EXAMPLE OF REAL USE OF CONSTRAINT PROGRAMMING (CP)
-
Using CP for the agroecological design of mixed fruit tree-vegetable cropping systems

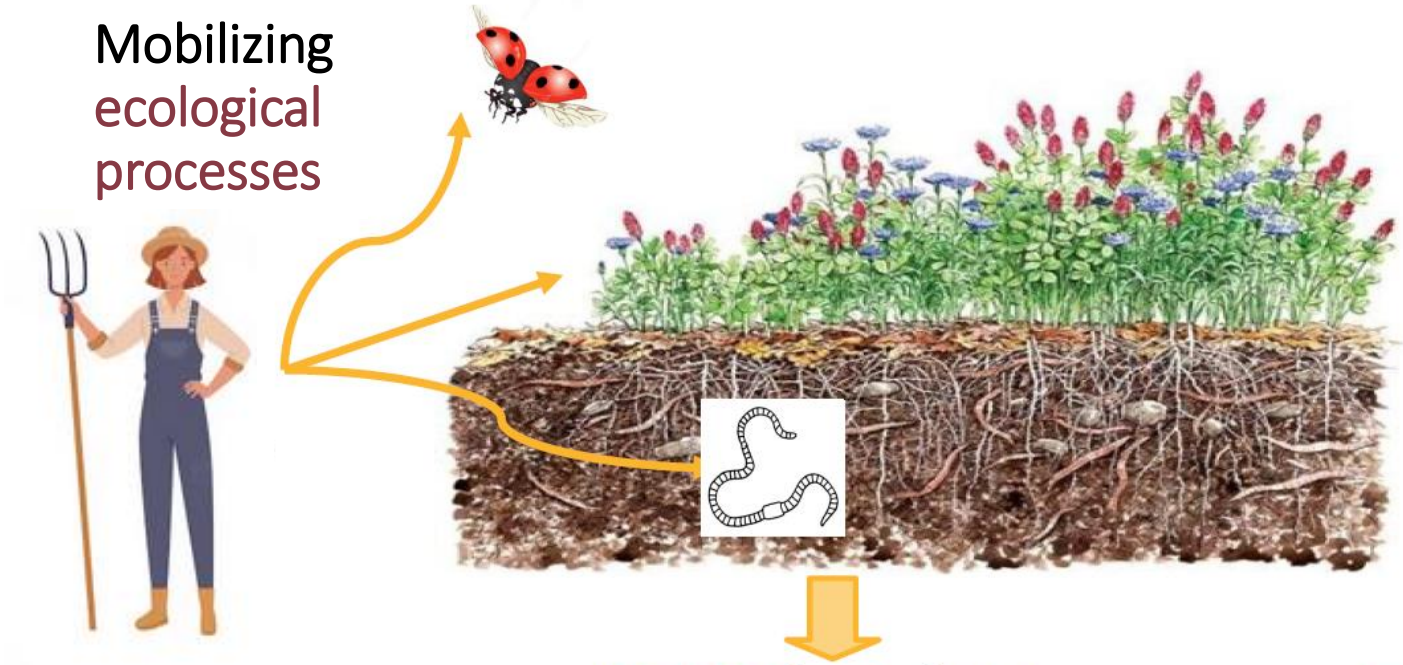
Work conducted as part of Margot Challand's PhD (2021-2024)

Margot Challand and Titouan Lorieul – 23/05/2025

1. Presentation of the agronomic problematic

Agroecology: a promising paradigm for ecologizing agriculture…

Mobilizing ecological processes



Ecosystem services

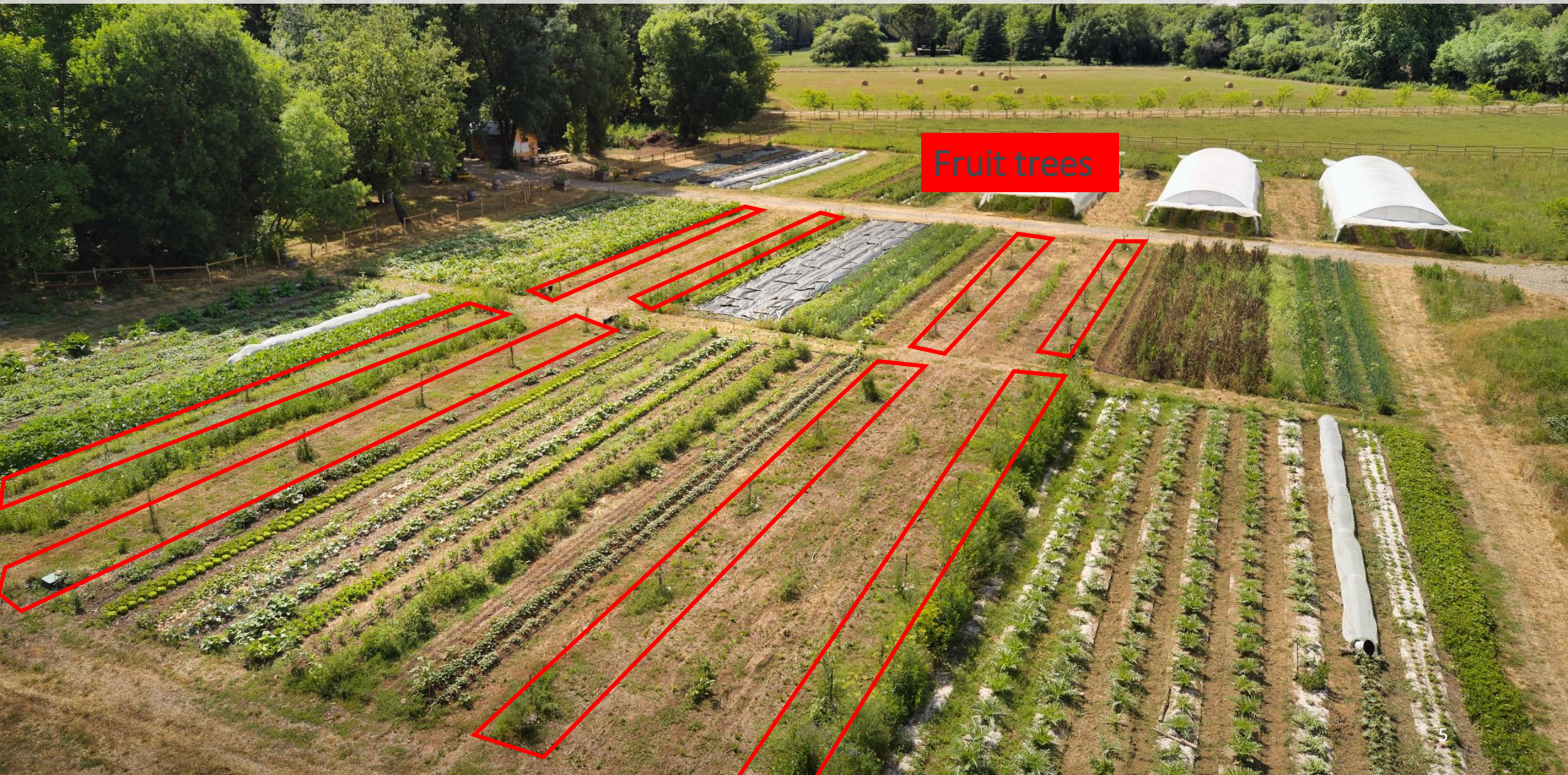
Reduction of inputs

?

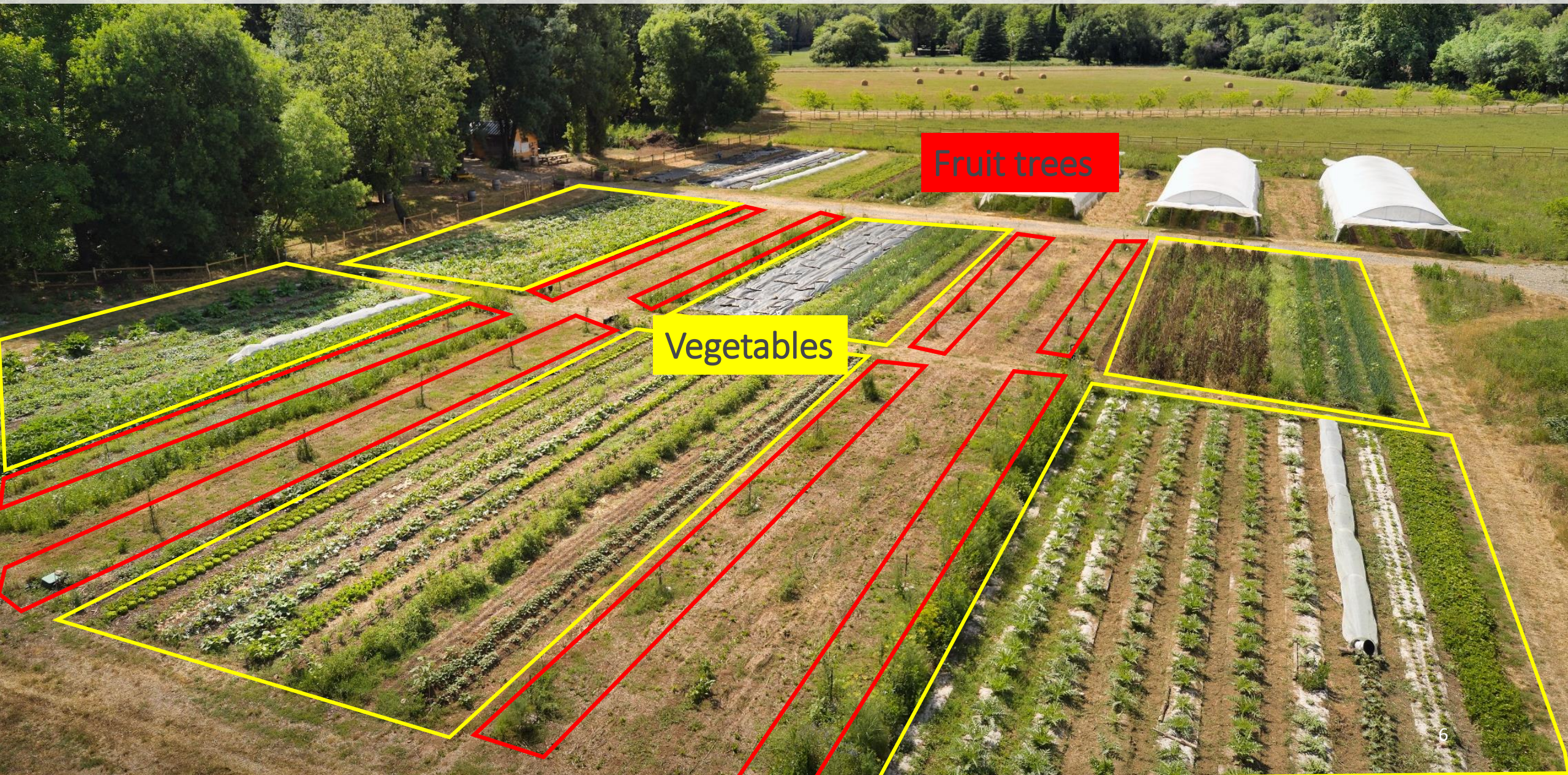
How to combine the components of the agro-ecosystem in space and time to enhance the synergies in a given context while ensuring the sustainability of the farming system ?

Mixed fruit tree-vegetable cropping systems

Mixed fruit tree-vegetable cropping systems



Mixed fruit tree-vegetable cropping systems



Mixed fruit tree-vegetable cropping systems

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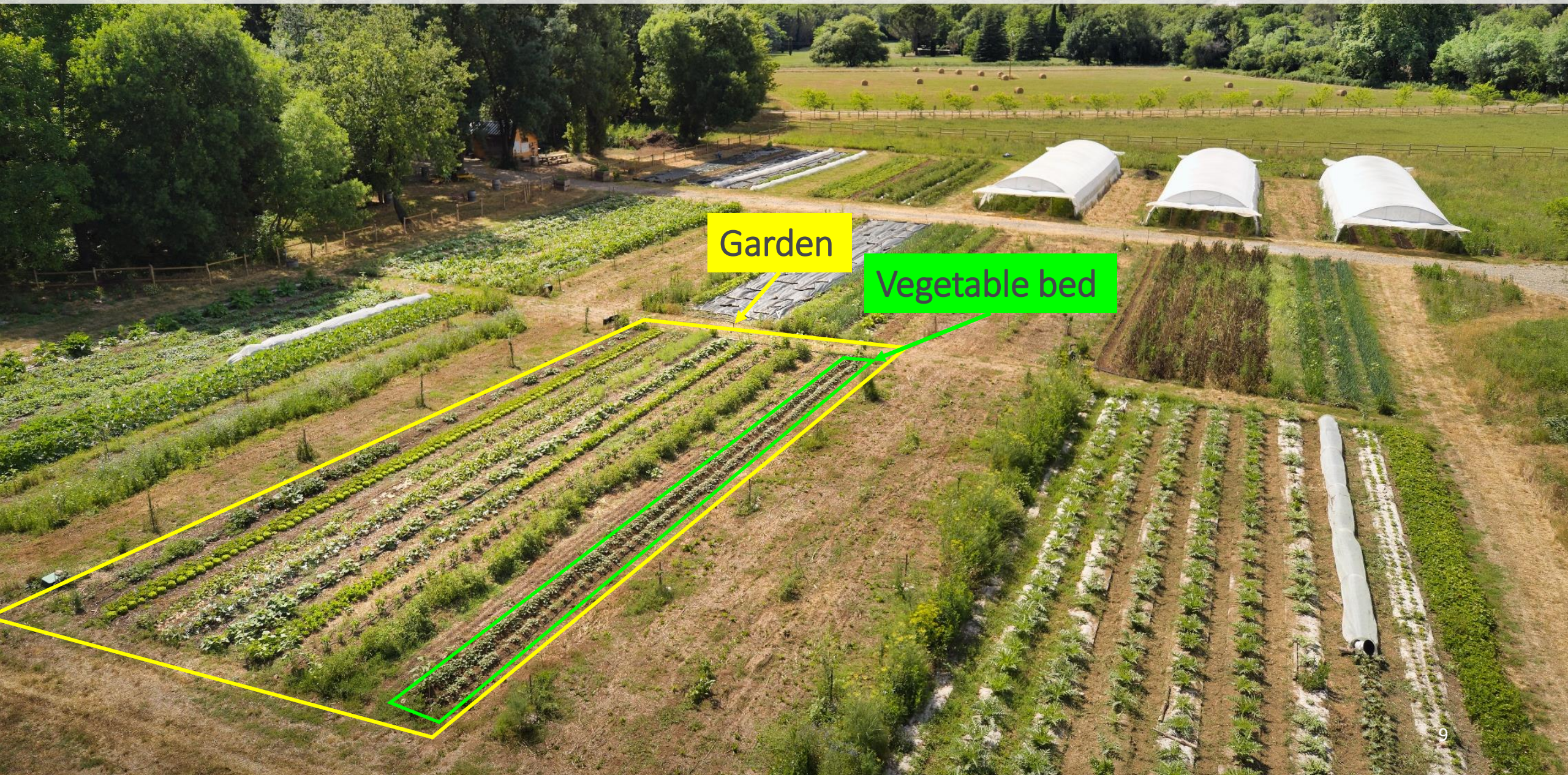
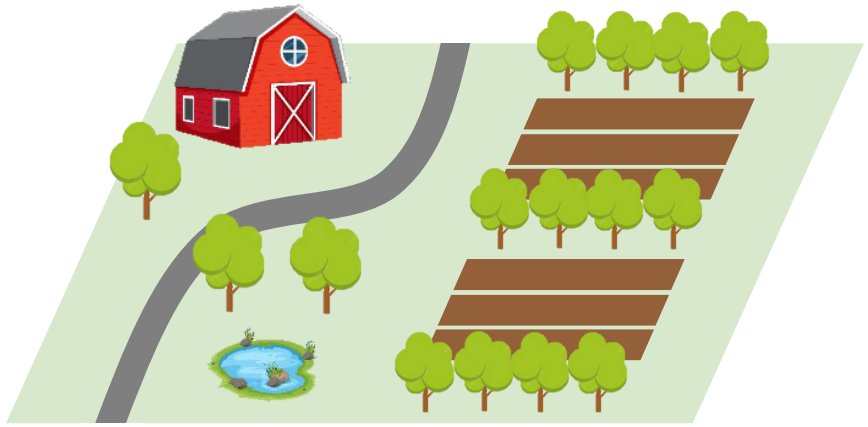


Mixed fruit tree-vegetable cropping systems

Mixed fruit tree-vegetable cropping systems

The crop allocation problem

Farm plan :

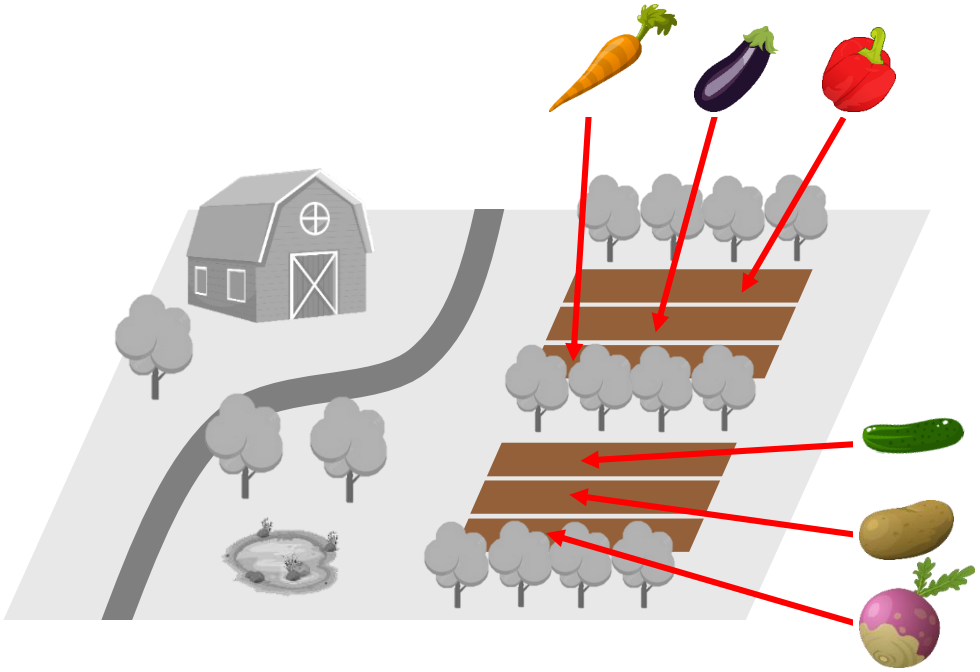


Cropping calendar :

Crop	Period	Quantity
	weeks 11-32	2
	weeks 38-52	1
	weeks 17-43	4
⋮	⋮	⋮

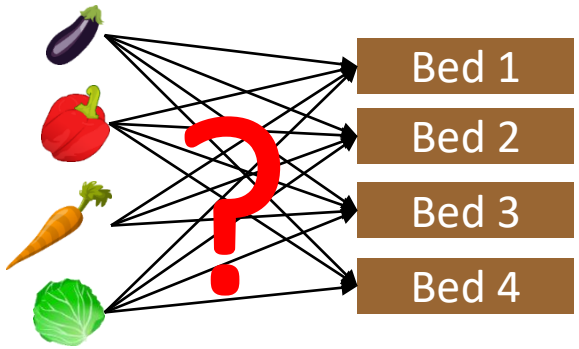
WHERE ?

Cropping plan :



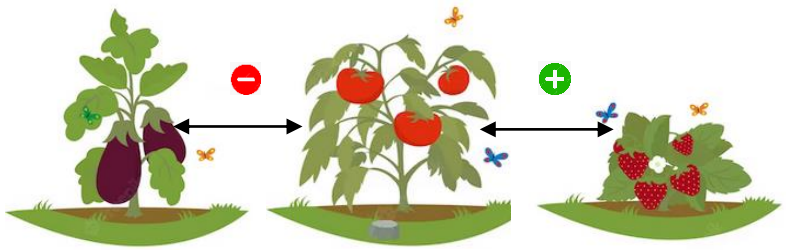
Main difficulties to design the cropping plan

→ Large number of crop **combinations** in time and space



→ Numerous **factors** to be taken into account

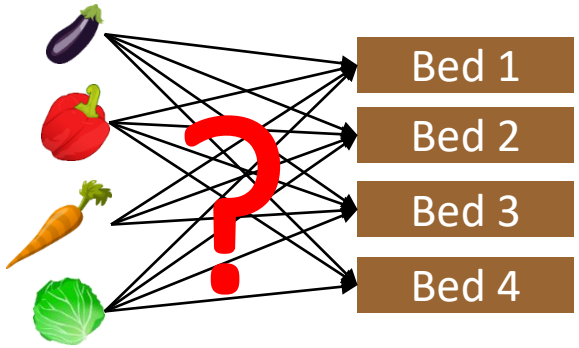
→ Need to combine different **types of knowledge**, suitable in the local context



2. Using CP to adress the crop allocation problem

Main difficulties to design the cropping plan

→ Large number of crop **combinations** in time and space



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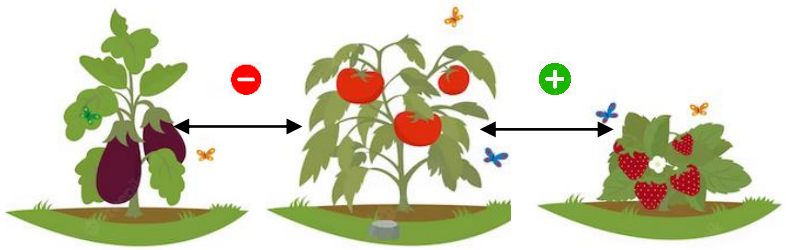


Allows to manage the **combinatorial** aspect of the problem

Provides formalisms with a high level of **expressivity**

Using **Constraint Programming** (CP)

Presentation of Pyagroplan model

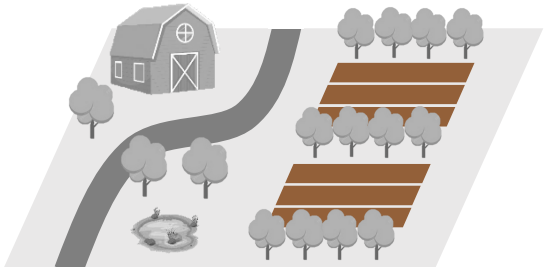
Input data

- Cropping calendar

Crop	Period	Quantity
	weeks 11-32	2
	weeks 38-52	1
	weeks 17-43	4
⋮	⋮	⋮

= Variables

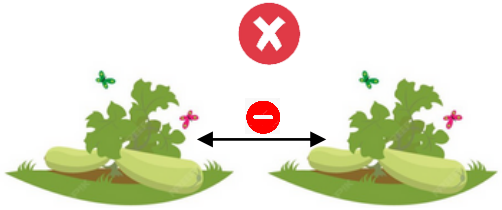
- Bed positionning



= Value domain

- List of real constraints

Ex :

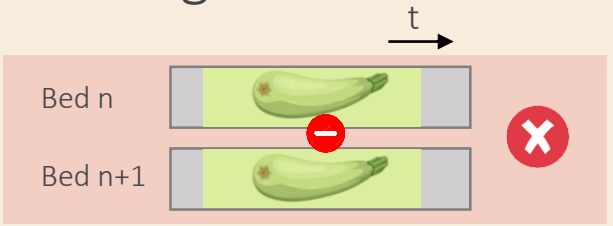


Pyagroplan

In Python using Pychoco library

- 5 model constraints

  Ex : No negative interaction



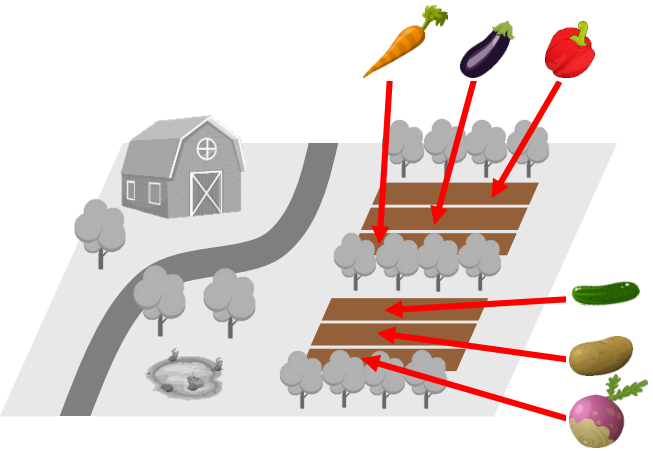
- Optimisation objectives

Programmatic interface to express real constraints

The solver combines **constraint filtering** and **search heuristics** to search for a crop-to-bed allocation **satisfying all constraints**.

Model output

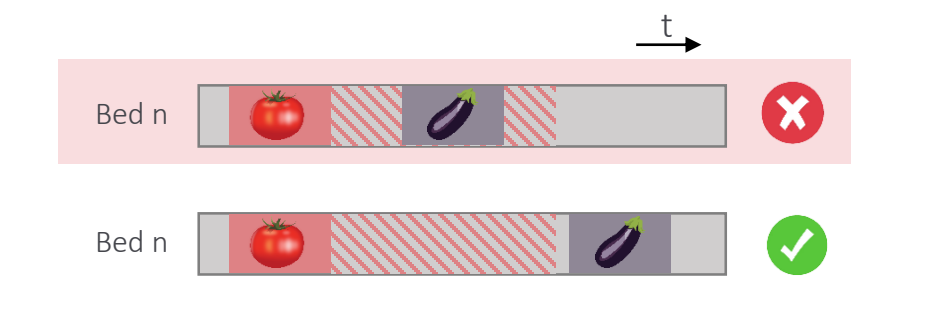
Cropping plan



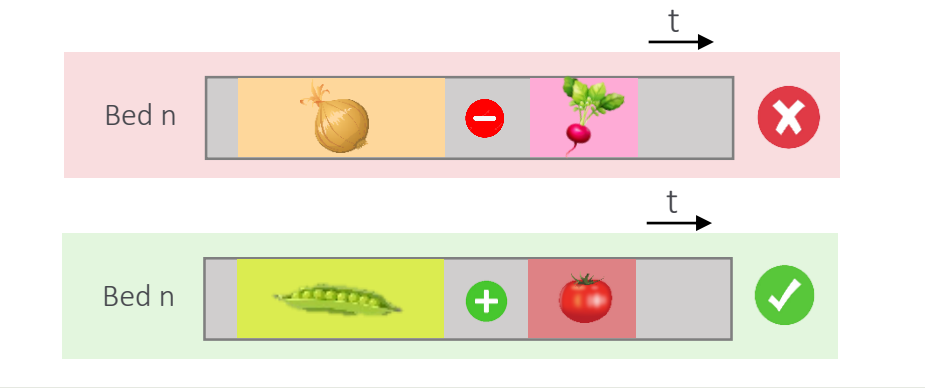
PyAgroplan contraints

Temporal constraints:

- Ensure return delays

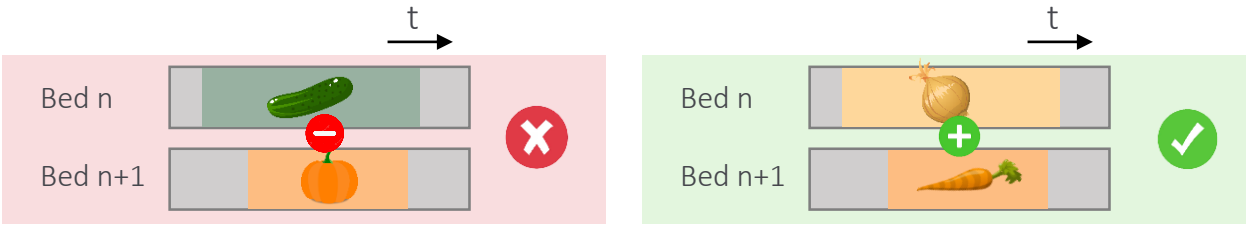


- Precedence constraint

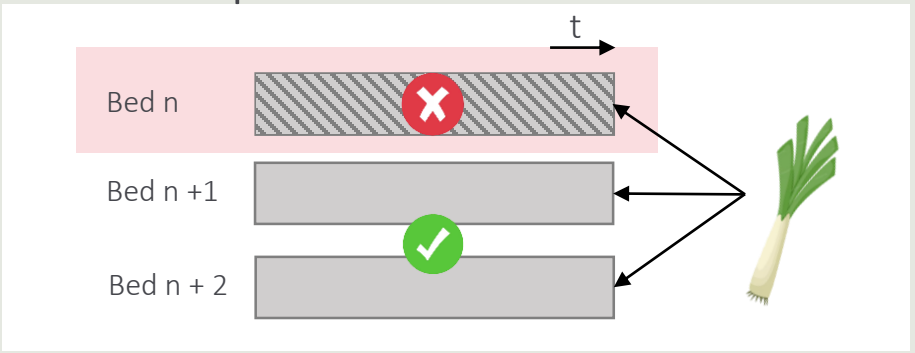


Spatial constraints:

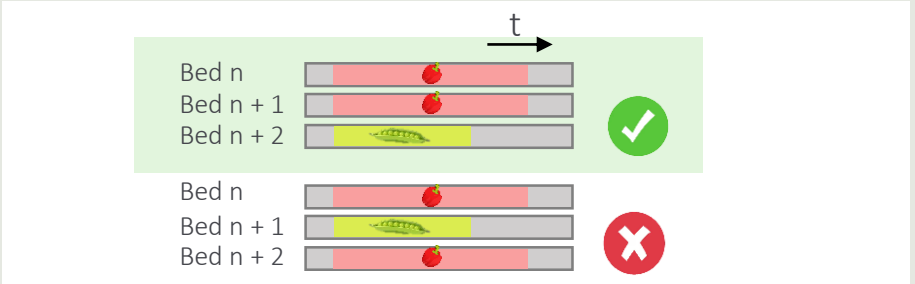
- Spatial interaction constraint



- Compatible beds



- Group crops



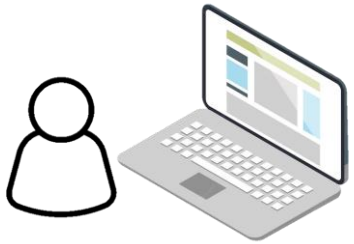
Combining the model with a participatory design approach

❶ SPECIFYING THE PROBLEM

- Diagnosis of the initial situation
- Identification of the problem
- Identification of the constraints

Scenario

❷ SOLUTION FINDING



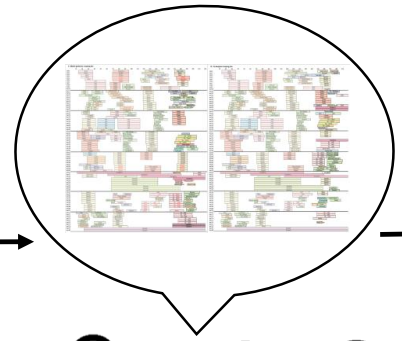
Using PYAGROPLAN to allocate crops to cultivation areas

If no solution

Modify the set of constraints

Cropping plan

❸ CO-ASSESSING SOLUTIONS



If unsatisfactory solution

Selected cropping plan

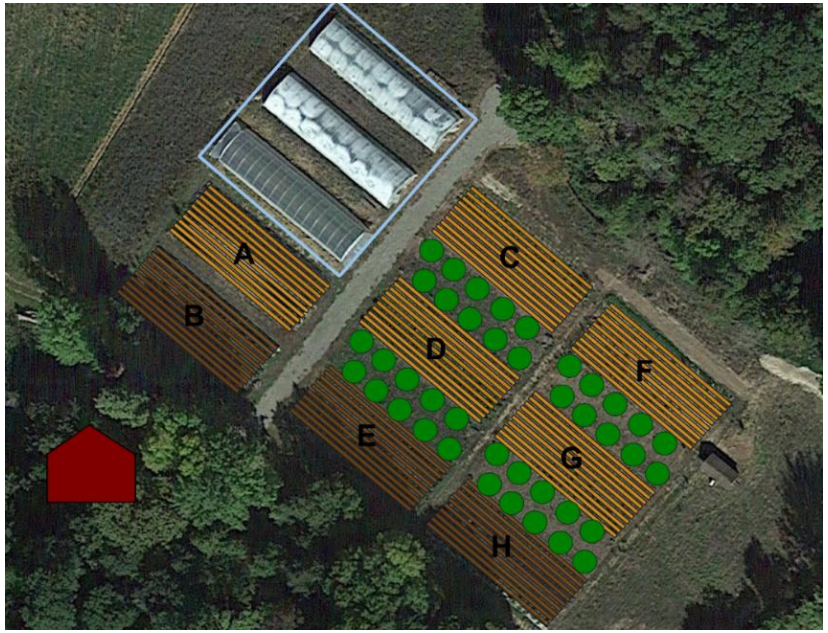
Flow of information between actions

Possible iteraction

Today's tutorial

Work on the crop allocation problem of a real case study of a microfarm located in south of France

Farm plan :



→ 80 vegetable beds

Cropping calendar :

crop_name	crop_type	starting_date	ending_date	quantity
Garlic	garlic	2025-W45	2026-W11	2
Eggplant	beetroot	2025-W17	2025-W38	1
Oc. - Beetroot	beetroot	2025-W30	2025-W49	1
Beetroot kohlrabi	beetroot	2025-W16	2025-W25	1
Beetroot kohlrabi	beetroot	2025-W31	2025-W42	1
Beetroot kohlrabi	beetroot	2025-W16	2025-W25	1
Broccoli	broccoli	2025-W30	2026-W2	1
Broccoli	broccoli	2025-W30	2025-W41	1
Broccoli	broccoli	2025-W30	2025-W43	1
Broccoli	broccoli	2025-W33	2025-W49	1
Oc. - Carrot	carrot	2025-W5	2025-W27	1
Oc. - Carrot	carrot	2025-W20	2025-W49	1
Oc. - Carrot	carrot	2025-W17	2025-W49	1
Oc. - Carrot	carrot	2025-W16	2025-W45	1
Oc. - Carrot	carrot	2025-W14	2025-W39	1
Cauliflower	cabbage	2025-W8	2025-W23	1
Cauliflower	cabbage	2025-W30	2026-W1	1
Cauliflower	cabbage	2025-W30	2025-W42	1
Cauliflower	cabbage	2025-W33	2025-W46	1
Kale	kale	2025-W27	2025-W51	1
Romanesco broccoli	cabbage	2025-W30	2025-W50	1
Red cabbage	cabbage	2025-W8	2025-W27	1
Red green cabbage	cabbage	2025-W30	2025-W47	2
Garlic chives	garlic	2025-W13	2025-W40	1
Squashs	squash	2025-W20	2025-W34	6
Squashs	squash	2025-W18	2025-W34	3

→ 85 crops

Farmers constraints :

6 operational constraints

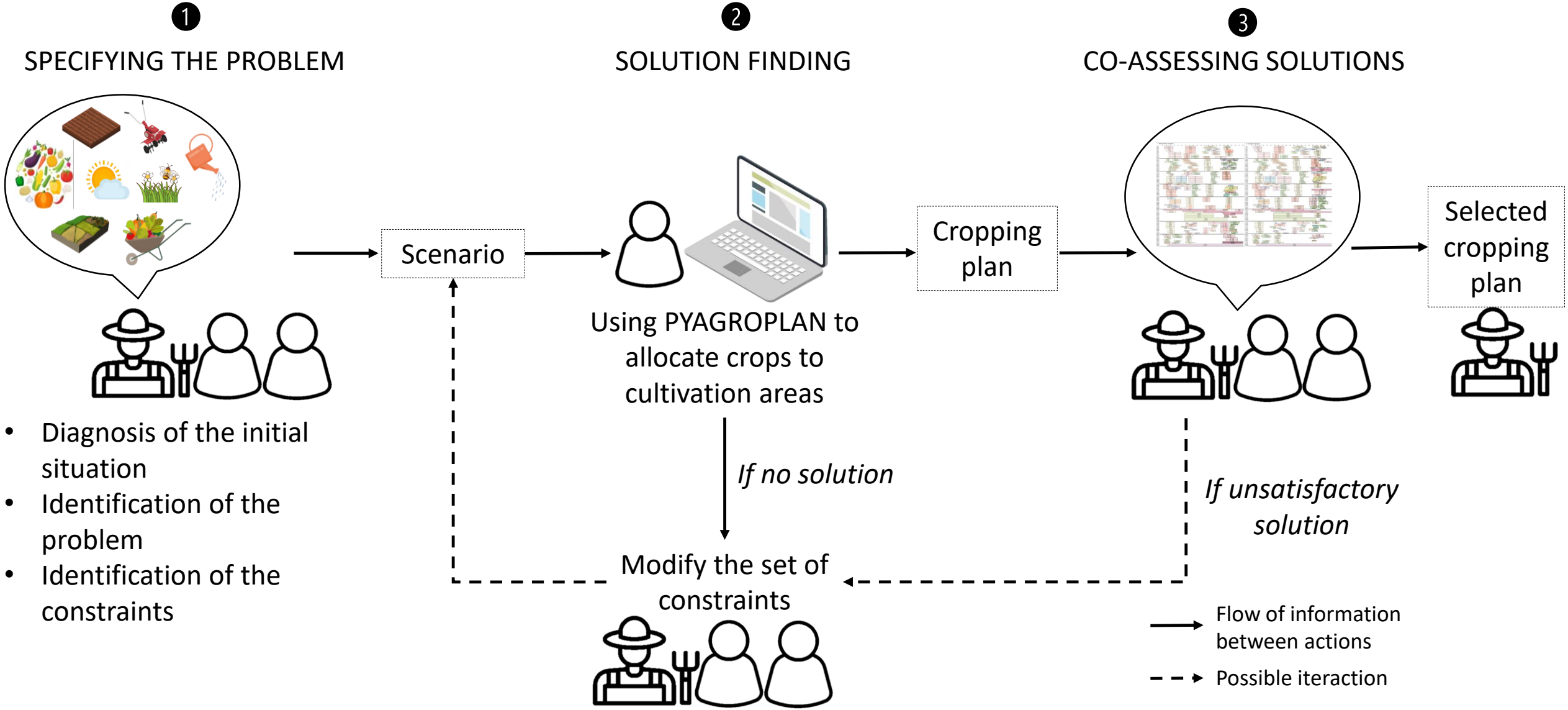
4 pedoclimatic constraints

7 agroecological constraints

Work on farmers cropping plan :

1. By hand
2. Using Pyagroplan model

Combining the model with a participatory design approach



Type of constraint	Initial constraints	Final constraints
Agroecological	Avoid allocating Cucurbitaceae crops on adjacent beds to reduce disease transmission.	Avoid allocating cucumber and courgettes on adjacent beds to reduce disease transmission.
	Maximize the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al.,	Maximyze the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al., 2014)
	Respect the return delays recommended in Produire des légumes biologiques (ITAB, 2015).	Respect return delays recommended in Produire des légumes biologiques (ITAB, 2015) and reduced by
	Forbid allocating weed-prone crops ( ) before crops highly sensitive to weedy soils ( ) on the same bed if the time interval between the two is less than 6 weeks.	Forbid allocating weed-prone crops before crops highly sensitive to weedy soils if the interval between the two is less than 6 weeks as it would otherwise require soil occultation between the two for at least six weeks to kill weeds.
	Maximize crops that have suppresive effect on weeds before crops highly sensitive to weedy soils.	Maximyze crops that have suppressive effect on weeds before crops highly sensitive to weedy soils if the time interval between the two is less than 4 weeks.
	Forbid two crops of the same family to follow each other directly on the same bed if the time interval between the two is less than 6 months.	X
	Maximizes the number of Fabaceae before crops with low nitrogen requirements	Maximizes the number of Fabaceae before crops with low nitrogen requirements
Pedoclimatic	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - All crops grown partly in winter must not be allocated to shaded beds (except leeks) - Crops that require sunlight musn't be allocated to shaded beds - Crops that need shade in summer must not be allocated to beds that are in the sun in summer	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - Frost-sensitive crops should not be in shaded areas if they are grown at least partially from beginning of December and end of January. - No planting after October and before April in shaded area. - Crops requiring full sun should not be allocated to shaded beds. - Crops requiring shade in summer period should be allocated to shaded beds.
Operational	Keep crops that need sprinkling ( ) away from those that cannot tolerate it ( ).	Keep crops that need sprinkling (i.e. watering for three weeks after sowing) away from those that cannot tolerate it: - Crops requiring irrigation to be cut off 3 weeks before harvest: watermelon, melon, onion, squash, garlic, shallot. - Crops prone to diseases when exposed to sprinklers (throughout their cycle): courgette, tomatoes,
	Maximize proximity between crops that need sprinkling	Maximize proximity between crops that need sprinkling
	Group same crops grown during the same period at the field	To reduce movement and share equipment efficiently, group the following identical crops together: squash, melon, onion, watermelon, leek, potato, strawberry, cabbage.
	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.
	Short-cycle crops and solanaceous plants must not be allocated to gardens F, G and H, as they need to be monitored (e.g. for disease), which means they need to be in gardens bordering the central	X
	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - Bulky crops	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - musquee and courgettes - Bulky crops - kale
		Avoid placing creeping crops next to non-creeping crops if the latter remains in place beyond eight weeks of the creeping crop's growth.

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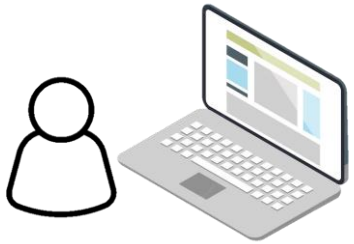

Using PYAGROPLAN to allocate crops to cultivation areas

If no solution

Modify the set of constraints

Flow of information between actions

Possible iteraction

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Pedoclimatic	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - All crops grown partly in winter must not be allocated to shaded beds (except leeks) - Crops that require sunlight musn't be allocated to shaded beds - Crops that need shade in summer must not be allocated to beds that are in the sun in summer	Shade constraints: The forest shades 10 beds in week 12 to week 45). Fruit trees are too young t - Frost-sensitive crops should not be in shaded a December and end of January. - No planting after October and before April in shaded area. - Crops requiring full sun should not be allocated to shaded beds. - Crops requiring shade in summer period should be allocated to shaded beds.
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➢Removing constraints

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	Certain crops must be allocated to garden border beds: - Heavy vegetables (KG) - Bulky crops	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - musquee and courgettes - Bulky crops - kale
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- Removing constraints
- Reducing constraints

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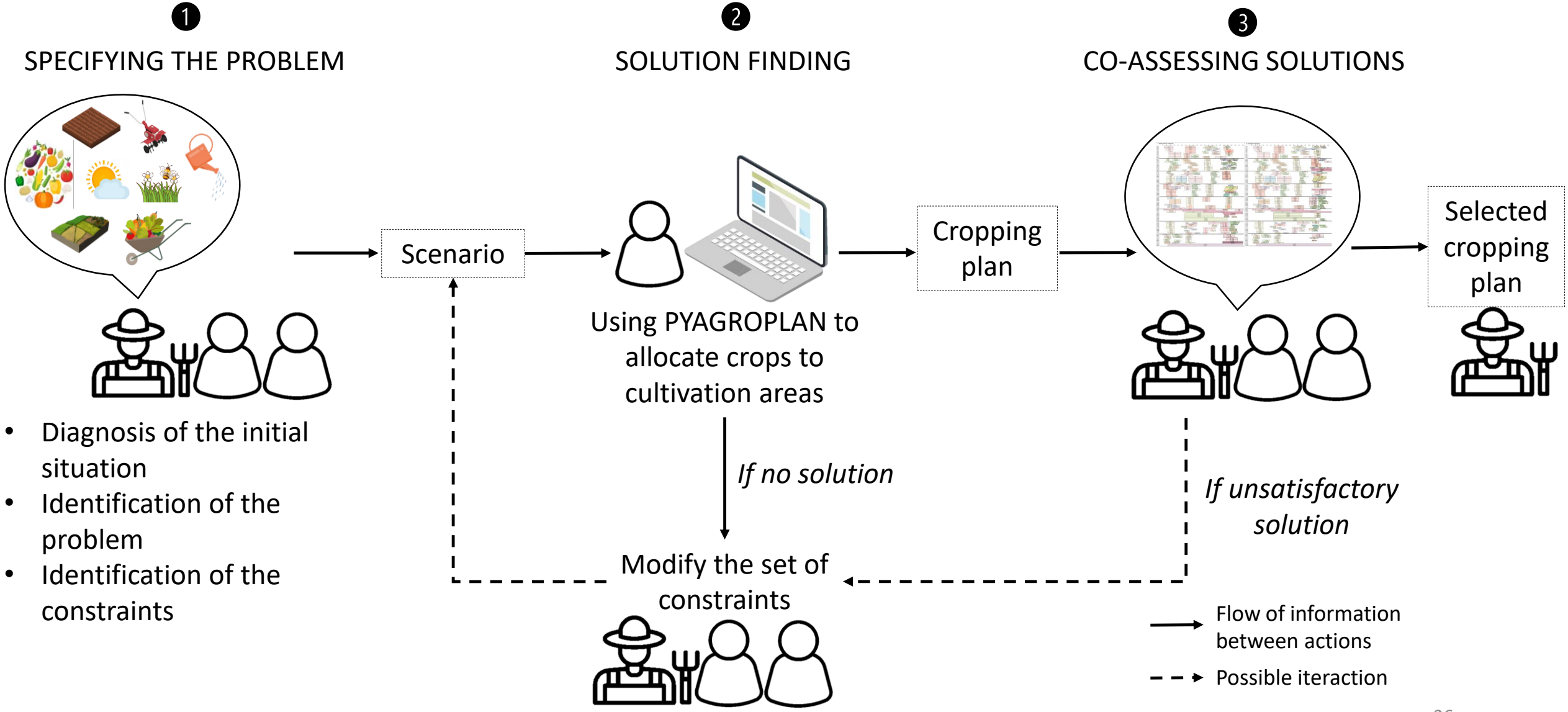
	Maximize the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al.,	Maximyze the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al., 2014)
	Respect the return delays recommended in Produire des légumes biologiques (ITAB, 2015).	Respect return delays recommended in Produire des légumes biologiques (ITAB, 2015) and reduced by
	Forbid allocating weed-prone crops ( ) before crops highly sensitive to weedy soils ( ) on the same bed if the time interval between the two is less than 6 weeks.	Forbid allocating weed-prone crops before crops highly sensitive to weedy soils if the interval between the two is less than 6 weeks as it would otherwise require soil occultation between the two for at least six weeks to kill weeds.
	Maximize crops that have suppresive effect on weeds before crops highly sensitive to weedy soils.	Maximyze crops that have suppressive effect on w… interval between the two is less than 4 weeks.
	Forbid two crops of the same family to follow each other directly on the same bed if the time interval between the two is less than 6 months.	X
	Maximizes the number of Fabaceae before crops with low nitrogen requirements	Maximizes the number of Fabaceae before crops …
Pedoclimatic	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - All crops grown partly in winter must not be allocated to shaded beds (except leeks) - Crops that require sunlight musn't be allocated to shaded beds - Crops that need shade in summer must not be allocated to beds that are in the sun in summer	Shade constraints: The forest shades 10 beds in … week 12 to week 45). Fruit trees are too young t… - Frost-sensitive crops should not be in shaded a… December and end of January. - No planting after October and before April in shaded area. - Crops requiring full sun should not be allocated to shaded beds. - Crops requiring shade in summer period should be allocated to shaded beds.
Operational	Keep crops that need sprinkling ( ) away from those that cannot tolerate it ( ).	Keep crops that need sprinkling (i.e. watering for three weeks after sowing) away from those that cannot tolerate it: - Crops requiring irrigation to be cut off 3 weeks before harvest: watermelon, melon, onion, squash, garlic, shallot. - Crops prone to diseases when exposed to sprinklers (throughout their cycle): courgette, tomatoes,
	Maximize proximity between crops that need sprinkling	Maximize proximity between crops that need sprinkling
	Group same crops grown during the same period at the field	To reduce movement and share equipment efficiently, group the following identical crops together: squash, melon, onion, watermelon, leek, potato, strawberry, cabbage.
	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.
	Short-cycle crops and solanaceous plants must not be allocated to gardens F, G and H, as they need to be monitored (e.g. for disease), which means they need to be in gardens bordering the central	X
	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - Bulky crops	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - musquee and courgettes - Bulky crops - kale
		Avoid placing creeping crops next to non-creeping crops if the latter remains in place beyond eight weeks of the creeping crop's growth.

- Removing constraints
- Reducing constraints
- Reformulating, refining constraints

Combining the model with a participatory design approach



- Diagnosis of the initial situation
- Identification of the problem
- Identification of the constraints

Type of constraint	Initial constraints	Final constraints
Agroecological	Avoid allocating Cucurbitaceae crops on adjacent beds to reduce disease transmission.	Avoid allocating cucumber and courgettes on adjacent beds to reduce disease transmission.
	Maximize the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al.,	Maximyze the adjacency between: - Carrots and onions for repulsive effects on carrot fly on carrots and Thrips tabaci on onions (Uvah and Coaker, 1984) - Basil and tomatoes for attracting pollinators and confusing tomato crop specific pests (Corbu et al., 2014)
	Respect the return delays recommended in Produire des légumes biologiques (ITAB, 2015).	Respect return delays recommended in Produire des légumes biologiques (ITAB, 2015) and reduced by
	Forbid allocating weed-prone crops ( ) before crops highly sensitive to weedy soils ( ) on the same bed if the time interval between the two is less than 6 weeks.	Forbid allocating weed-prone crops before crops highly sensitive to weedy soils if the interval between the two is less than 6 weeks as it would otherwise require soil occultation between the two for at least six weeks to kill weeds.
	Maximize crops that have suppresive effect on weeds before crops highly sensitive to weedy soils.	Maximyze crops that have suppressive effect on weeds before crops highly sensitive to weedy soils if the time interval between the two is less than 4 weeks.
	Forbid two crops of the same family to follow each other directly on the same bed if the time interval between the two is less than 6 months.	X
	Maximizes the number of Fabaceae before crops with low nitrogen requirements	Maximizes the number of Fabaceae before crops with low nitrogen requirements
Pedoclimatic	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - All crops grown partly in winter must not be allocated to shaded beds (except leeks) - Crops that require sunlight musn't be allocated to shaded beds - Crops that need shade in summer must not be allocated to beds that are in the sun in summer	Shade constraints: The forest shades 10 beds in winter (from week 45 to week 12) and 5 in summer (from week 12 to week 45). Fruit trees are too young to generate shade. - Frost-sensitive crops should not be in shaded areas if they are grown at least partially from beginning of December and end of January. - No planting after October and before April in shaded area. - Crops requiring full sun should not be allocated to shaded beds. - Crops requiring shade in summer period should be allocated to shaded beds.
Operational	Keep crops that need sprinkling ( ) away from those that cannot tolerat	Keep crops that need sprinkling (i.e. watering for three weeks after sowing) away from those that cannot tolerate it: o be cut off 3 weeks before harvest: watermelon, melon, onion, squash, garlic, hen exposed to sprinklers (throughout their cycle): courgette, tomatoes,
	Maximize proximity between crops that need sprinkling	n crops that need sprinkling
	Group same crops grown during the same period at the field	hare equipment efficiently, group the following identical crops together: squash, melon, onion, watermelon, leek, potato, strawberry, cabbage.
	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.	Short-cycle crops must not be allocated to gardens F, G and H as they have high care requirements and need to be located close to the heart of the farm to reduce travel.
	Short-cycle crops and solanaceous plants must not be allocated to gardens F, G and H, as they need to be monitored (e.g. for disease), which means they need to be in gardens bordering the central	X
	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - Bulky crops	Certain crops must be allocated to garden border beds: - Heavy vegetables ( ) - musquee and courgettes - Bulky crops - kale
		Avoid placing creeping crops next to non-creeping crops if the latter remains in place beyond eight weeks of the creeping crop's growth.

➢ Adding new constraints