

AI applications in agriculture

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Agriculture



Benefits of agriculture

- **Food** being produced in **appreciable abundance**
- Farming creates **opportunities to lift people out of poverty** in developing nations
- Over 60 percent of the world's working poor works in agriculture
- **Farming creates more jobs:**
 - farmers, farm equipment makers, food processing plants, transportation, infrastructure and manufacturing
- Agriculture – a **scientific area**
- Farmers more **educated**
- Agriculture - **modernized**



Threats



- Human population approaches 10 billion people by 2050
- Modern agriculture's huge reliance upon a few crops
- Climate change
- Huge environmental and health pressure (biodiversity loss, water pollution, pesticides, ...)

Modernization of agriculture

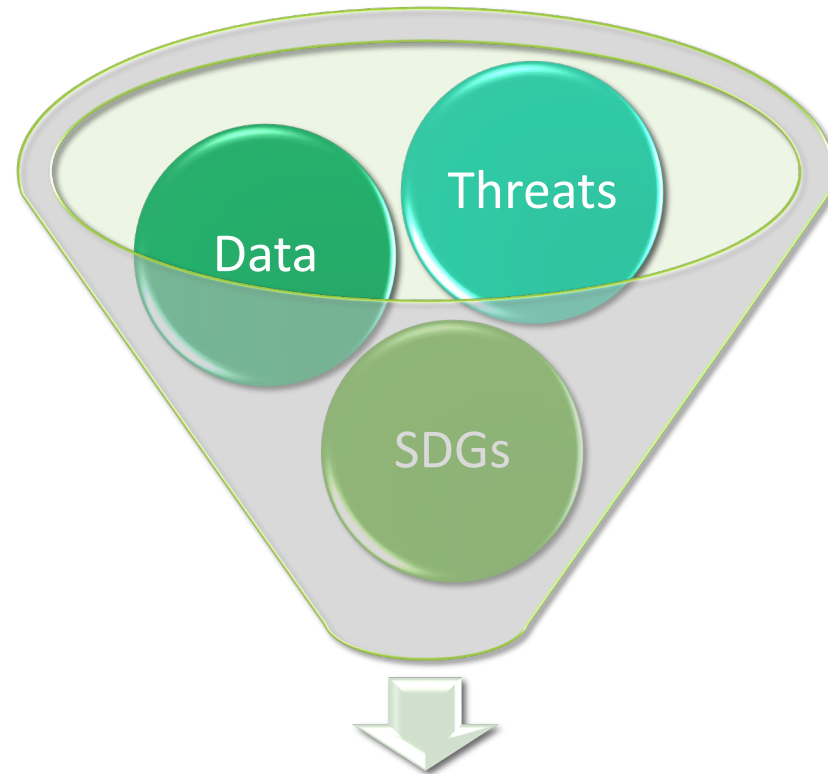
- Transforming agriculture from **traditional labour-based** to **technology-based agriculture**
- New technologies (precision farming, drones, robots) for
 - combatting disease and pests
 - monitoring nutrient levels
 - monitor soil and growing conditions
 - ...



- **Huge amounts of structured or unstructured data produced daily!**

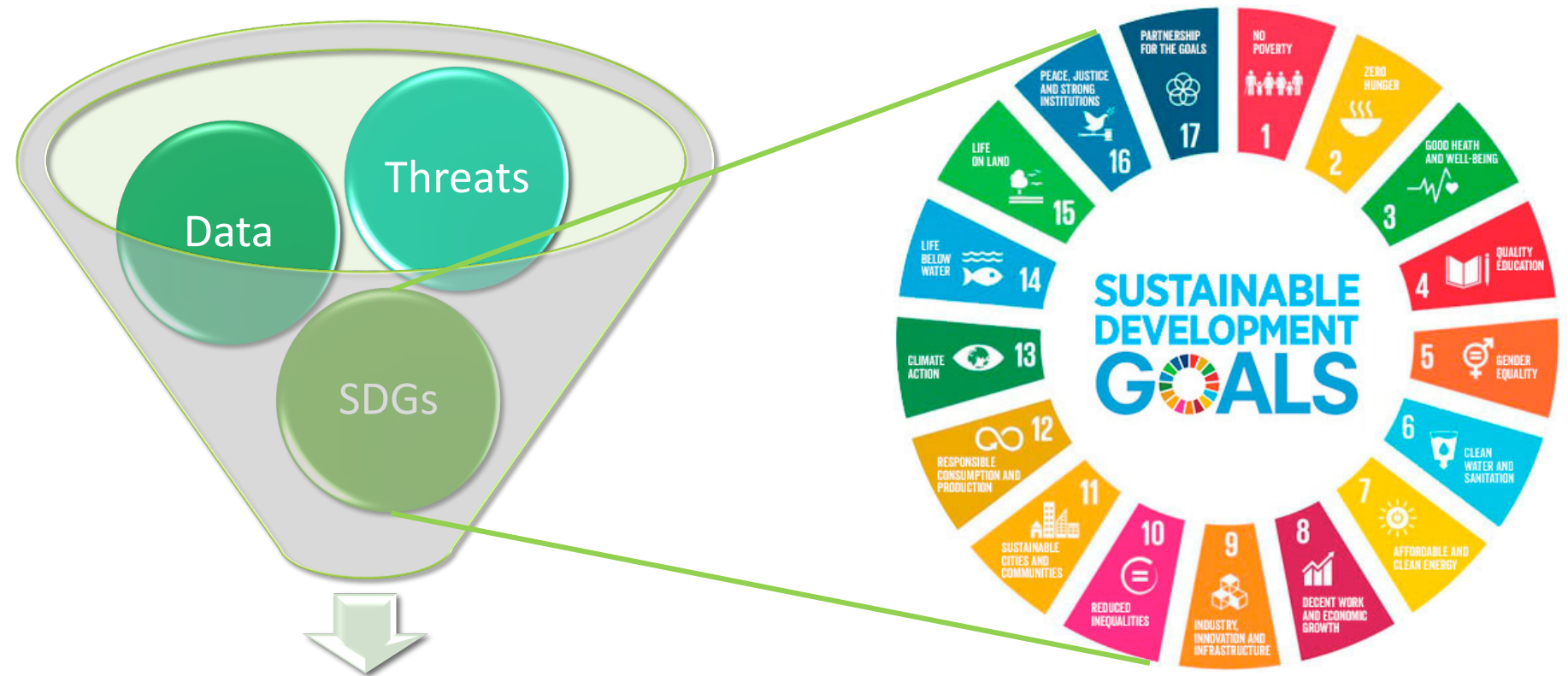


Challenges



AI in agriculture

Challenges



AI in agriculture

AI in agriculture

- Most popular applications of AI in agriculture fall into three major categories:
 - **Agricultural robots** – autonomous robots to handle essential agricultural tasks at a higher volume and faster pace than human laborers
 - **Crop and soil monitoring** – computer vision and deep learning algorithms to process data captured from drones and/or software-based technology to monitor crop and soil health
 - **Predictive analytics** – machine learning models developed to track and predict various variables/aspects in agriculture

AI applications in agriculture at JSI

- More than 15 years of work in this area
- Different areas of agriculture:
 - **Co-existence of GM and conventional crops**
 - **Water pollution** with plant protection products
 - **Biological pest control**
 - Soil preservation and **assessment of soil functions**
 - **Tomato resilience** and resource use efficiency
 - **Sustainability** of legume agri-food chains
 - **Integrated pest management**

Co-existence of GM and conventional crops

- Analysis of results of **large-scale** and **individual-based simulation models**

- Crops: **oilseed rape** and **maize**
- Simulation models: GENESYS, MAPOD, IBM-OSR

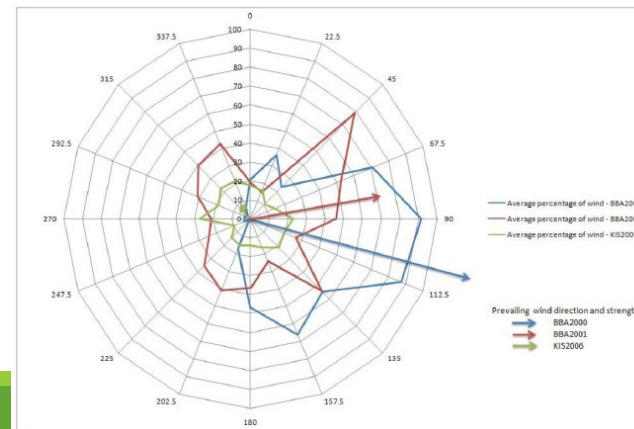
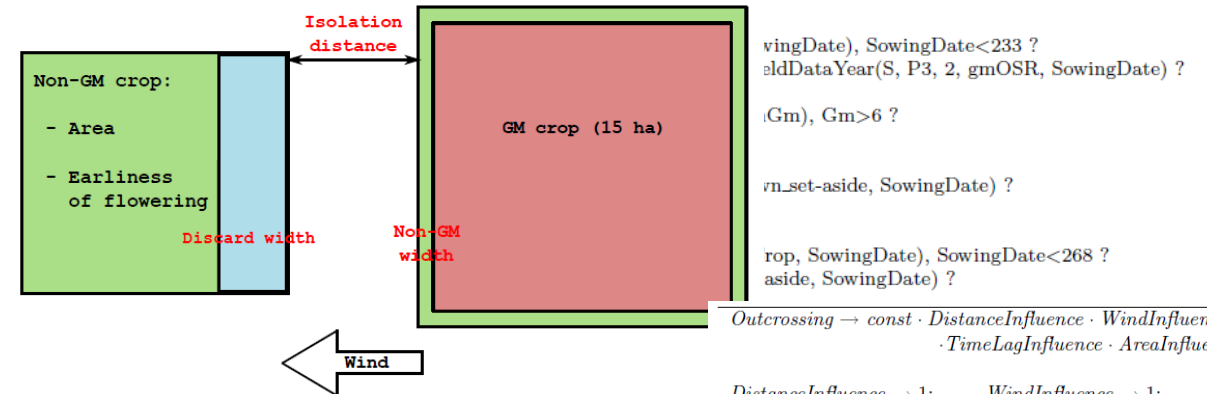
- Problem:

- Co-existence** issue
- Influence on **natural habitats**
- Consequences on **human health**
- 0.9% of GM material** in conventional harvest

- Machine learning analysis:**

- Relational decision trees
- Equation discovery
- Process-based modelling

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contamination(-A)
targetField(S, B),fieldDataYear(S, B, 0, Crop, SowingDate), SowingDate<252 ?
+ yes: fieldDataYear(S, B, 1, non-GmOSR, SowingDate) ?
+ yes: fieldDataYear(S, B, 1, Crop, SowingDate), SowingDate<233 ?
+ yes: [pos]
+ no: fieldDataYear(S, B, 1, Crop, SowingDate), SowingDate<252 ?
+ yes: [pos]
+ no: [neg]
+ no: neighbor(S, B, B2, edge), fieldDataYear(S, B2, 1, gmOSR, SowingDate) ?
+ yes: fieldDataYear(S, B, 0, Crop, SowingDate), SowingDate<233 ?
+ yes: [pos]
+ no: neighbor(S, B2, B3, corner) ?
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$$\text{Outcrossing} \rightarrow \text{const} \cdot \text{DistanceInfluence} \cdot \text{WindInfluence} \cdot \text{TimeLagInfluence} \cdot \text{AreaInfluence};$$

$$\text{DistanceInfluence} \rightarrow 1; \quad \text{WindInfluence} \rightarrow 1;$$

$$\text{DistanceInfluence} \rightarrow D; \quad \text{WindInfluence} \rightarrow W;$$

$$D \rightarrow e^{-\text{Dist}}; \quad W \rightarrow \text{const} + \text{const} \cdot P\text{Wind};$$

$$D \rightarrow \frac{1}{\text{Dist}}; \quad P\text{Wind} \rightarrow \text{variable_wind};$$

$$D \rightarrow \frac{1}{\text{Dist}^2}; \quad D \rightarrow \text{Dist}^{-\text{const}};$$

$$\text{Dist} \rightarrow \text{variable_distance};$$

$$\text{TimeLagInfluence} \rightarrow 1; \quad \text{AreaInfluence} \rightarrow 1;$$

$$\text{TimeLagInfluence} \rightarrow T; \quad \text{AreaInfluence} \rightarrow A;$$

$$T \rightarrow e^{-\text{TLag}}; \quad A \rightarrow \frac{1}{\text{const} \cdot \text{Area} + 1};$$

$$T \rightarrow \frac{1}{\text{TLag}}; \quad A \rightarrow \frac{\text{const}}{\text{Area} \cdot \sqrt{1 + (\frac{\text{const}}{\text{Area}})^2}};$$

$$T \rightarrow \frac{1}{\text{TLag}^2}; \quad A \rightarrow \frac{1}{\text{const} \cdot \text{Area}^2 + 1};$$

$$T \rightarrow \text{TLag}^{-\text{const}}; \quad A \rightarrow 1 - e^{-\frac{\text{const}}{\text{Area}}};$$

$$\text{TLag} \rightarrow \text{variable_timeLag}; \quad \text{Area} \rightarrow \text{variable_nonGMarea};$$

Water pollution with plant-protection products

Crop production without environment pollution

Water pollution with plant-protection products

Crop production without environment pollution

PESTICIDES
APPLICATION

Water pollution with plant-protection products

Crop production without environment pollution

Directives

- European water framework directive
- Directive on the sustainable use of plant protection products

Application instructions
of pesticide producers

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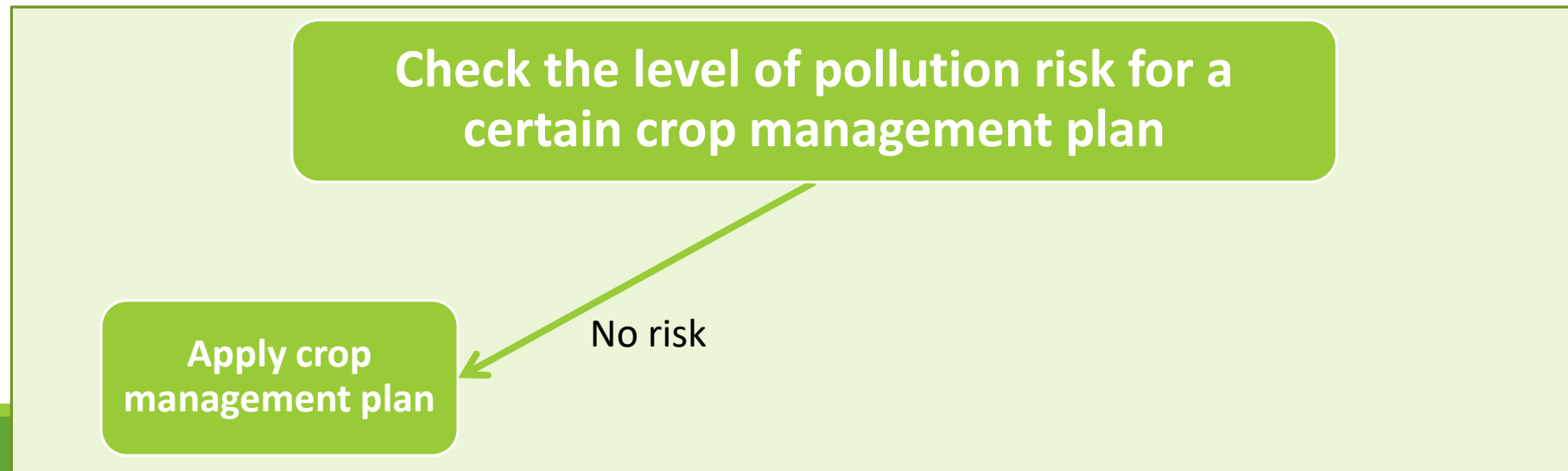
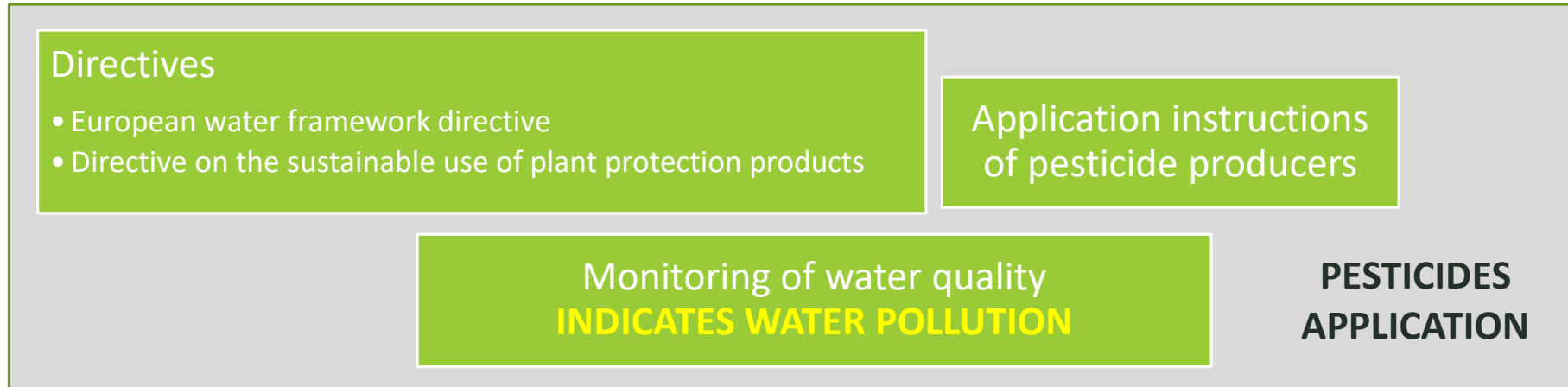
Monitoring of water quality
INDICATES WATER POLLUTION

**PESTICIDES
APPLICATION**

**Check the level of pollution risk for a
certain crop management plan**

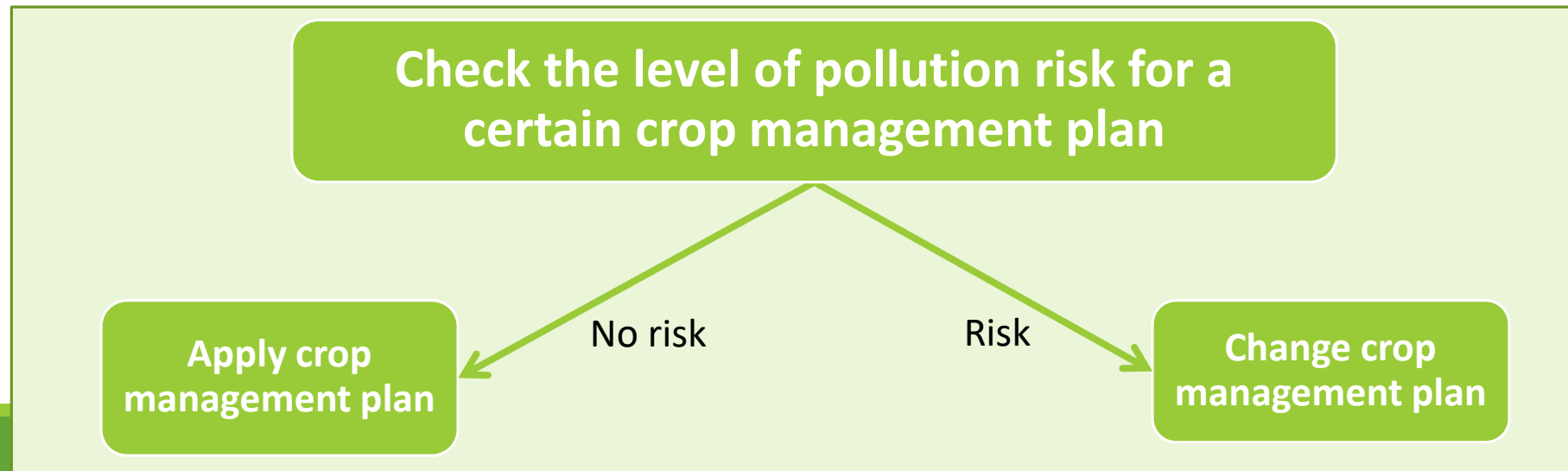
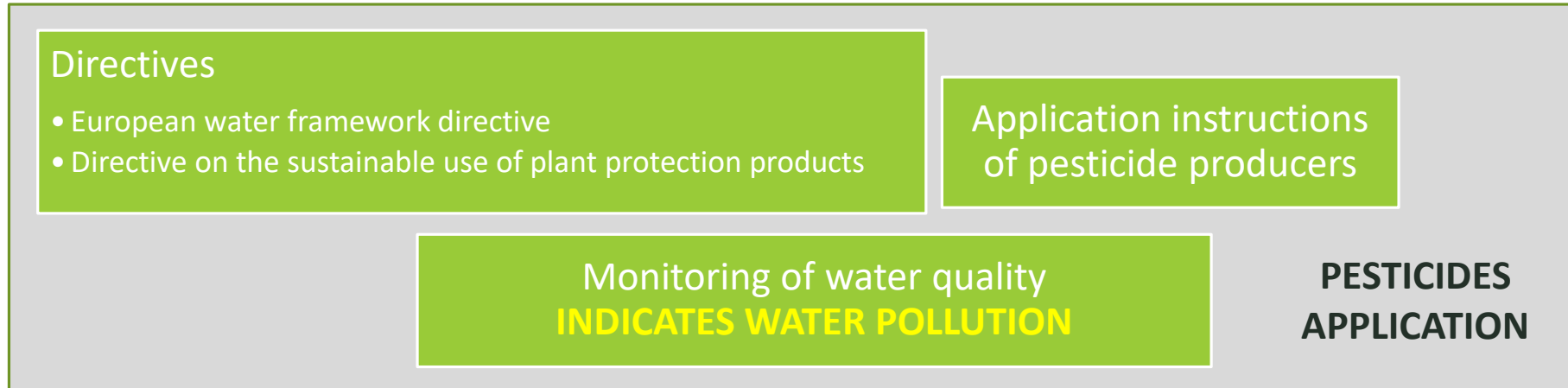
Water pollution with plant-protection products

Crop production without environment pollution

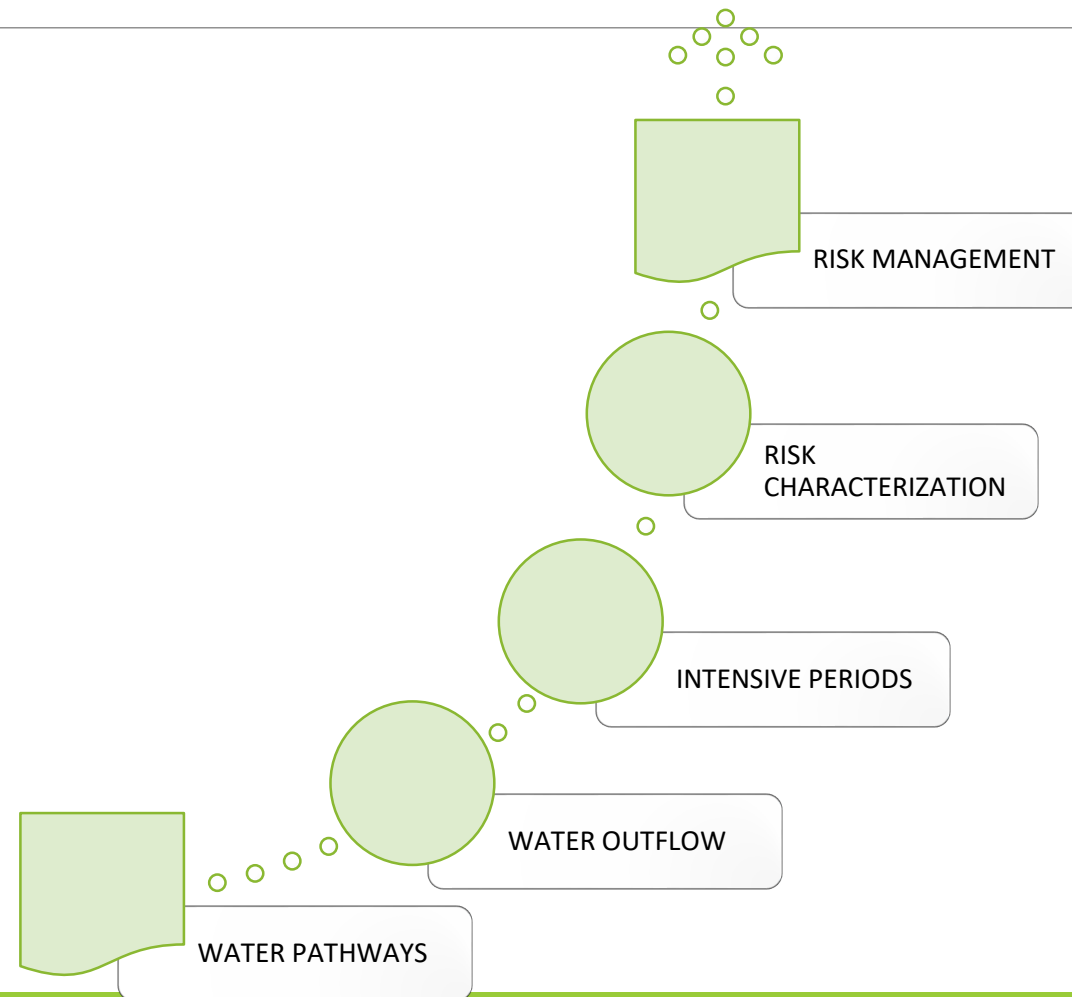


Water pollution with plant-protection products

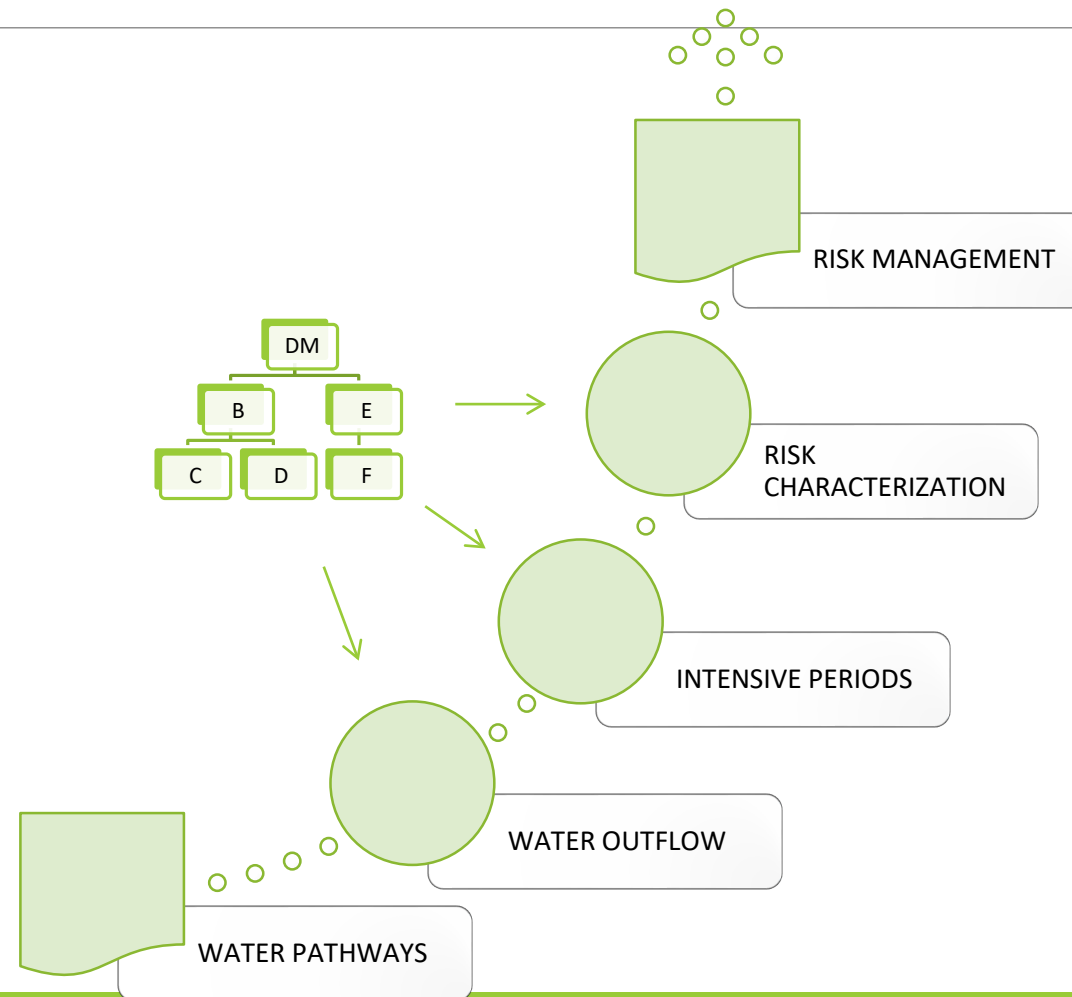
Crop production without environment pollution



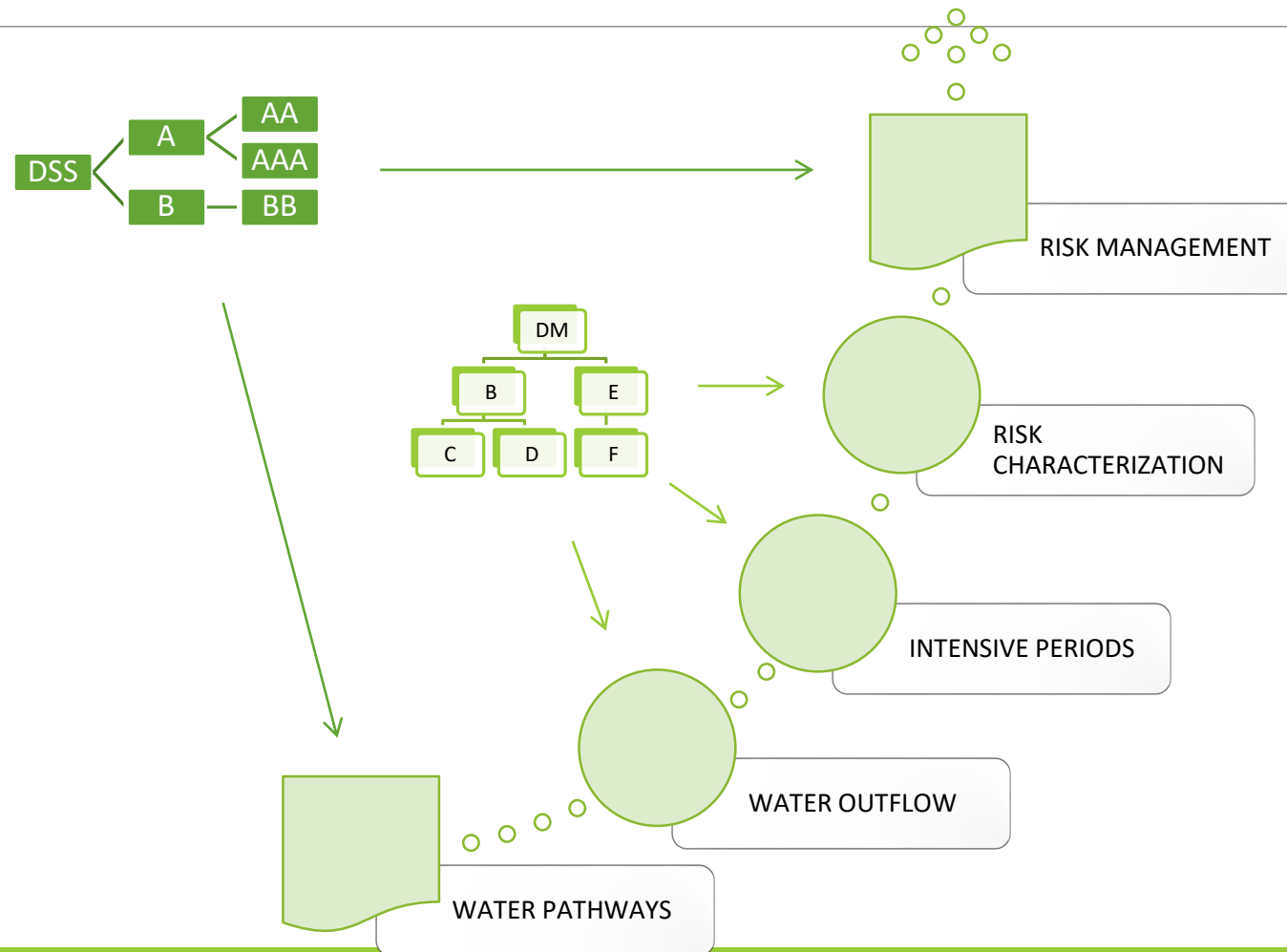
Water pollution with plant-protection products



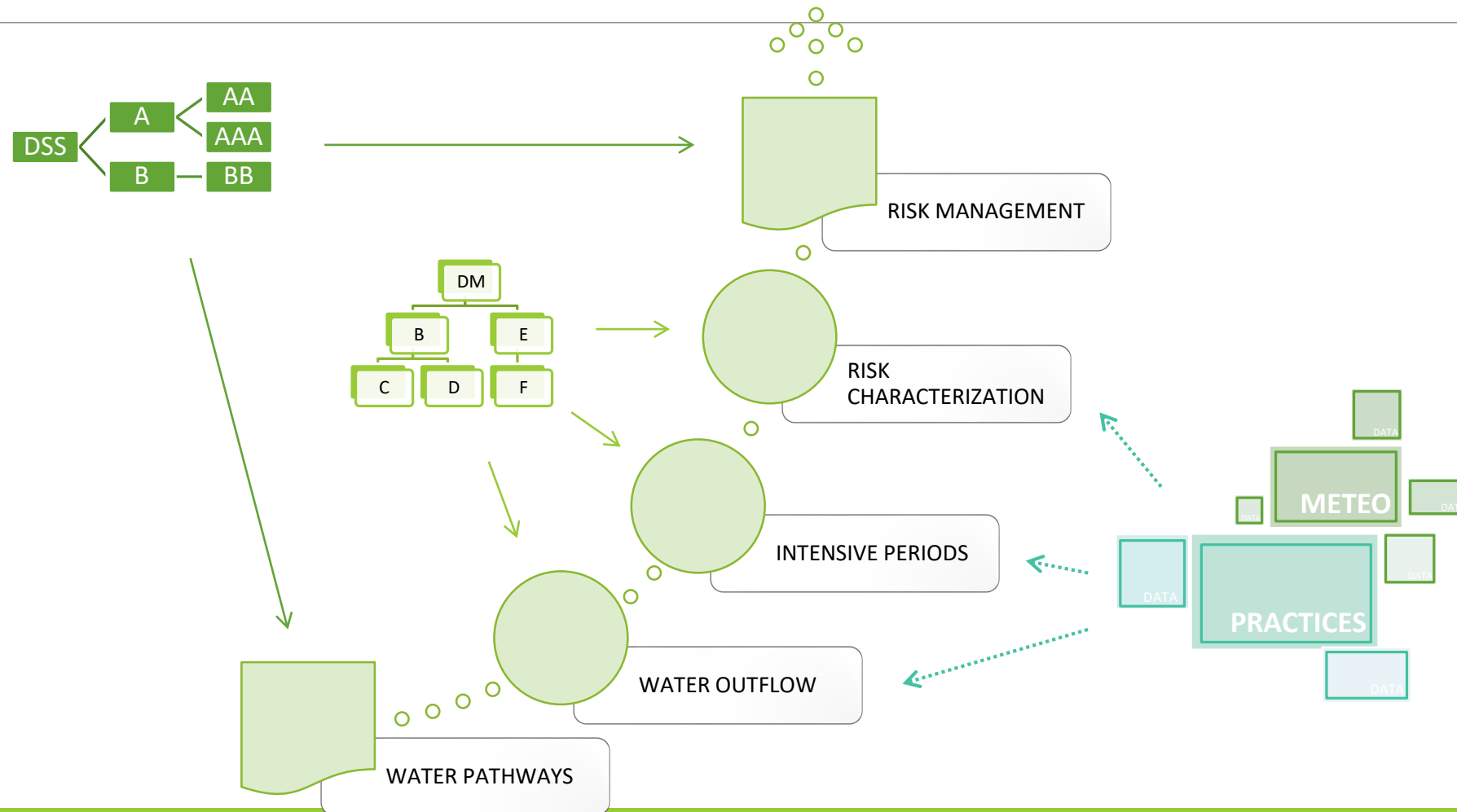
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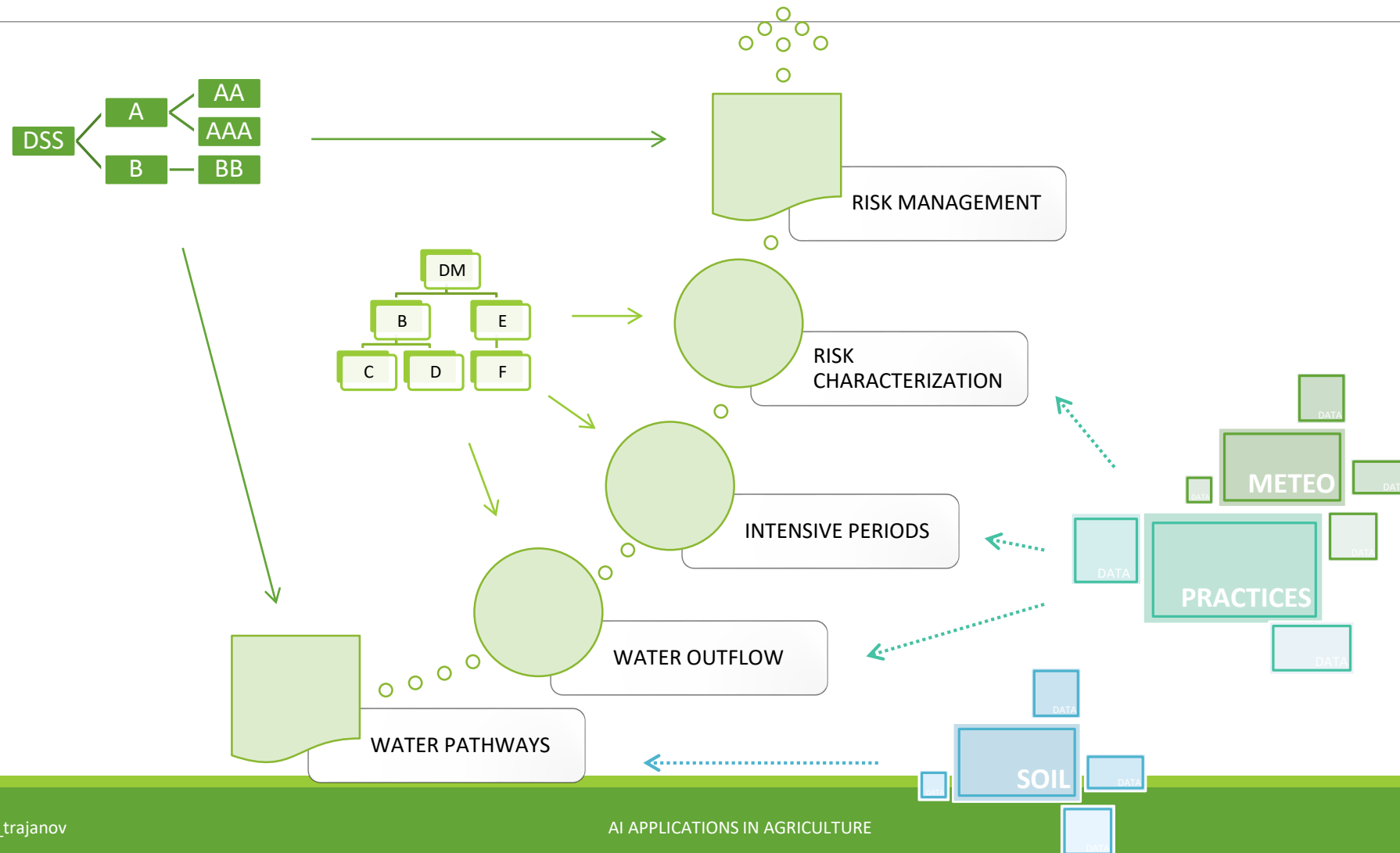
Water pollution with plant-protection products



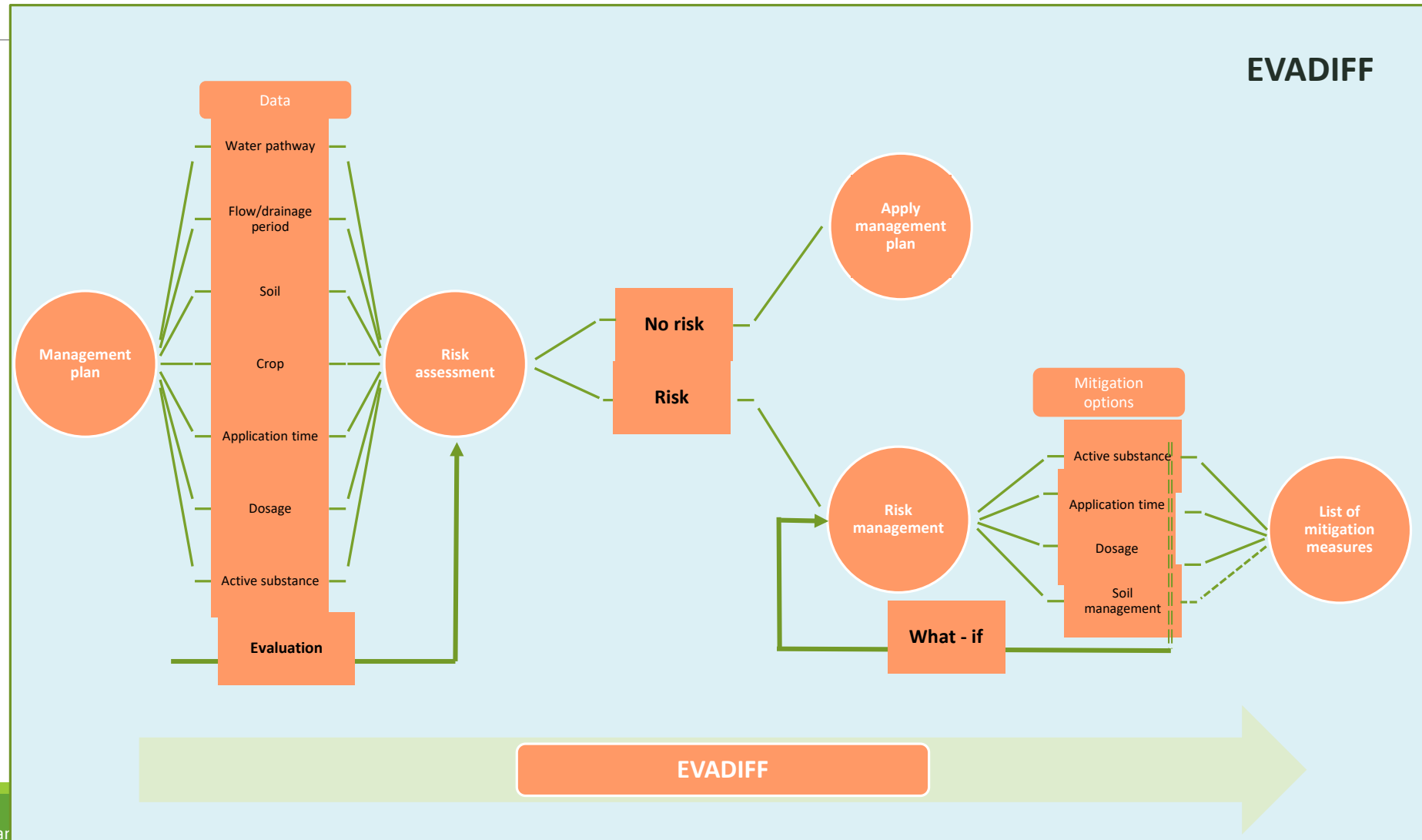
Water pollution with plant-protection products



Water pollution with plant-protection products



Water pollution with plant-protection products



Biological pest control

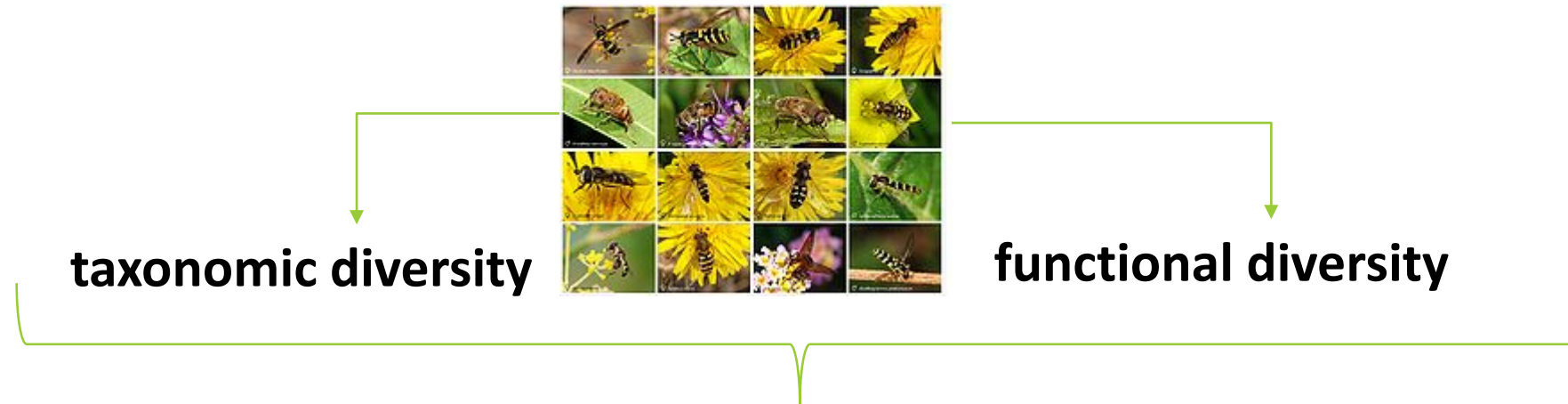
- **Understanding and management of biodiversity** of agricultural ecosystems (natural enemies of pests)
- **Reduce pressure of agriculture** on the environment
 - Smaller amounts of plant protection products used
 - Enhanced biological pest control
- **Research goals:**
 - **Effects of agricultural management, cropping systems, landscape and climate on natural enemies populations (abundance and diversity)**
 - **Effect of natural enemies on pests** (aphids, slugs) populations
 - Case study: Boigneville, Erceville, Maise, Picardie (France)
 - Natural enemies: **syrphids, carabids**



Biological pest control

The potential of Syrphids and Carabids for biological pest control

Syrphidae (hoverflies) and Carabidae



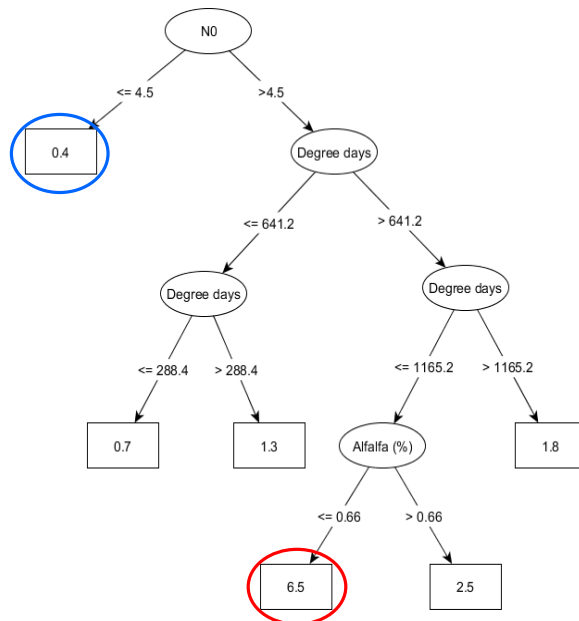
Modelling the size and structure of populations of syrphid and carabid species

Biological pest control

- Huge amount of **preprocessing** to harmonize datasets → very **complex dataset**
 - **Taxonomic, meteorological and landscape data**
 - **Diversity indexes** calculated
 - **Functional categories** defined

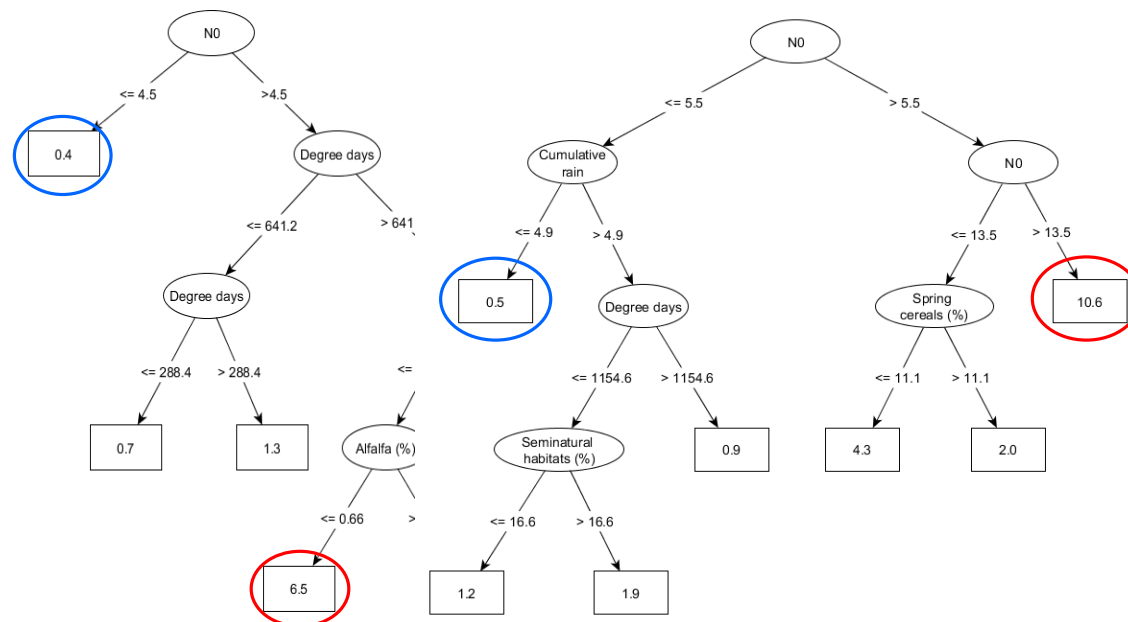
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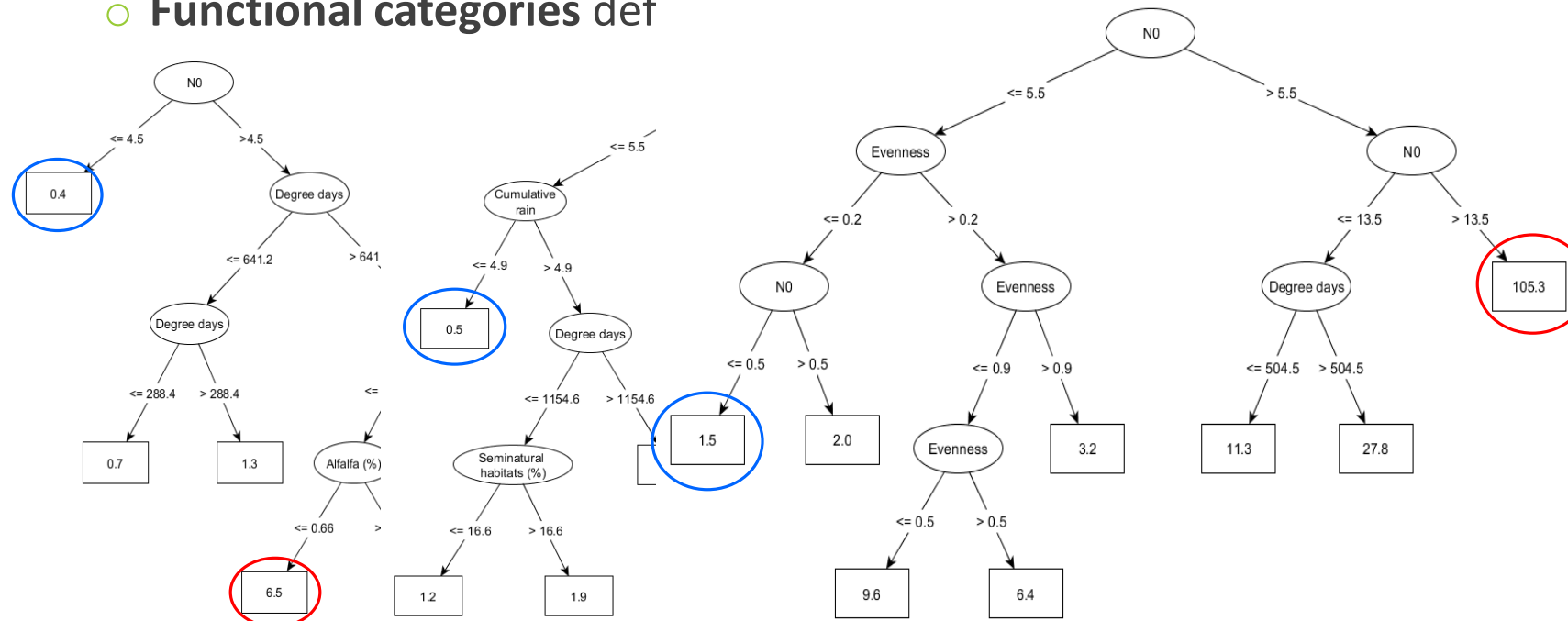
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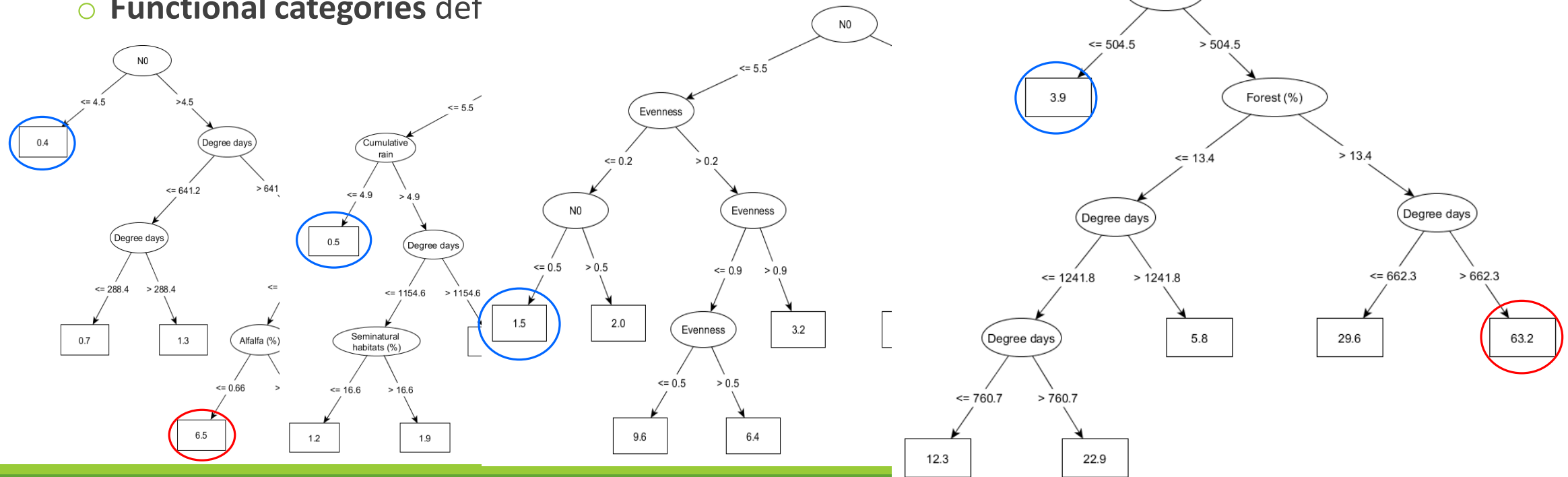
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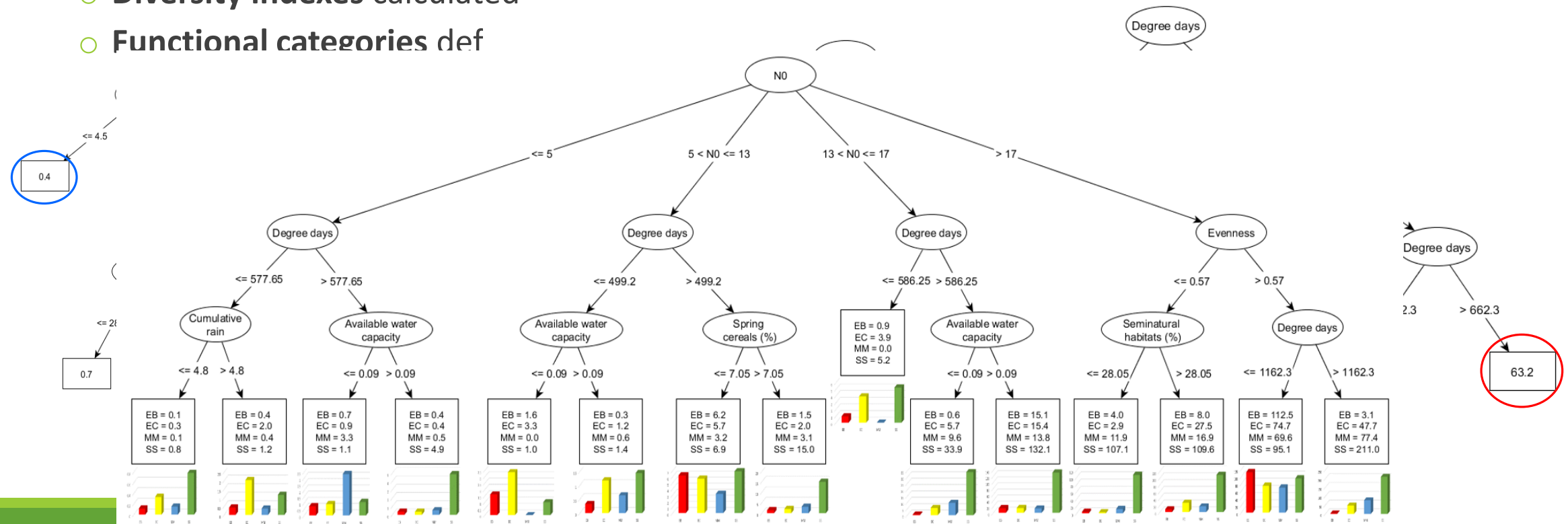
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Biological pest control

- Huge amount of preprocessing to harmonize datasets → very complex dataset
 - Taxonomic, meteorological and landscape data
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 - Functional categories def



Assessment of soil functions

- **5 soil functions**
- **Goal:** development of the **Soil Navigator DSS** that operates on field level
- Provides **advices** on the management of soils that **optimizes** the 5 soil functions

Water regulation & purification



Carbon sequestration



Biodiversity



Nutrient cycling



Primary production

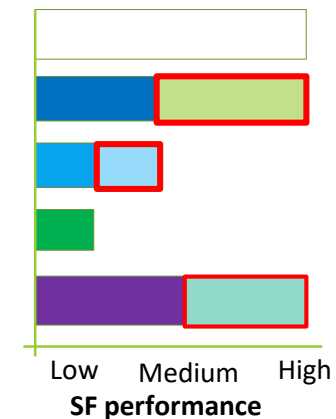
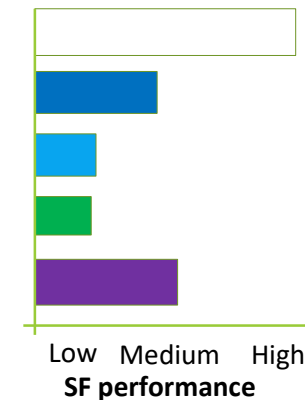
Assessment of soil functions

Assessing the performance of the five soil functions

- specific management practices
- environmental/climatic conditions
- soil characteristics

Choosing appropriate management practices that will improve the performance of the soil functions under:

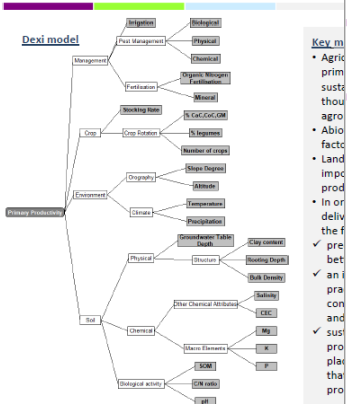
- climatic conditions
- soil characteristics
- management options



Assessment of soil functions

PRIMARY PRODUCTIVITY

The capacity of a soil to produce plant biomass for human food, feed, fibre and fuel within natural or managed boundaries.



Key messages:

- Agricultural primary productivity is affected by soil functions through agro-ecological processes.
- Abiotic factors (climate, soil) and biotic factors (crop, soil organisms) are important in the delivery of soil functions.
- The Dexi model can be used to assess the impact of management practices on soil functions and primary productivity.

Take-home messages:

- An ideal decision support model will enable farmers to optimize simultaneously accounting for management effects on other soil functions and the effects of other soil functions on primary productivity and vice versa to more holistically and sustainably manage their soils. When farmers will consider a range of factors including performance, compatibility with compliance demands before making a decision.

References:

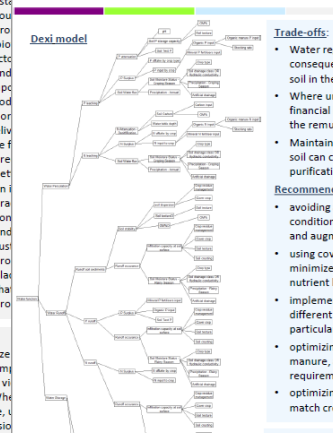
- Trajanov, A. et al. (2018). Using data mining techniques to model primary productivity from agricultural experiments in Austria. *Regional Environmental Change Journal*.
- Wiegand, M. et al. (2018). Key indicators and management strategies for primary productivity.
- Sanden T. et al. (2019). Development of an Agricultural Primary Productivity Decision Support Model. *Environmental Science*, 7, 58.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101019742.



WATER REGULATION and PURIFICATION

Capacity of a soil to receive, store and conduct water, prevent droughts, flooding, erosion and sedimentation of compounds.



Trade-offs:

- Water regulation and purification are affected by soil functions through agro-ecological processes.
- Where or when a soil function is performed affects the amount of GHG emissions from the soil (carbon dioxide, methane and nitrous oxide).
- Maintaining soil carbon stocks is important for soil purification.

Recommendations:

- avoiding soil compaction and soil acidification
- using cover crops to minimize nutrient loss
- implementing different management practices to optimize soil functions
- optimizing match between soil functions and management practices

Take-home messages:

- Considering soil functions and their trade-offs is important for agricultural decision support.
- Better use of soil functions can lead to improved soil health and increased agricultural productivity.

References:

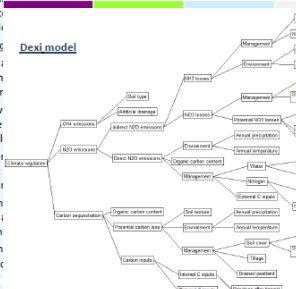
- Wall, D.P. et al. (2018). Key indicators and management strategies for Water Regulation and Purification. *LANDMARK Report 3.5*.
- Delgado A. et al. (submitted). Farming systems targeted to water regulation and purification. *LANDMARK Report 3.6*.

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CLIMATE REGULATION and CARBON SEQUESTRATION

Carbon sequestration is the capacity of a soil to store carbon in a stable form. Climate Regulation is the capacity of a soil to reduce the amount of GHG emissions from the soil (carbon dioxide, methane and nitrous oxide).



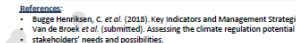
Take-home messages:

- The modelling approach couples a simplified representation of complex biogeochemical cycles of C and N in soils with the different aspects of the climate regulation potential of soils.
- To assess the effect of management practices on the climate regulation soil function of arable soils, we must look beyond carbon sequestration, and include trade-offs with N₂O and CH₄, which often dominate GHG emissions from arable soils enhancing climate change.

References:

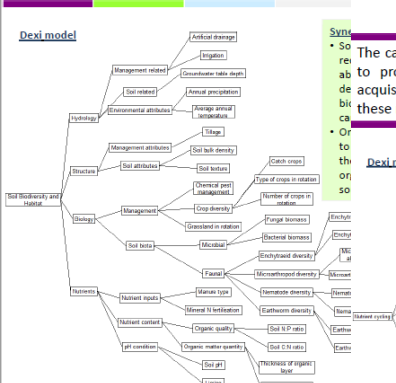
- Bugge Henriksen, C. et al. (2018). Key Indicators and Management Strategies for Climate Regulation and Carbon Sequestration. *LANDMARK Report 3.4*.
- Van de Broek et al. (submitted). Assessing the climate regulation potential of soils: a decision support model. *LANDMARK Report 3.5*.

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HABITAT FOR BIODIVERSITY

The multitude of soil organisms and processes, interacting in an ecosystem, providing society with a rich biodiversity service contributing to a habitat for above ground organisms.



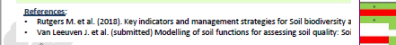
Take-home messages:

- Suggested management practices: integrate legumes, permanent cover crops in arable farming; recycle organic matter by incorporating crop residues; limit the use of pesticides; longer cycles and include as many different crops, where possible; include biological attributes in soil monitoring programs; include in the landscape as many as possible and viable non-productive areas.

References:

- Rutgers M. et al. (2018). Key indicators and management strategies for Soil Biodiversity and Habitat for Biodiversity. *LANDMARK Report 3.3*.
- Van Leeuwen J. et al. (submitted). Modelling of soil functions for assessing soil quality: Soil Biodiversity and Habitat for Biodiversity. *LANDMARK Report 3.4*.

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NUTRIENT CYCLING

The capacity of a soil to receive nutrients in the form of by-products, to provide nutrients from intrinsic resources or to support the acquisition of nutrients from air or water, and to effectively carry over these nutrients into harvested crops.

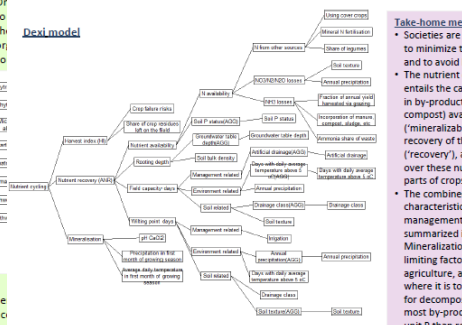


Table 1. Links (green = positive effect; red = negative effect; amber = variable effect) between threats of soil quality (climate change, management practices and soil functions) (P) (primary productivity), (W) (water regulation and purification), (C) (climate regulation and carbon sequestration), (B) (habitat for biodiversity), (N) (nutrient cycling), (H) (habitat for biodiversity).

Threats of soil functions	Management practices	Effects of practices on soil functions
Climate change	Soil structure	Soil water
Temperature	Plant Management	Soil water
Humidity	Fertilization	Soil water
Wind	Plant Management	Soil water
Soil structure	Plant Management	Soil water
Soil density	Fertilization	Soil water
Soil water	Plant Management	Soil water
Soil pH	Fertilization	Soil water
Soil C/N ratio	Plant Management	Soil water
Microbes	Fertilization	Soil water
Enzymes	Plant Management	Soil water
Plant roots	Fertilization	Soil water

References:

- Schröder, J.J. et al. (2016). The relative role of soil quality in nutrient cycling: a review. *Soil Use and Management*, 32, 476-486. doi:10.1111/sum.12282
- Schröder, J.J. et al. (2018). Key indicators and management strategies for nutrient cycling. *LANDMARK Report 3.5*.
- Trajanov, A. et al. (2019). Assessing the nutrient cycling potential in agricultural soils using decision modelling. *Proceedings Conference on Operational Research*, September 2019, Bled, Slovenia (<http://oar19.zrj.uni-lj.si/>) (in press).

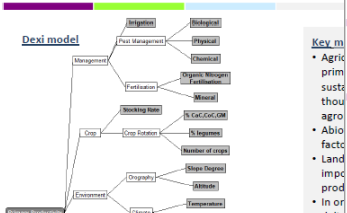
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Assessment of soil functions

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WATER REGULATION and PURIFICATION

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CLIMATE REGULATION and CARBON SEQUESTRATION

Carbon sequestration is the capacity of a soil to store carbon in a stable form. Climate Regulation is the capacity of a soil to reduce the amount of GHG emissions from the soil.

HABITAT FOR BIODIVERSITY

Soil function models	Total number of attributes	Number of aggregated attributes	Number of input attributes	Number of hierarchical levels	Number of integration rules
Primary productivity	42	16	25	4	294
Nutrient cycling	51	27	24	5	302
Climate regulation	540	21	19	5	301
Water regulation and purification	116	77	39	6	800
Biodiversity and habitat	55	24	31	5	612



sequestration, and include trade-offs with N₂O and CH₄, which often dominate GHG emissions from arable soils enhancing climate change.

- References:**
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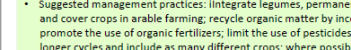
- References:**
- Ruijs M. et al. (2018). Key indicators and management strategies for soil biodiversity and management.
 - Van Leeuwen J. et al. (submitted). Modelling of soil functions for assessing soil quality: Soil Quality Decision Support System (SQDSS).



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- Take-home messages**
- Suggested management practices: integrate legumes, permanent cover crops in arable farming; recycle organic matter by incorporating crop residues; limit the use of pesticides; longer cycles and include as many different crops; where possible include biological attributes in soil monitoring programs;
 - Include in the landscape as many as possible and viable non-pro



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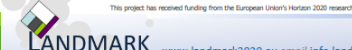
- Table 1.** Links (green = positive effect, red = negative effect, amber = variable effect) between threats of soil quality (erosion, compaction, salinization, acidification, nutrient depletion, loss of organic matter, loss of biodiversity, etc.) and soil functions (primary productivity, water regulation, climate regulation, etc.).

Threats of soil quality	Primary productivity	Water regulation	Climate regulation	Habitat for biodiversity
Erosion	Red	Green	Green	Green
Compaction	Red	Red	Red	Red
Salinization	Red	Red	Red	Red
Acidification	Red	Red	Red	Red
Nutrient depletion	Red	Red	Red	Red
Loss of organic matter	Red	Red	Red	Red
Loss of biodiversity	Red	Red	Red	Red



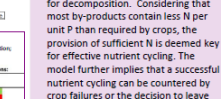
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- References:**
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 - Schroder, J.J. et al. (2018). Key indicators and management strategies for nutrient cycling. *LANDMARK Report 3.5*.
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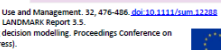
characteristics, climate and management on nutrient cycling are summarized in a Dexi model. Mineralization is not seen as the major limiting factor for nutrient cycling in agriculture, apart from rare situations where it is too dry, too cold or too acid for decomposition. Considering that most by-products contain less N per unit P than required by crops, the provision of sufficient N is deemed key for effective nutrient cycling. The model further implies that a successful nutrient cycling can be countered by crop failures or the decision to leave crop residues.

- Threats of soil quality may ask for adjustments of the management of soils. Note that management decisions in favour of nutrient cycling can conflict with those needed for other soil functions (Table 1).



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- References:**
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 - Schroder, J.J. et al. (2018). Key indicators and management strategies for nutrient cycling. *LANDMARK Report 3.5*.
 - Trajanov, A. et al. (2019). Assessing the nutrient cycling potential in agricultural soils using decision modelling. *Proceedings Conference on Operational Research*, September 2019, Bled, Slovenia (<http://www.opr.si>) (in press).



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Verification





Verification

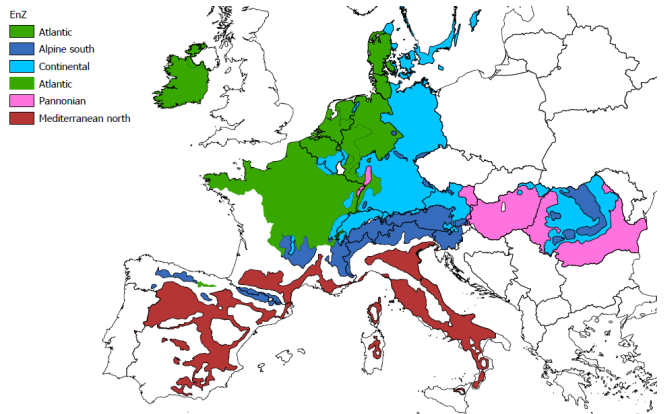


Sensitivity analysis



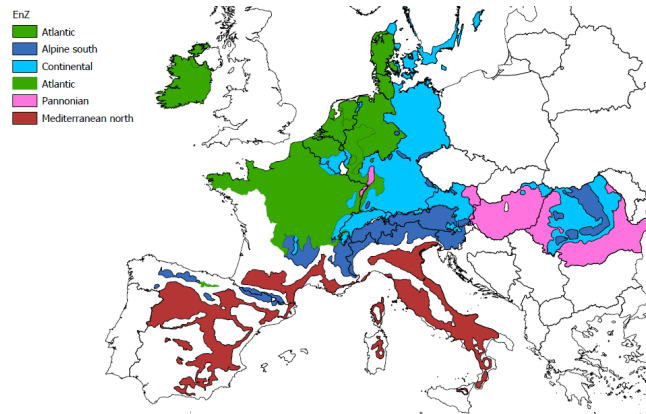
Average weights

Attribute	Local	Global	Loc.norm.	Glob.norm.
Primary Productivity				
Soil	19	19	22	22
Biological activity	26	5	31	7
pH	50	2	50	3
C/N ratio	20	1	20	1
SOM	30	1	30	2
Chemical	26	5	31	7
Macro Elements	33	2	43	3
P	57	1	57	2
K	26	0	26	1
Mg	17	0	17	1
Other Chemical Attributes	67	3	57	4
CEC	25	1	25	1
Salinity	75	2	75	3
Physical	47	9	37	8
Structure	50	4	50	4
Bulk Density	41	2	41	2
Rooting Depth	27	1	27	1
Clay content	32	1	32	1
Groundwater Table Depth	50	4	50	4



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Groundwater Table Depth	50	4	50	4



Verification



Sensitivity analysis



Calibration



Validation



Average weights

Attribute	Local	Global	Loc.norm.	Glob.norm.
Primary Productivity				
Soil	19	19	22	22
Biological activity	26	5	31	7
pH	50	2	50	3
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SOIL NAVIGATOR

Open access: www.soilnavigator.eu

SOIL NAVIGATOR

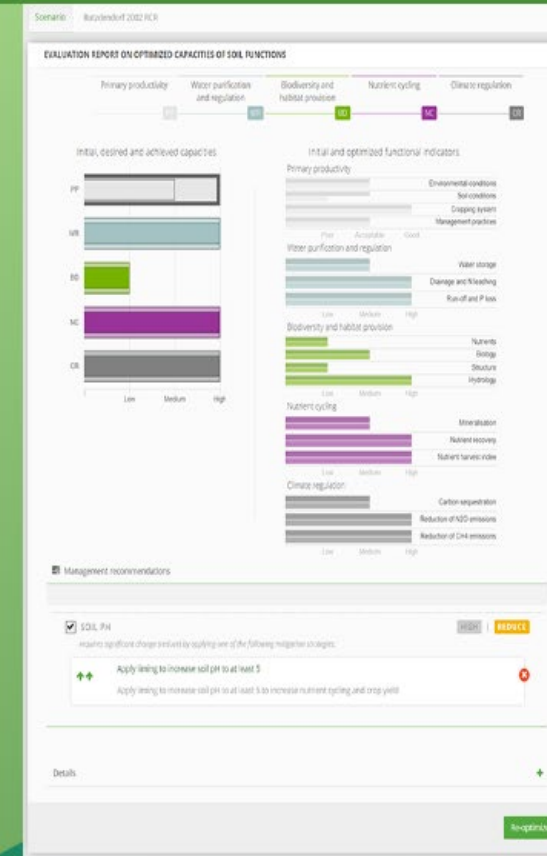
Home Decision support system Soil functions Team Publications Tutorials RUN

A Decision Support System for assessing and optimizing soil functions

The Soil Navigator decision support system (DSS) was developed in the Horizon 2020 project **LANDMARK**. It assesses the initial capacities of five soil functions within a field including primary productivity, nutrient cycling, water purification and regulation, carbon sequestration and climate regulation, as well as biodiversity and habitat provision. In addition, this evidence based DSS offers targeted solutions and management recommendations to improve the supply of several soil functions simultaneously and assisting farmers and farm advisors to make the right decisions for long term sustainability.

Watch video

Run Soil Navigator DSS



GRAPHICAL USER INTERFACE - DATA ENTRY

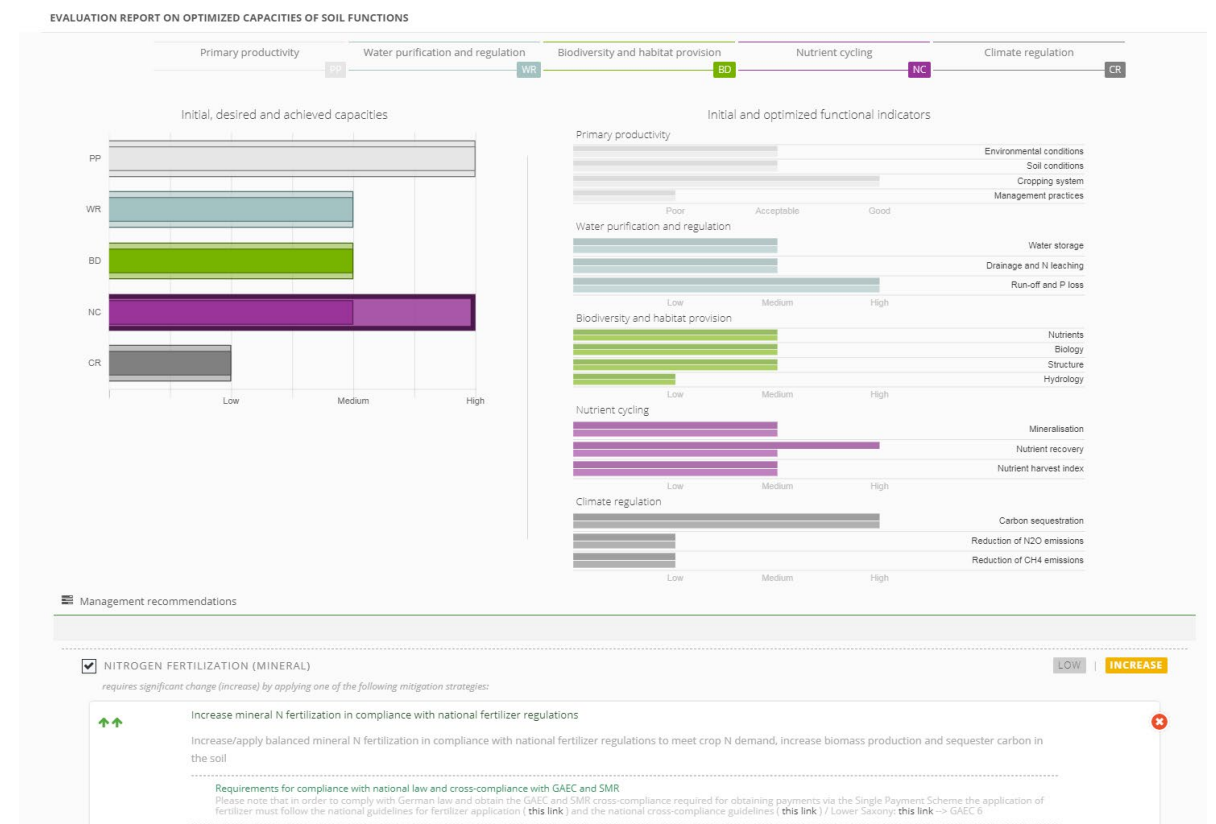
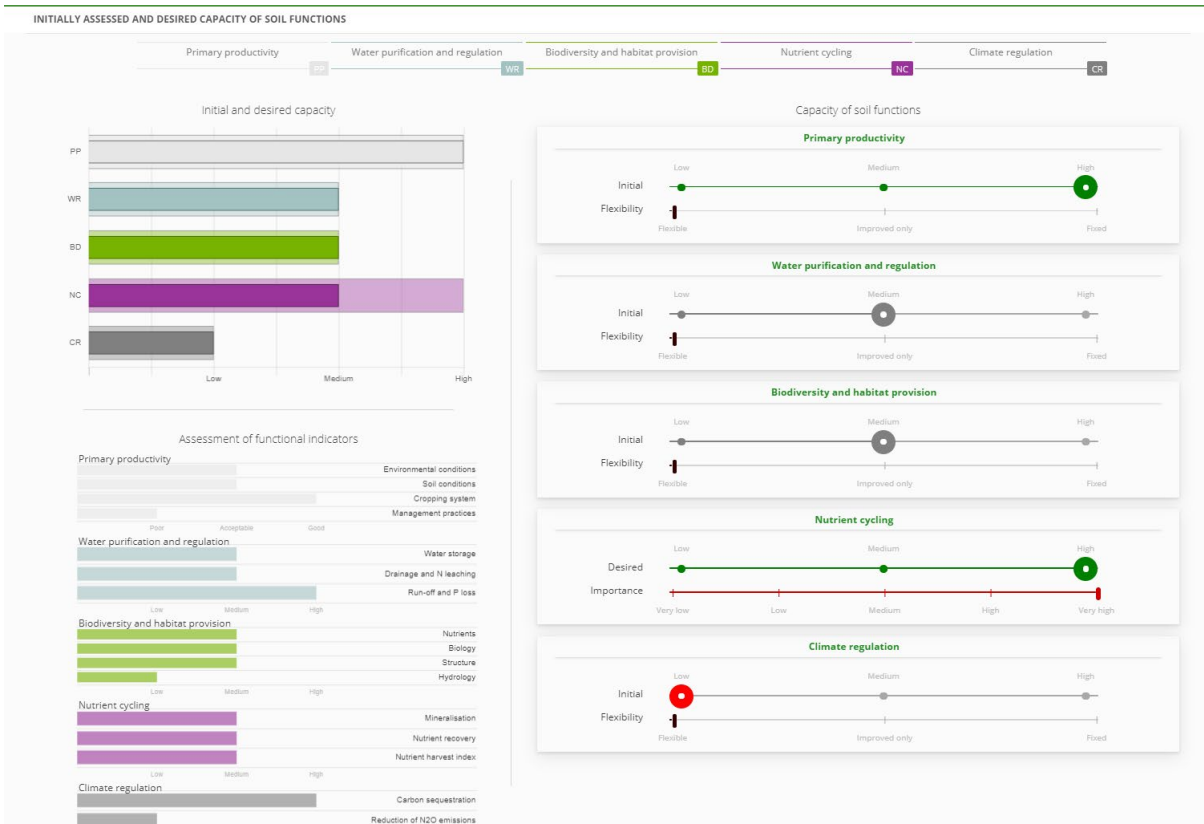
The screenshot shows the 'SOIL NAVIGATOR' web application interface. The top navigation bar is green and contains the text 'SOIL NAVIGATOR' and a hamburger menu icon. Below the navigation bar, there is a breadcrumb trail 'Home / Navigator'. The main content area is titled 'Navigator' and shows a scenario named 'Germany4bog (new)'. The 'INPUT DATA' section is displayed on 'PAGE 4 / 4'. A green banner at the top of the input section states: 'Unless otherwise specified, all input values are for the specific field and soil measurements are in the 0 to 25 cm soil layer'. The input form is titled 'Soil physical properties' and contains several rows of data entry options, each with a help icon and a delete icon (x):

- Soil type: Organic, Mineral
- Soil texture: Clay, Loam, Sand
- Clay content:
- Soil crusting/capping: Yes, No
- Thickness of organic layer: <10 cm, 10-20 cm, >20 cm
- Potential rooting depth: <50 cm, 50-100 cm, >100 cm
- Groundwater table depth: <0.4 m, 0.4-1.0 m, 1.0-2.0 m, >2.0 m
- Soil organic carbon: <1 %, 1-3 %, >3 %

On the right side of the interface, there is a vertical sidebar with buttons for 'Agroecosystem', 'Management', 'Environment', and 'Soil'. Below these buttons are three action buttons: 'Assess soil functions' (green), 'Save' (orange), and 'Save As New' (orange). A yellow circular help icon with a question mark is located at the bottom right of the sidebar.



ASSESSMENT AND SUGGESTIONS FOR IMPROVEMENT OF THE SOIL FUNCTIONS



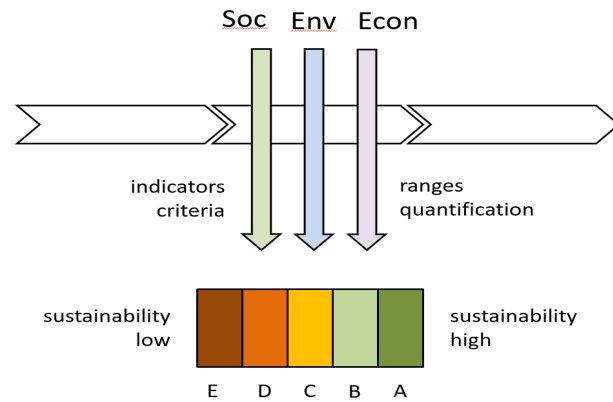
Sustainability of legume agri-food chains

- Identify “**transition paths**” to increase **sustainable legume cultivation and consumption** across Europe
- Include the **entire value chain** of legume feed and food
- Develop a **decision support tool** for primary producers, agronomists, processors, associated businesses and decision makers
 - Help determine a **range of options for successful transitions**
 - Take into account the **three different aspects of sustainability** and their intersections

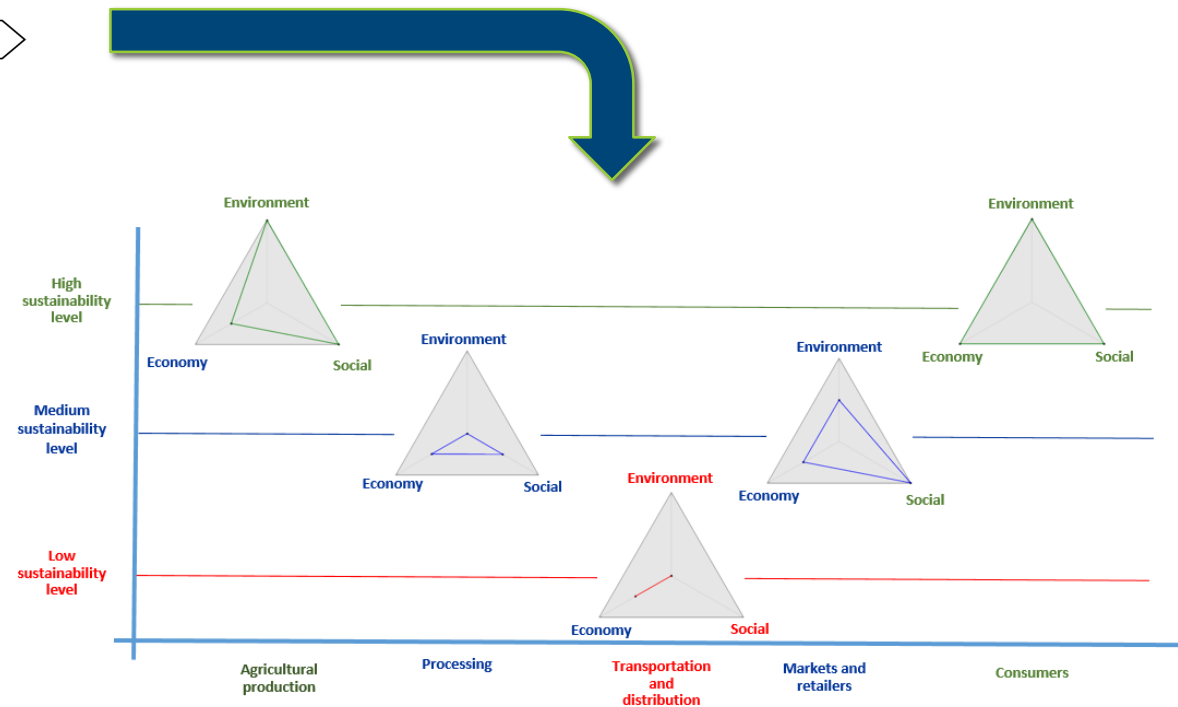
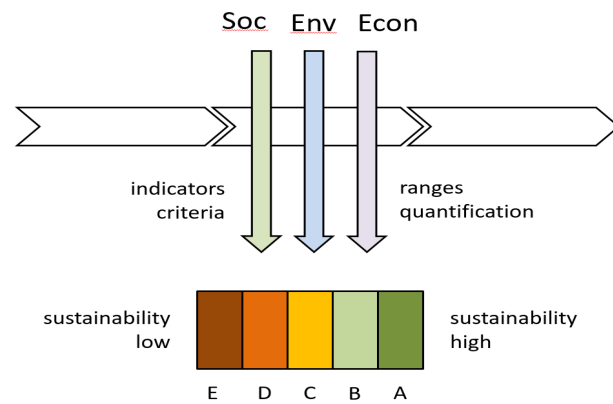


Sustainability of legume agri-food chains

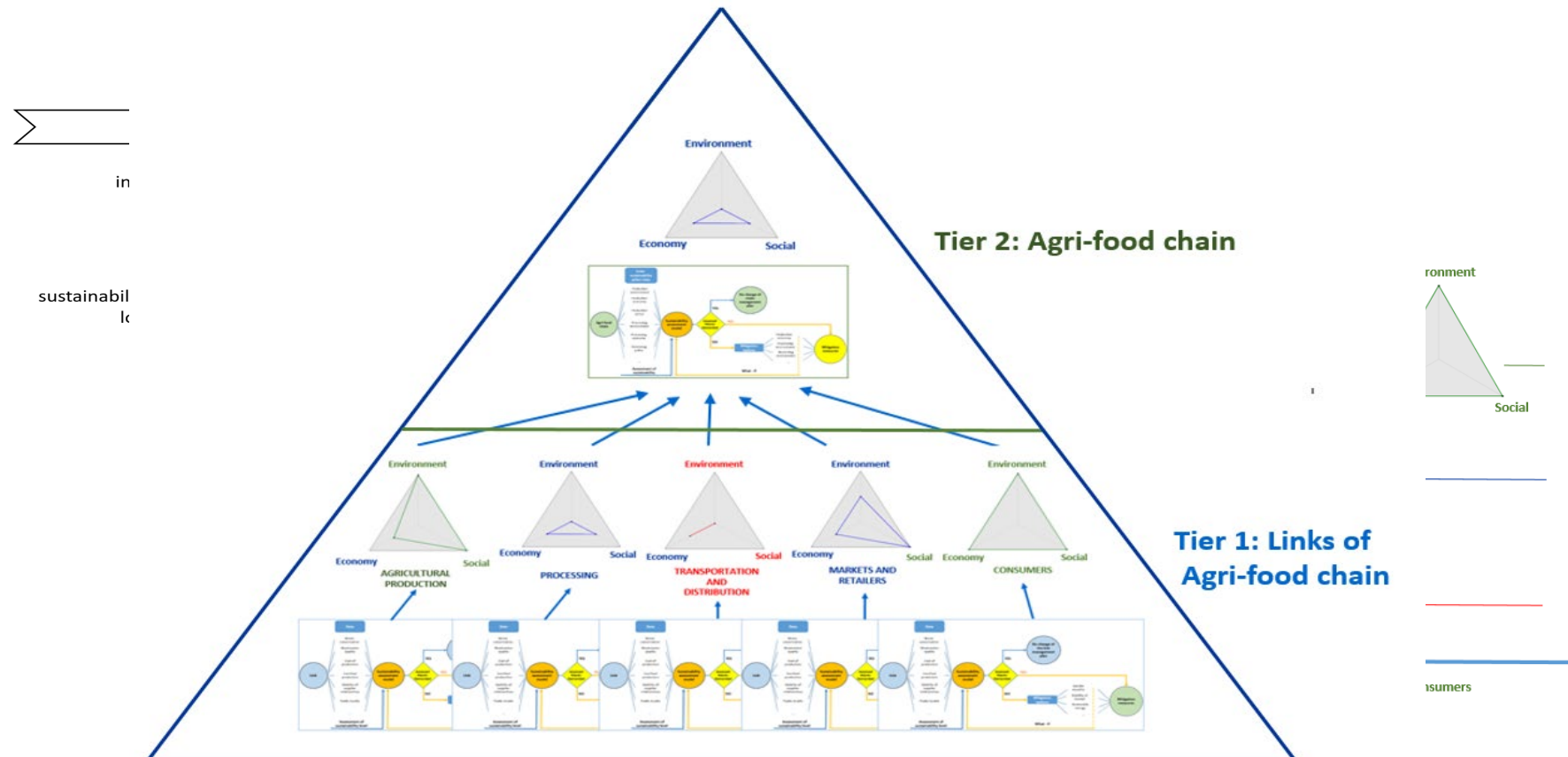
Sustainability of legume agri-food chains



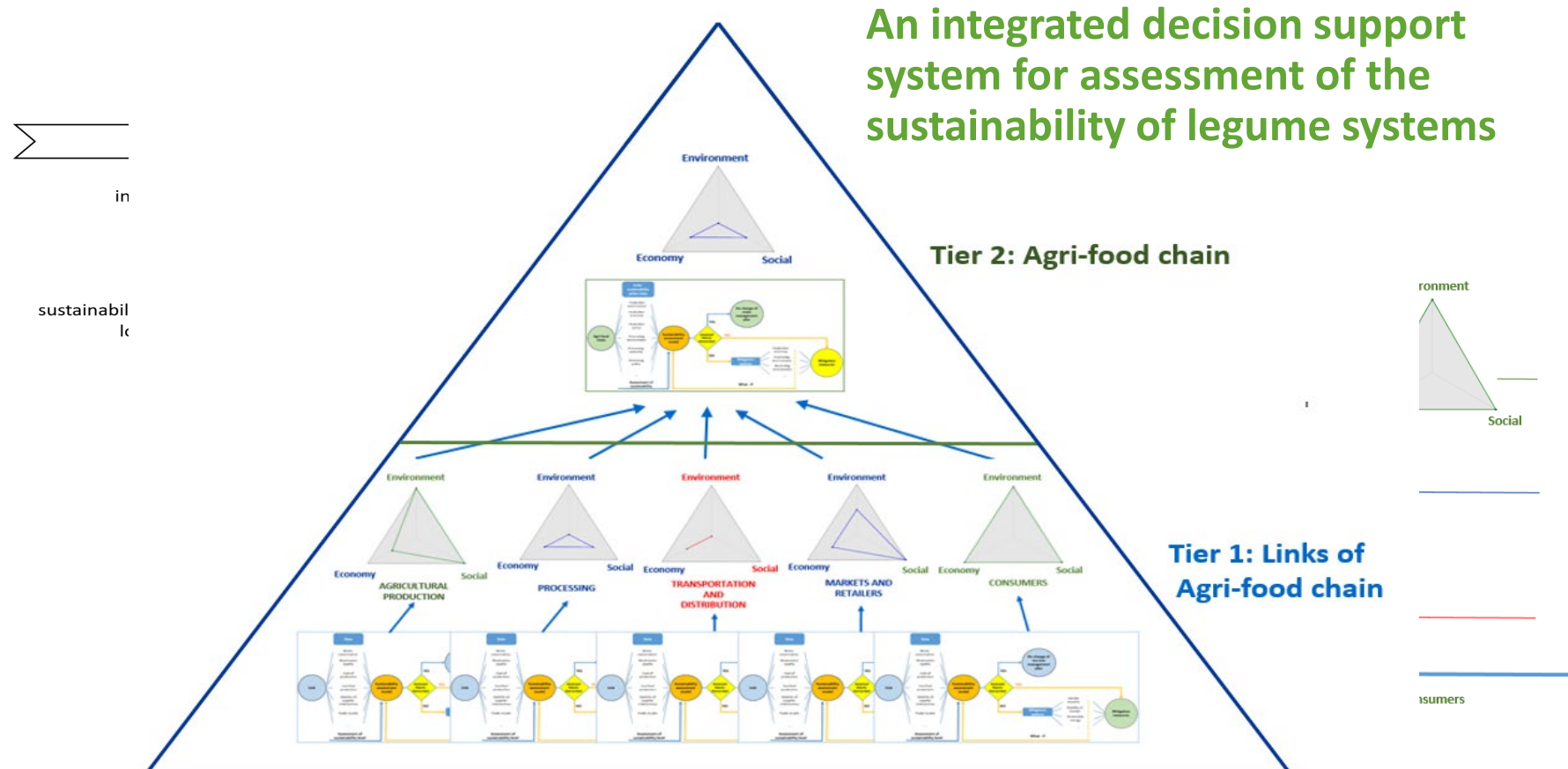
Sustainability of legume agri-food chains



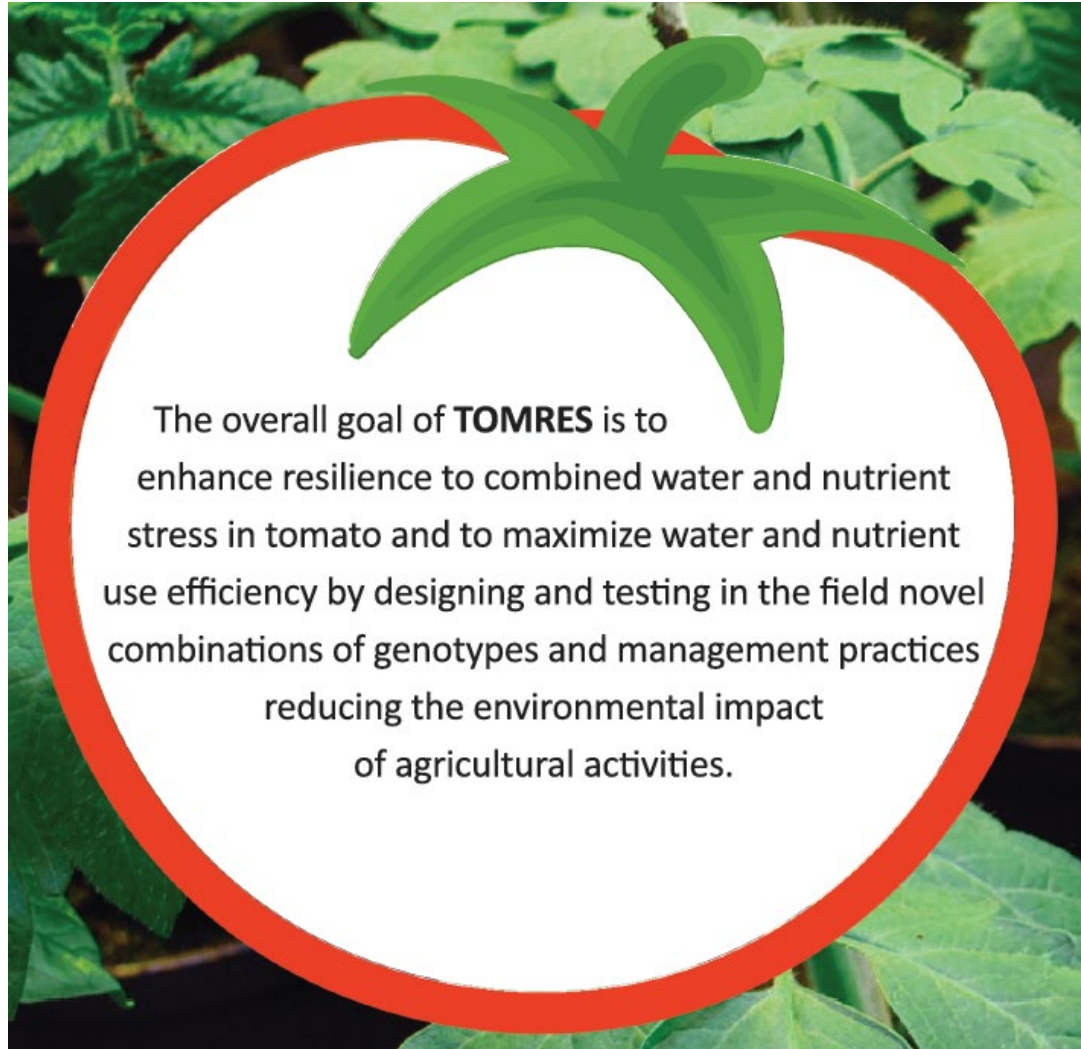
Sustainability of legume agri-food chains



Sustainability of legume agri-food chains



Tomato resilience and resource use efficiency



- Goals:
 - To investigate the factors that influence the water, nitrogen and phosphorus use efficiency under experimental conditions using **machine learning**
 - To assess open-field and glasshouse tomato production from socio-economic, environmental and RUE perspective using **qualitative decision modelling**

Conclusions

- Agriculture is becoming **digital**
- **AI in agriculture** is already a **reality**
- More efficient and **sustainable agriculture**
 - Environmental benefits
- Some **disadvantages:**
 - Modernization/digitalization of agriculture is **expensive**
 - **Decrease in employment** and workforce in the agricultural sector