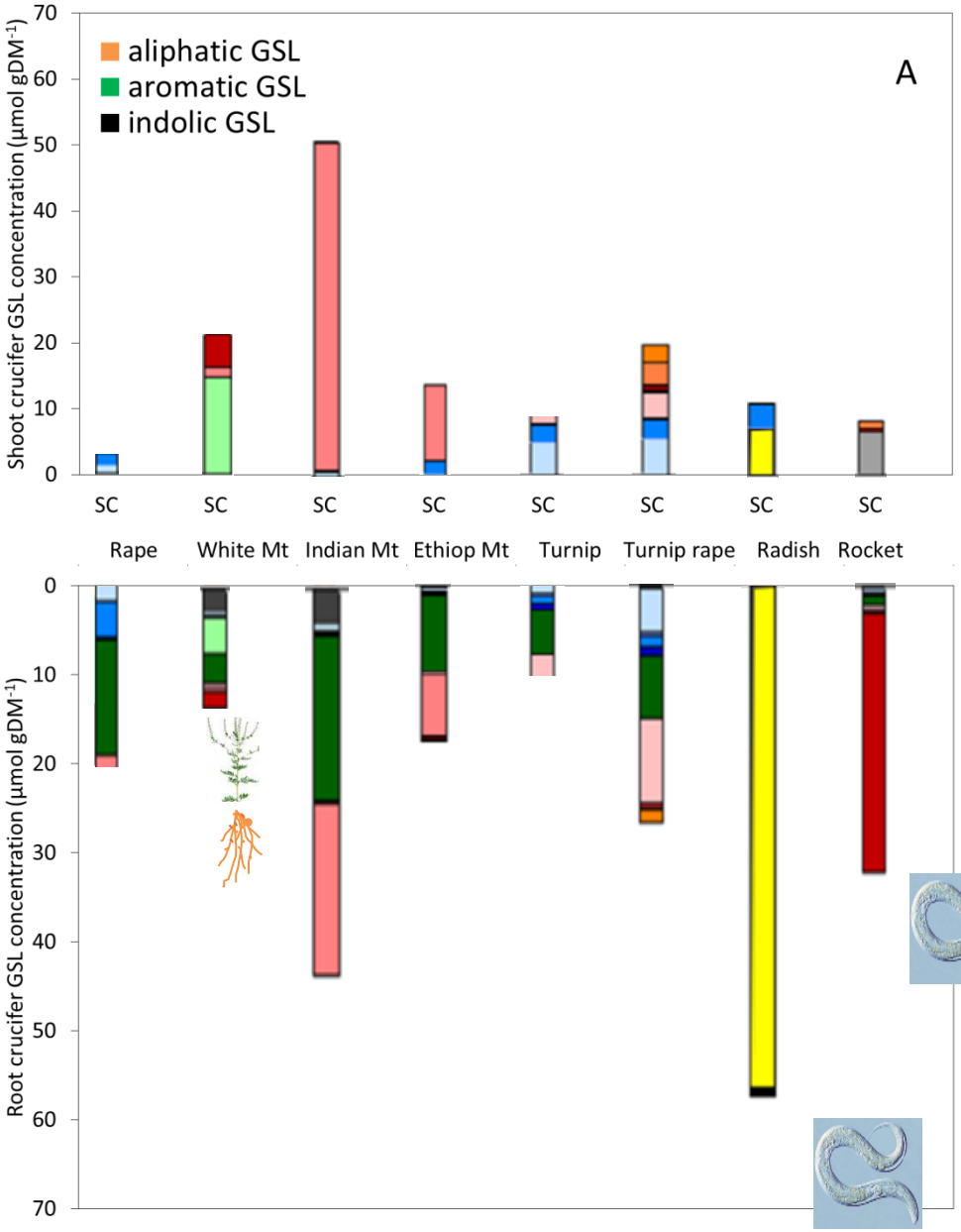
- Inter species differences

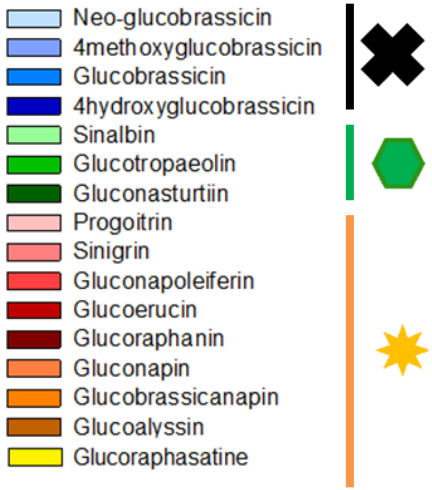
- Root and shoot differences

Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Crucifer glucosinolate profile?



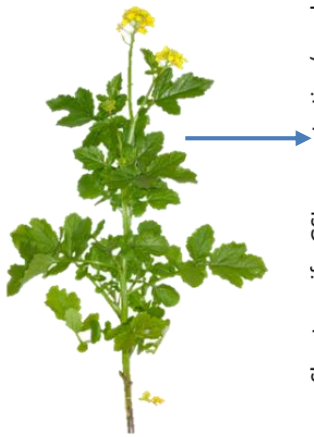


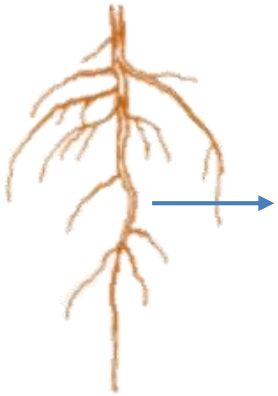


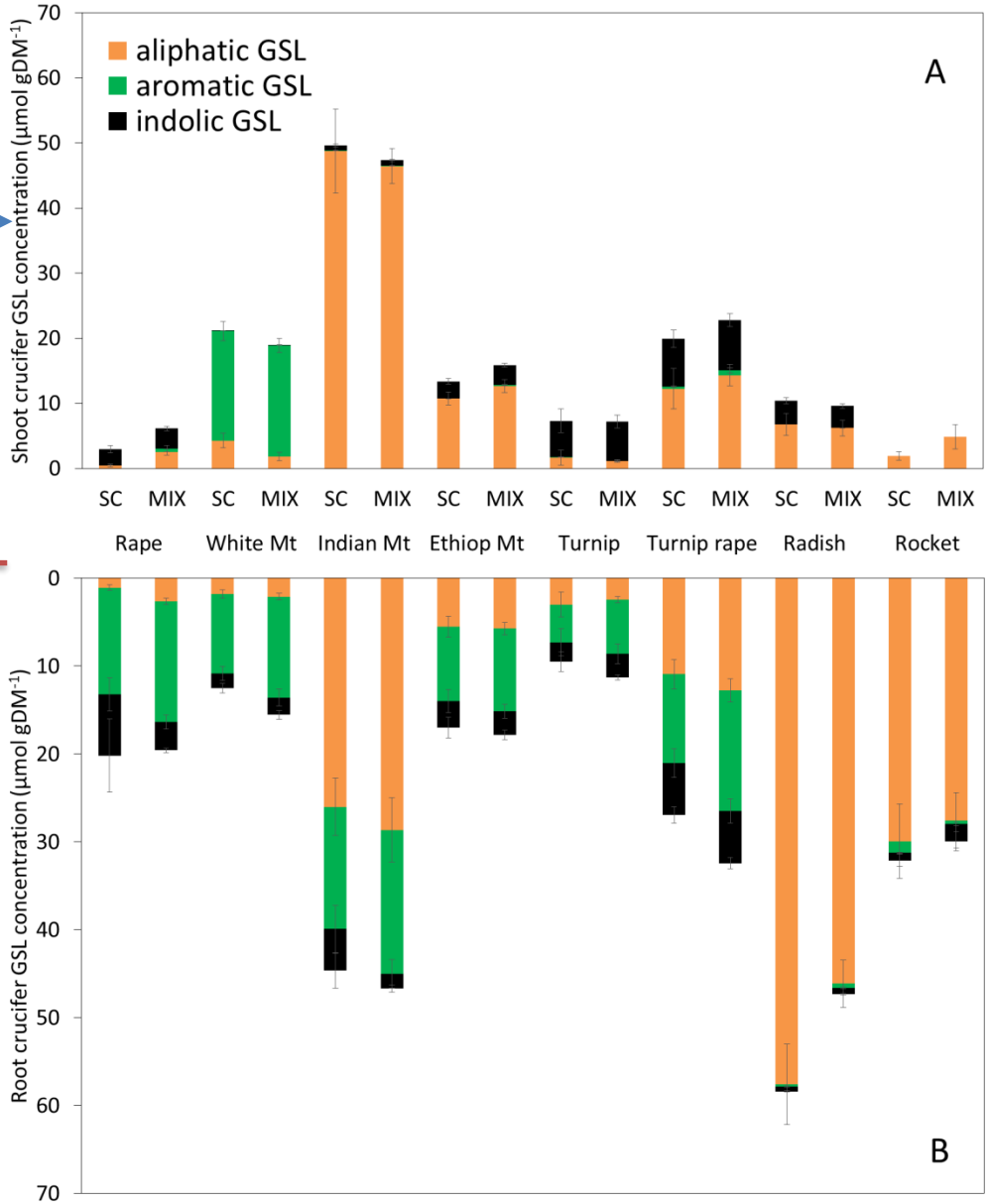
High diversity of GSL = myriad of effects on pathogens?

Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Do mixtures have an effect on crucifer glucosinolate profile?







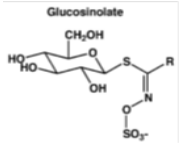
No effect of mixtures on GSL profile:

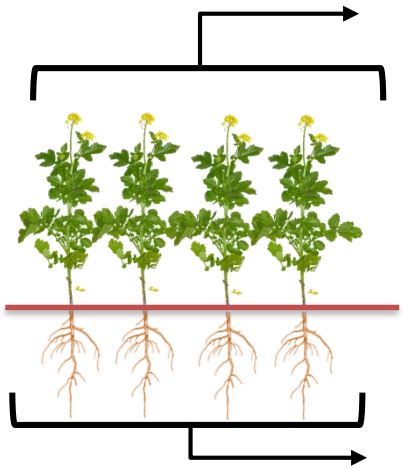
- GSL total concentration
- type of GSL
- relative proportion of GSL

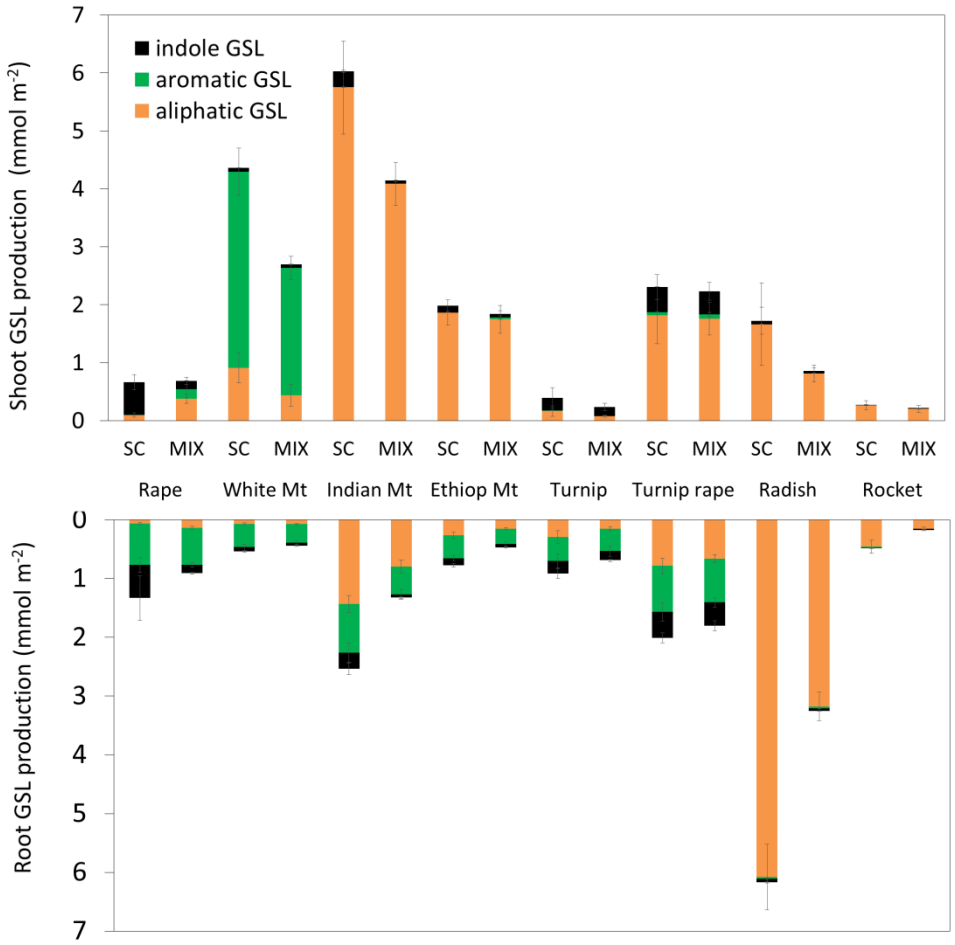
= similar interaction of crucifers with their pests in pure cover crops and mixtures

Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Glucosinolate production per hectare in mixtures

	Pure crucifers	Pure legumes	Crucifers + legumes
Glucosinolates 	+++	/	??





Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Glucosinolate production per hectare in mixtures

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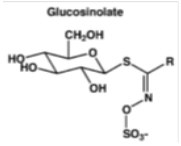
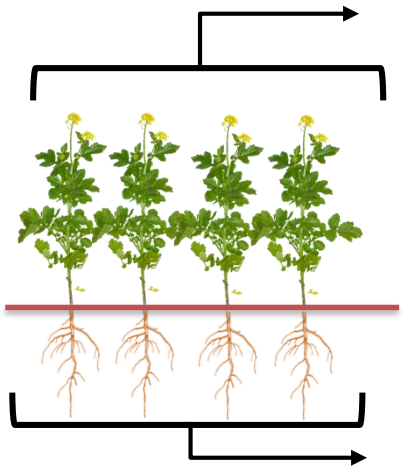
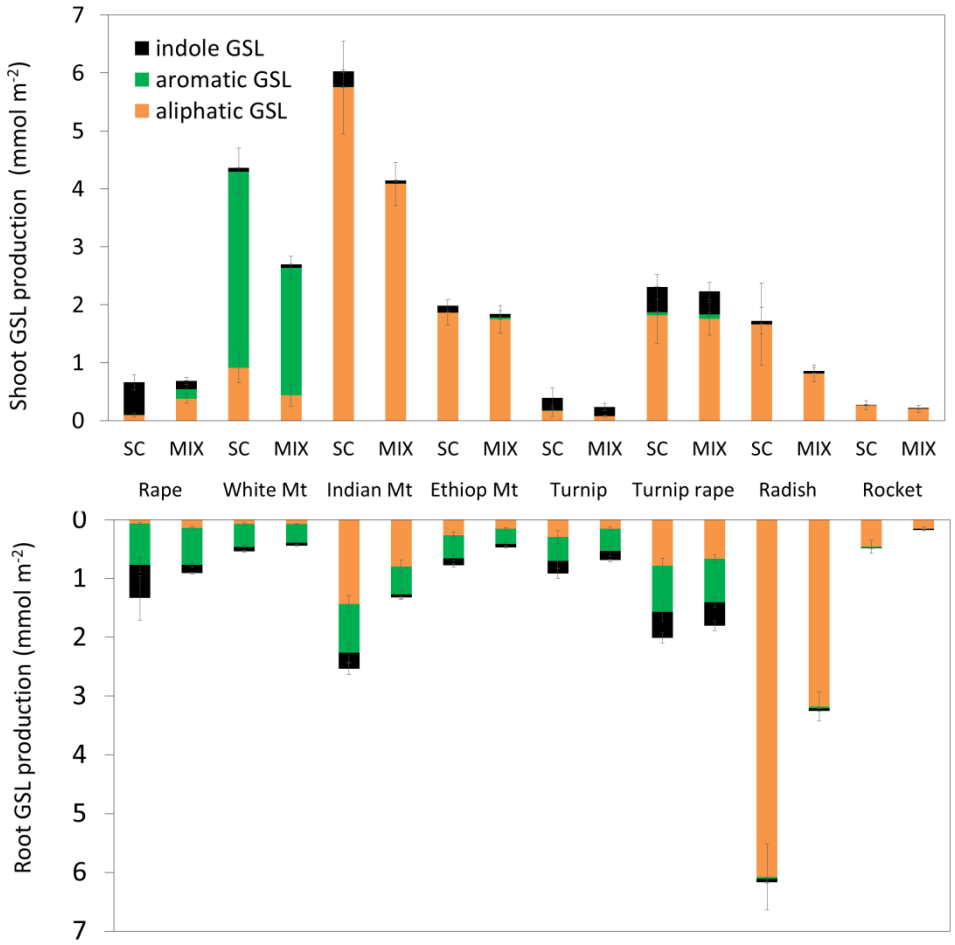
Glucosinolates 	100%	/	81%



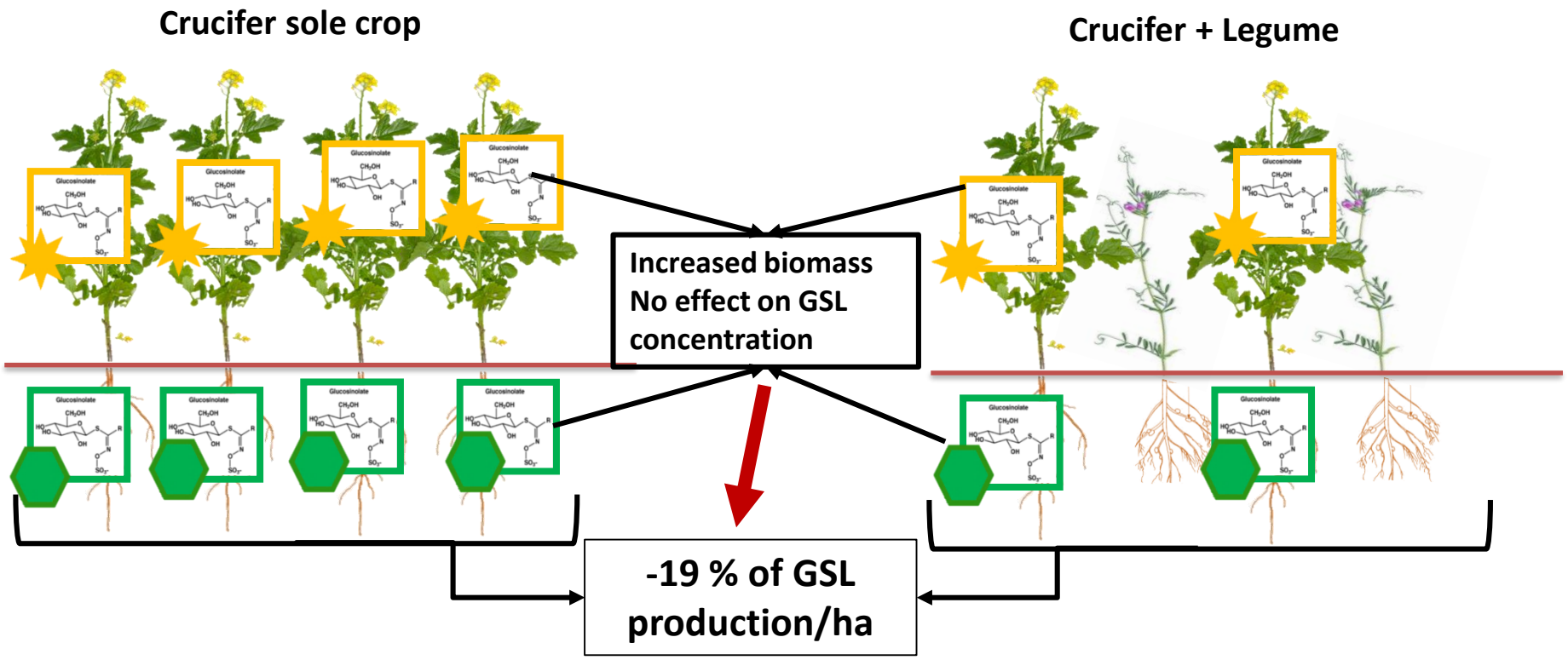


- 10% of shoot GSL

- 30% of root GSL

Couëdel et al. 2018c. Crucifer glucosinolate production in legume-crucifer cover crop mixtures. Eur. J. Agron. 96, 22–33.

Impact of mixtures on glucosinolate production



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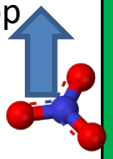
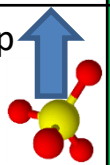
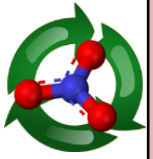
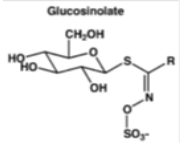
Multiservice approach

	Pure crucifers	Pure legumes	Crucifers + Legumes
N Catch crop Service 	100%	66%	98%
S catch crop Service 	100%	30%	99%
N Green manure Service 	18%	100%	63%
S Green manure Service 	100%	23%	85%
Glucosinolates 	100%	/	81%
Biocontrol	?	?	??

Presentation outline

1- Overview of multi-service cover crops

2- Cover crops mixtures : levels of services provided

3- Revisiting the biocontrol potential

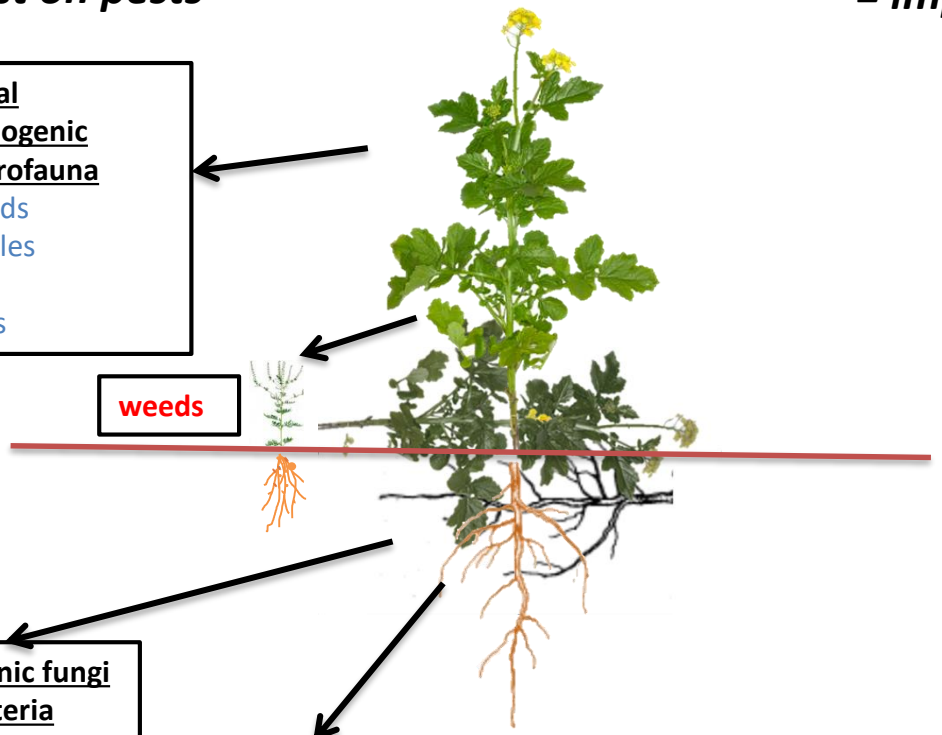
Biocontrol potential?

= impact on pests

= impact on beneficials

Aerial pathogenic macrofauna
Aphids
Beetles
Flies
Slugs

weeds



Pathogenic fungi and bacteria
R. solani
G. tritici
V. dahliae
A. euteiches
R. solanacearum
S. scabies
Fusarium spp.
Sclerotinia spp.
Pythium spp.

Pathogenic nematodes
M. incognita
P. neglectus
H.schachtii

Suppressive effects
Enhancement effects
Neutral/unknown effects

Couëdel et al., (2019) Crucifer - legume cover crop mixtures for biocontrol: towards a new multi-services paradigm. Advances in Agronomy.

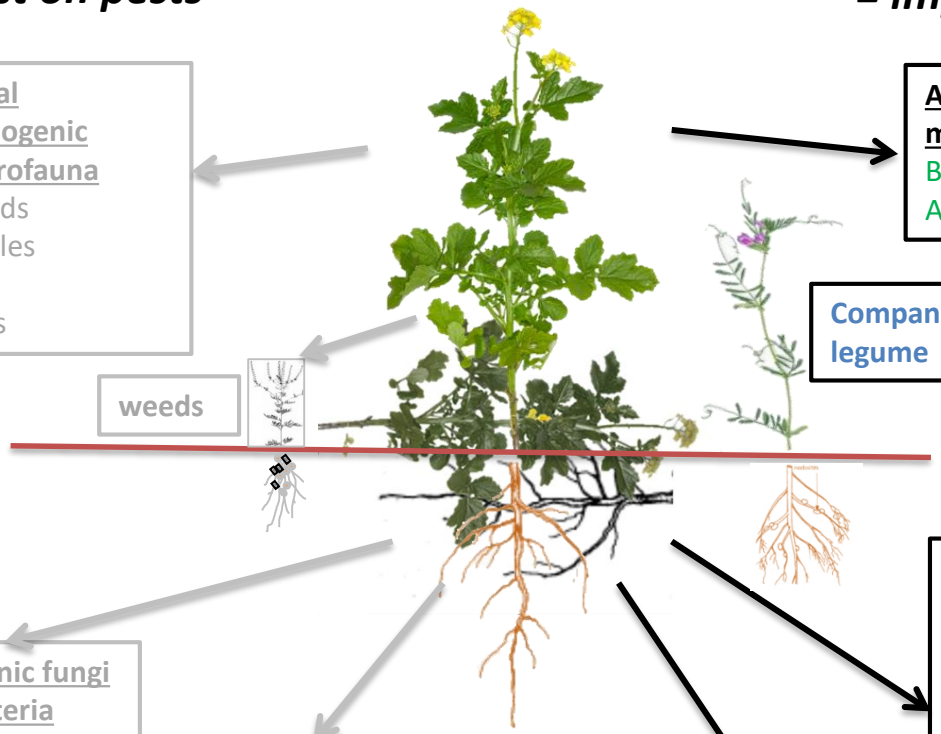
Biocontrol potential?

= impact on pests

= impact on beneficials

Aerial pathogenic macrofauna
Aphids
Beetles
Flies
Slugs

weeds



Companion legume

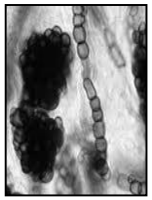
Aerial beneficial macrofauna
Bees
Arthropodes

Next crop

Beneficial microbes
Mycorrhizae
Nitrifying bacteria
Rhizobium
Trichoderma spp.
General microbes

Underground beneficial macrofauna
Beneficial nematodes
Earthworms

Pathogenic fungi and bacteria
R. solani
G. tritici
V. dahliae
A. euteiches
R. solanacearum
S. scabies
Fusarium spp.
Sclerotinia spp.
Pythium spp.



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Suppressive effects

Enhancement effects

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Couëdel et al. 2019 Crucifer - legume cover crop mixtures for biocontrol: towards a new multi-services paradigm. Advances in Agronomy.

Biocontrol potential?

= impact on pests

= impact on beneficials

Aerial

Aerial beneficial

Determination of biofumigation potential (BP)

$$BP = \sum_{i=1}^{n} Biomass_{total} \times [GSL]_i \times Toxicity_{GSLi}$$

with i = glucosinolate i

From Kirkegaard and Sarwar (1998)

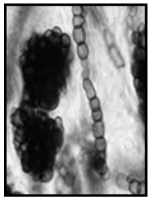
Pesticide derived approach

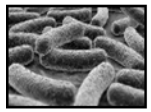
1) % of conversion GSL → ITC

2) % ITC to reach targeted organism

3) Toxicity ITC on targeted organisms

Mechanistic approach → Pandora's Box





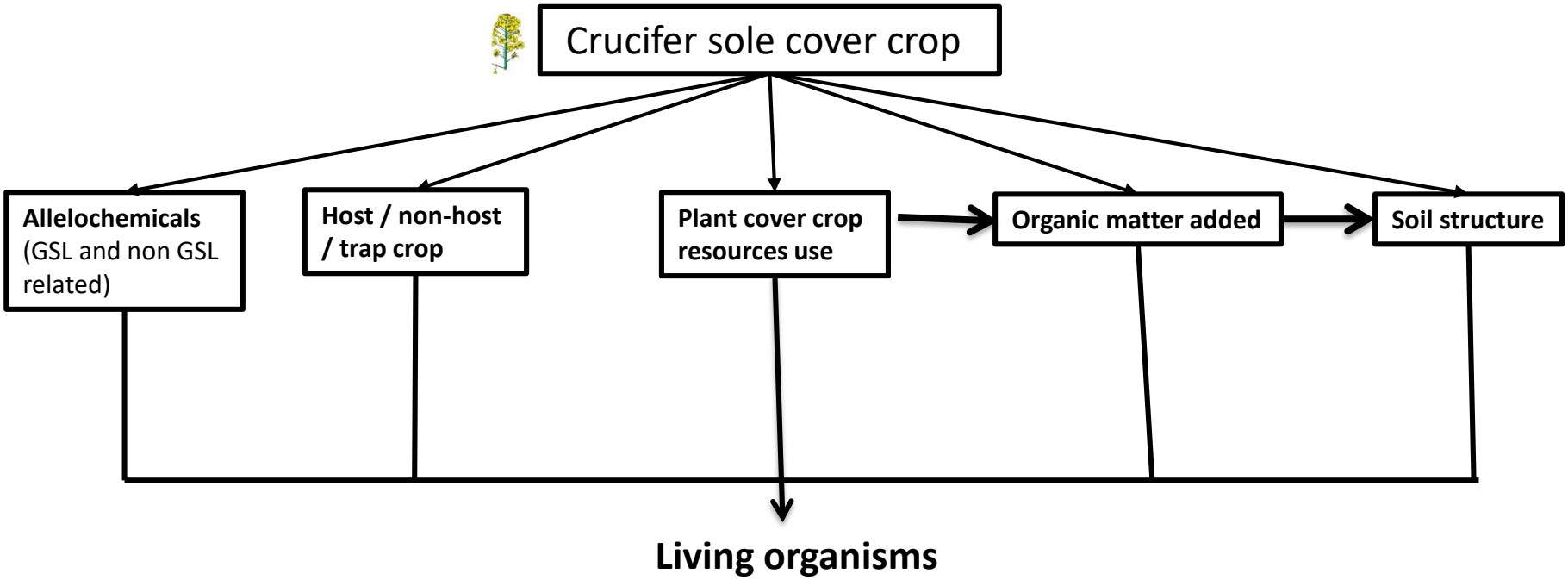
Pythium spp.

Suppressive effects

Enhancement effects

Neutral effects

Biocontrol potential?



Biocontrol potential?

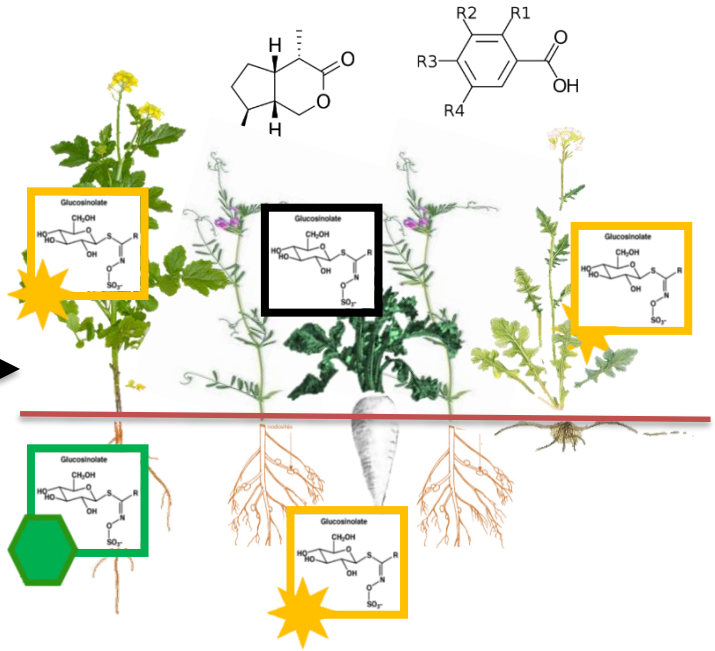
Crucifer sole cover crop

Allelochemicals (GSL and non GSL related)

- ↑ Increase allelochemicals diversity
- ↓ Decrease allelochemicals individual production per basis area

Host / non-host / trap crop

Plant cover crop resources use → **Organic matter added** → **Soil structure**



Increased cover crop diversity
= more biocontrol?

Biocontrol potential?

Crucifer sole cover crop

Allelochemicals (GSL and non GSL related)

- ⬆ Increase allelochemicals diversity
- ⬇ Decrease allelochemicals individual production per basis area

Host / non-host / trap crop

- ⬆ Reduce host of crucifers trought:
  - dilution effect
  - Physical barrier effect
  - Change plant traits
  - Change plant sussessibility
- ⬇ Could decrease non host and trap effects

Plant cover crop resources use → **Organic matter added** → **Soil structure**

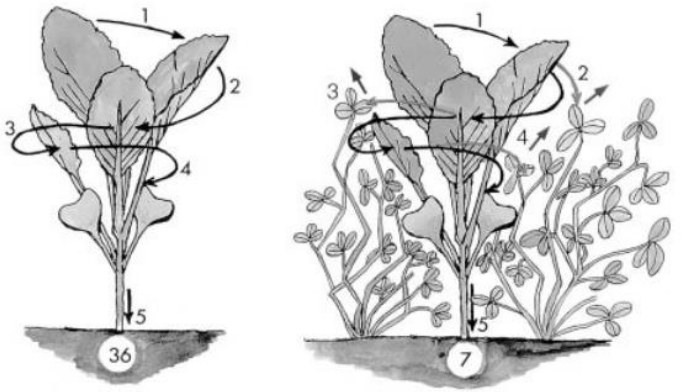


Figure 3. Schematic diagram to illustrate how diverse backgrounds, here represented by clover (*Trifolium* spp.), influence host plant acceptance by the cabbage root fly. Numbers represent the four (mean no.) leaf-to-leaf flights made by the fly to ascertain whether the plant is a suitable substrate around which to lay its eggs.

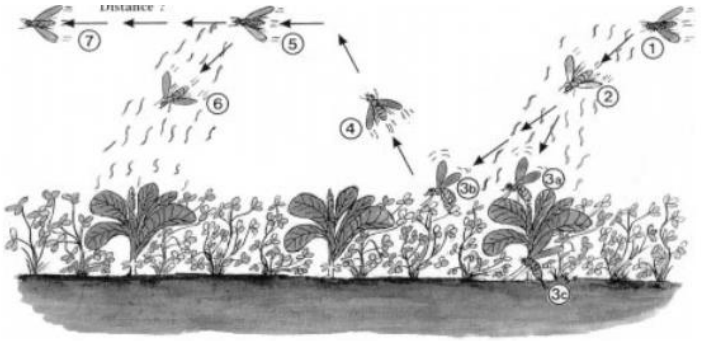
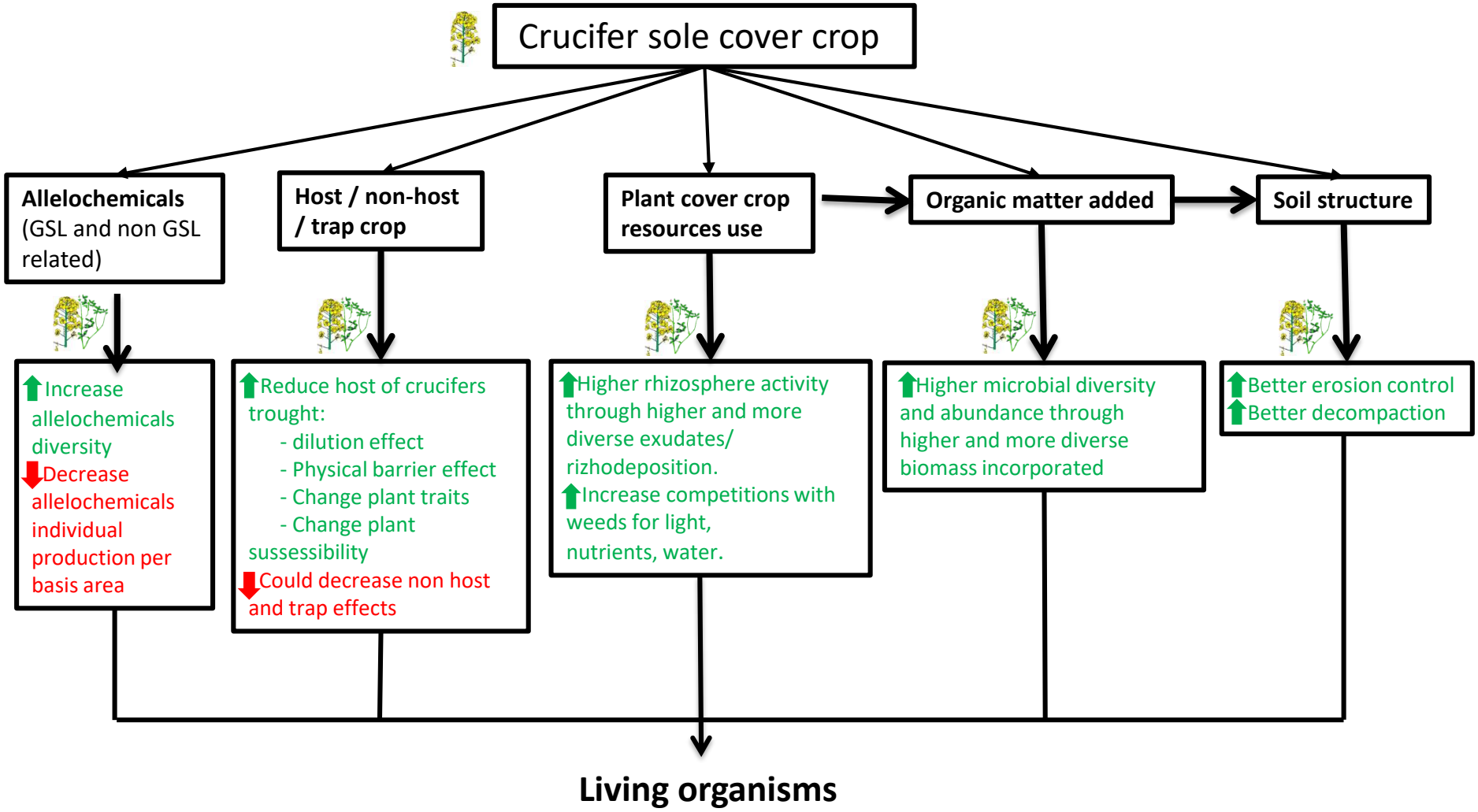


Figure 2. Schematic diagram to illustrate how diverse backgrounds, here represented by clover (*Trifolium* spp.), influence host plant finding by the cabbage root fly. Numbers represent insect actions 1–7 (see text).

from Finch and Collier 2000

Biocontrol potential?

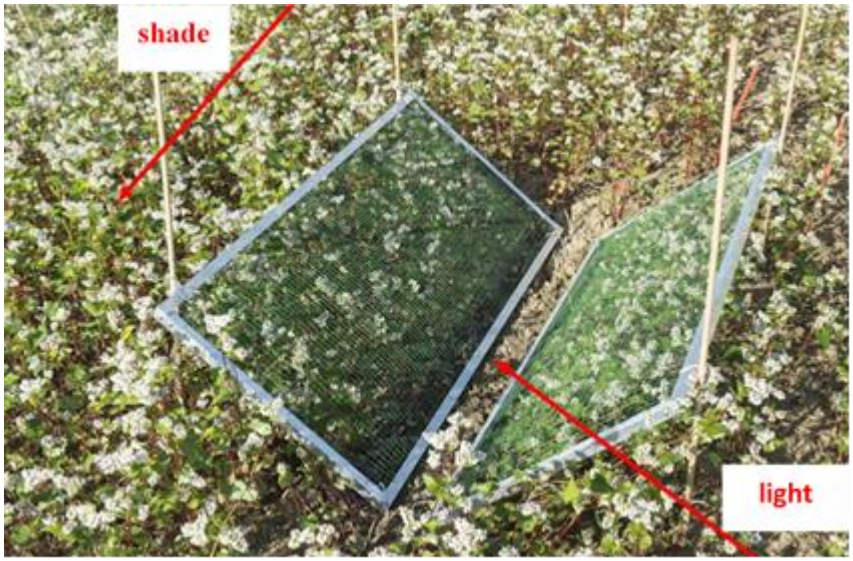


Isolating GSL effects

- **Need for control without GSL** : canola double 0 (“00”) or canola quality Indian mustard cultivars not suitable

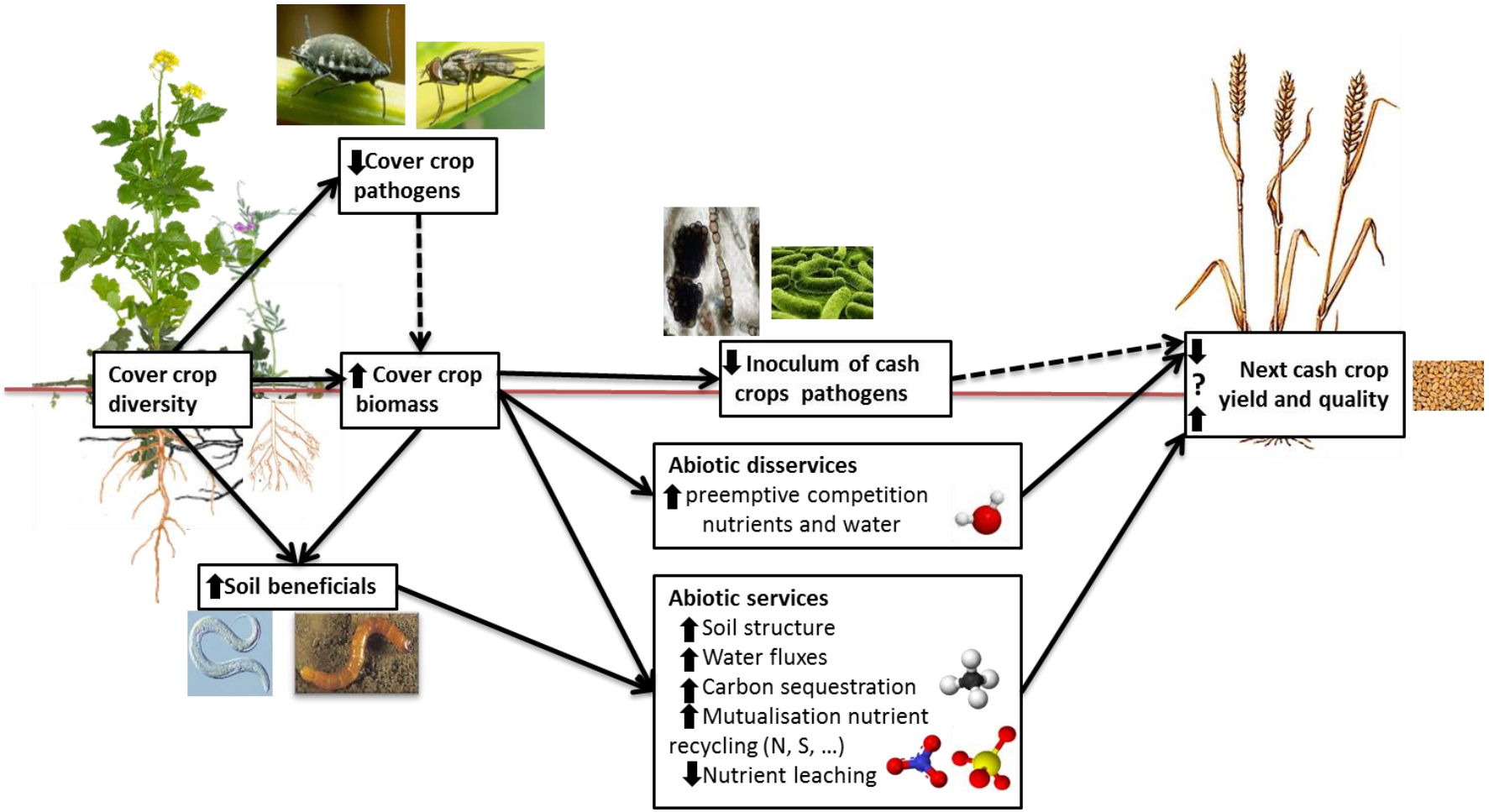
- Design crucifers free of certain GSLs = **effects of individual GSL** on plant pathogens + unravel the confusing **GSL “cocktail” effects** to understand unexpected causes of pathogen suppression (Halkier and Gershenzon (2006))

- **Experimental designs** aimed to isolate allelochemical effects (Falquet et al., (2014))



Experimental design to differentiate effects of light competition from other effects on pigweed suppression by buckwheat in Switzerland (© Judith Wirth).

Links between biotic and abiotic services



Take home messages

- Mixtures enable **to mutualise services of N, S, GSL** production and **biocontrol**

- **This study provides new knowledge:**
  - Quantitative information on levels of services provided by a wide range of crucifer-legume mixtures
  - A first methodological approach to design mixtures

- **This study highlights** a strong knowledge gap on:
  - **Pathogens'** suppression by mixtures
  - **Beneficials'** impact
  - **Multiservices** assessment
  - Integration of **cover crops in farming system design**

→ Multi-Service Cover Crops as a pillar of Agroecological transition

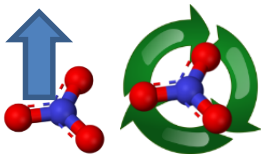
Thank you for your attention!

Technicians

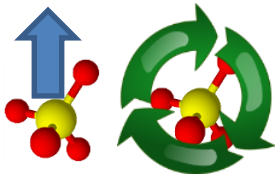
Administrators

Colleagues

For more details



Couëdel, A., Alletto, L., Tribouillois, H., Justes, E., 2018a. Cover crop crucifer-legume mixtures provide effective nitrate catch crop and nitrogen green manure ecosystem services. Agric. Ecosyst. Environ. 254, 50–59. doi:10.1016/j.agee.2017.11.017



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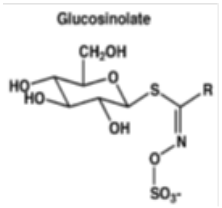

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