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Modelling dry farming systems: a roadmap for tool development

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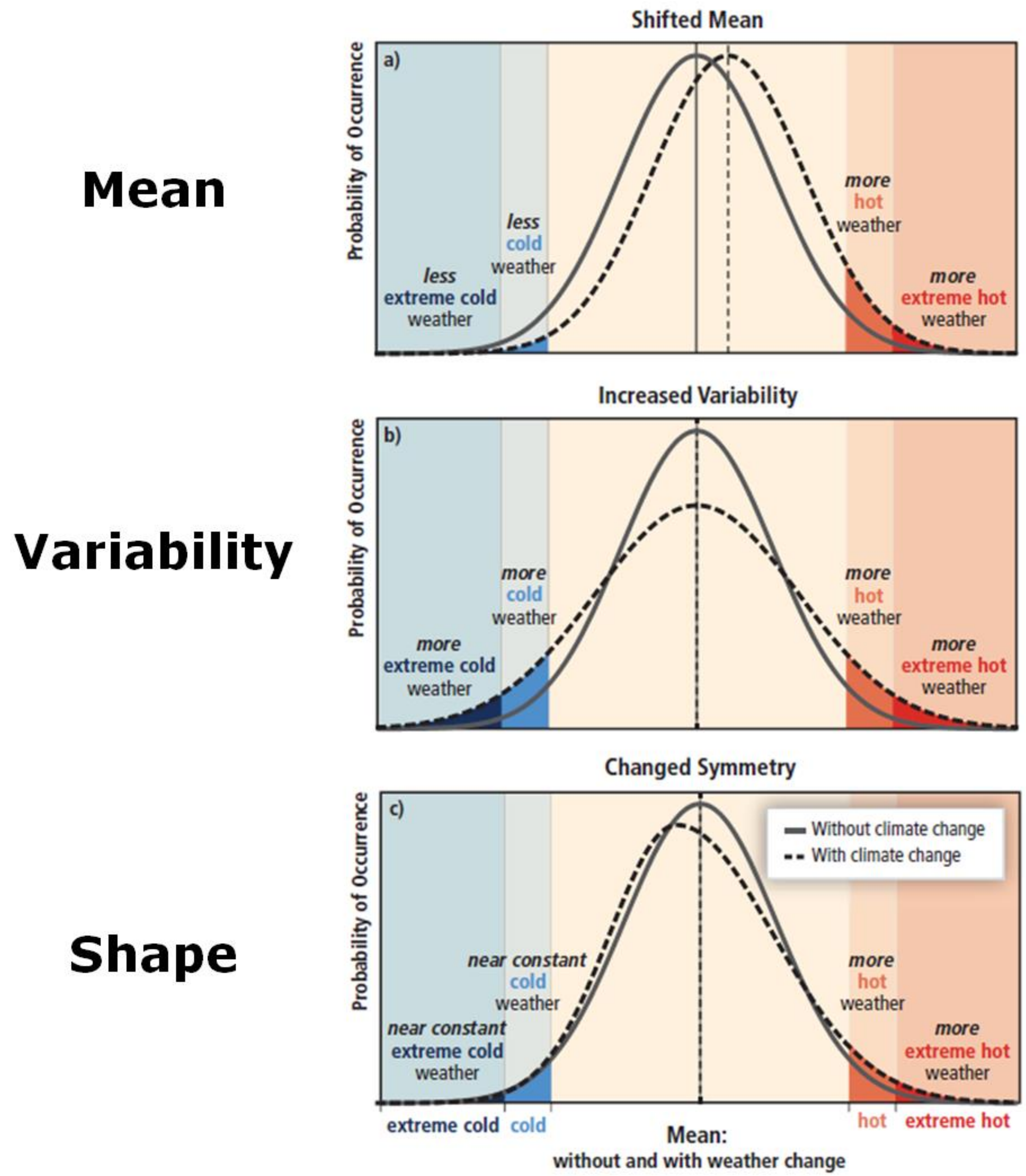
Weather patterns under climate change

- A changing climate leads to changes in the frequency, intensity, spatial extent, duration, and timing of extreme weather and climate events (IPCC, 2012)
- Seasonal patterns of rainfall may also change markedly.
- These changes may require new production systems, rather than optimizing exiting ones. But how to test hypothesis and estimate risk for known and innovative systems using climate projections?



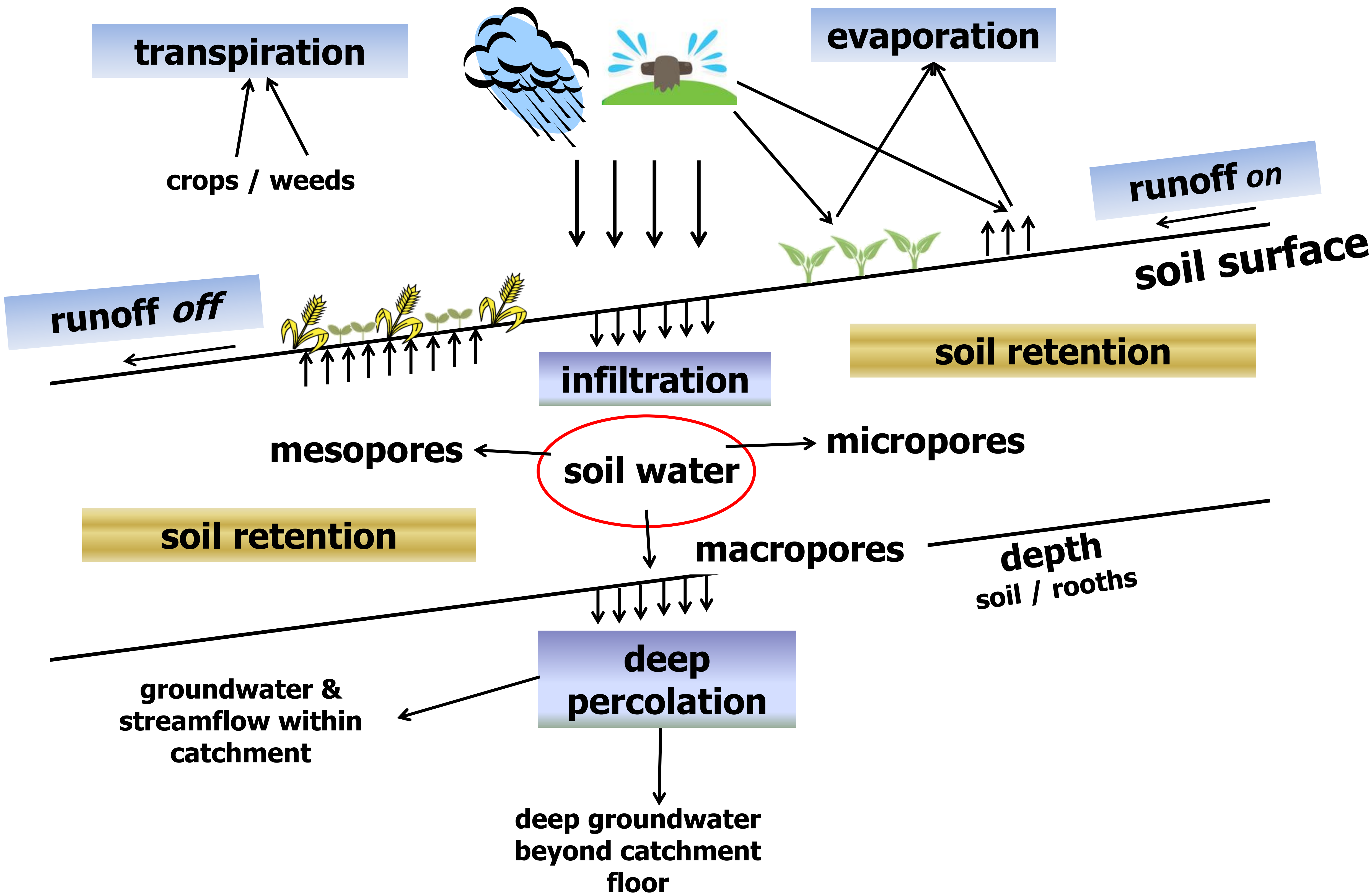
The role of modelling for agricultural systems

- Models allow exploring the performance of production systems via simulation, which enables creating an artificial history of the system.
- Weather projections originated from global circulation models can be used as inputs, and with soil and field conditions they define an environment.
- Given the environmental conditions, models allow exploring the performance of the genotype x management interactions.
- Different production systems can be simulated to estimate yield and yield stability, and use of resources.
- However, currently available model tools may have limits in some extreme environments and for some production enterprises.
- Also, the comparison of production systems in given environmental condition would require a common framework to access data and to compare results. Instead, simulation tools often are discrete units with their own data format requirements and with a dedicated user interface.

Modelling agricultural production in arid systems: challenges

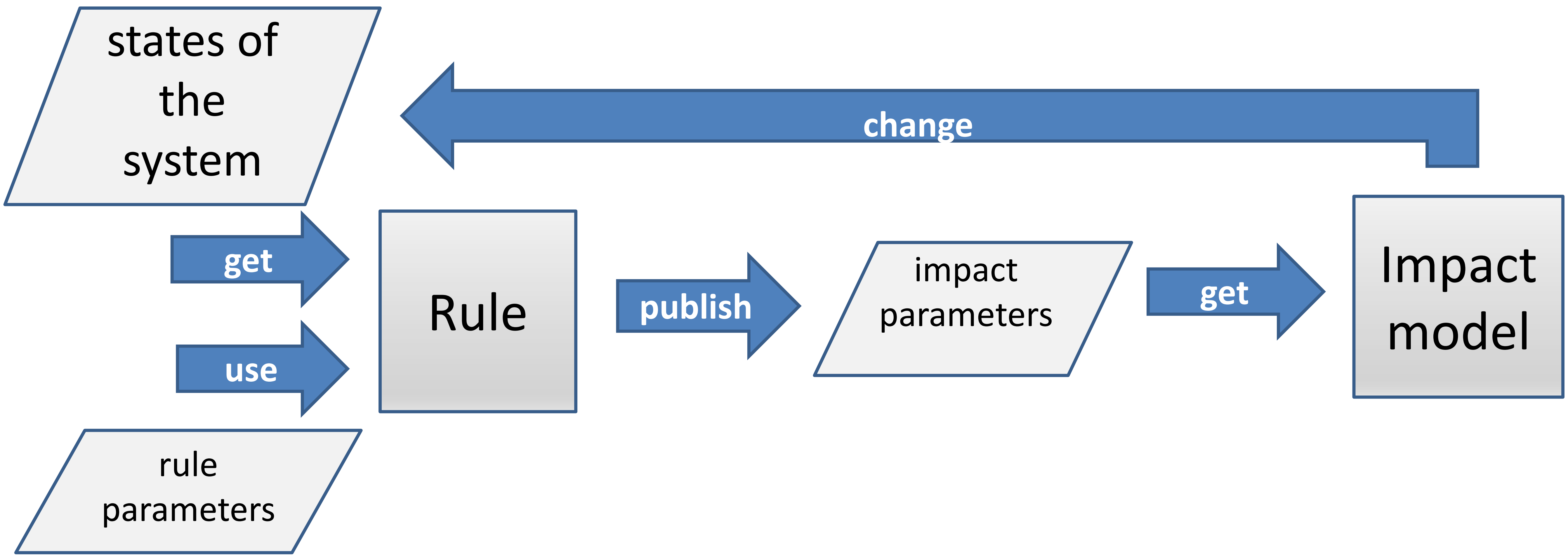
- The development of cropping system models started targeting production systems in temperate climates, in sub-humid or, at worse, in semi-dry environmental conditions, with a medium to high yield potential.
- Main drivers of production considered in such environments are: intercepted solar radiation, thermal regimes, water, nutrients.
- Modelling such complex systems requires the simulation of a number of processes and their interactions, but it allows for some simplifications/assumptions. Assumptions in building modelling solutions which can be perfectly adequate in temperate environments may not be acceptable in very dry environments.
- Also, the excess of data fitting during calibration of model parameters has led at times to instable modelling solutions for environments and crops different from the ones used to develop models.

Water dynamics in agricultural fields



Modelling agricultural management in scenario analyses - *unattended*

- Agricultural management operations can be implemented in simulation models according to the so called *rule-impact* approach. Two questions:
  - **When?** The answer is provided by a *rule*;
  - **What?** The answer defines the type of *impact* by making available relevant parameters to impact models - more than one impact model may use the same set of parameters.



Modelling agricultural management: agro-management plans

Rules example

Fixed date
Parameter: day of year
States: current day

Development stage (DVS)
Parameter: DVS value
States: DVS code

Soil water (SW) availability
Parameters: soil depth, SW threshold
States: SW content

Infection events
Parameter: events value
States: number of events

Impacts example

Sowing
Parameters: crop name, sowing depth

Fertilization
Parameters: NPK content, amount, type of application

Irrigation
Parameters: water amount, type of application

Pesticide
Parameters: chemical amount, Active principle concentration

Agro-management plans

Reproduction of a known situation:
Agro-management events are triggered based on fixed dates.
MODEL LISTENERS: crop, soil, disease

Phenology-based scenario:
Agro-management events are triggered based on crop development stage.
MODEL LISTENERS: crop, soil, disease

Optimization of nitrogen and water resources:
Agro-management events are triggered based on soil water availability.
MODEL LISTENERS: soil

Optimization of pesticide use
Fungicide chemical applications are triggered based on simulated infection events.
MODEL LISTENERS: disease

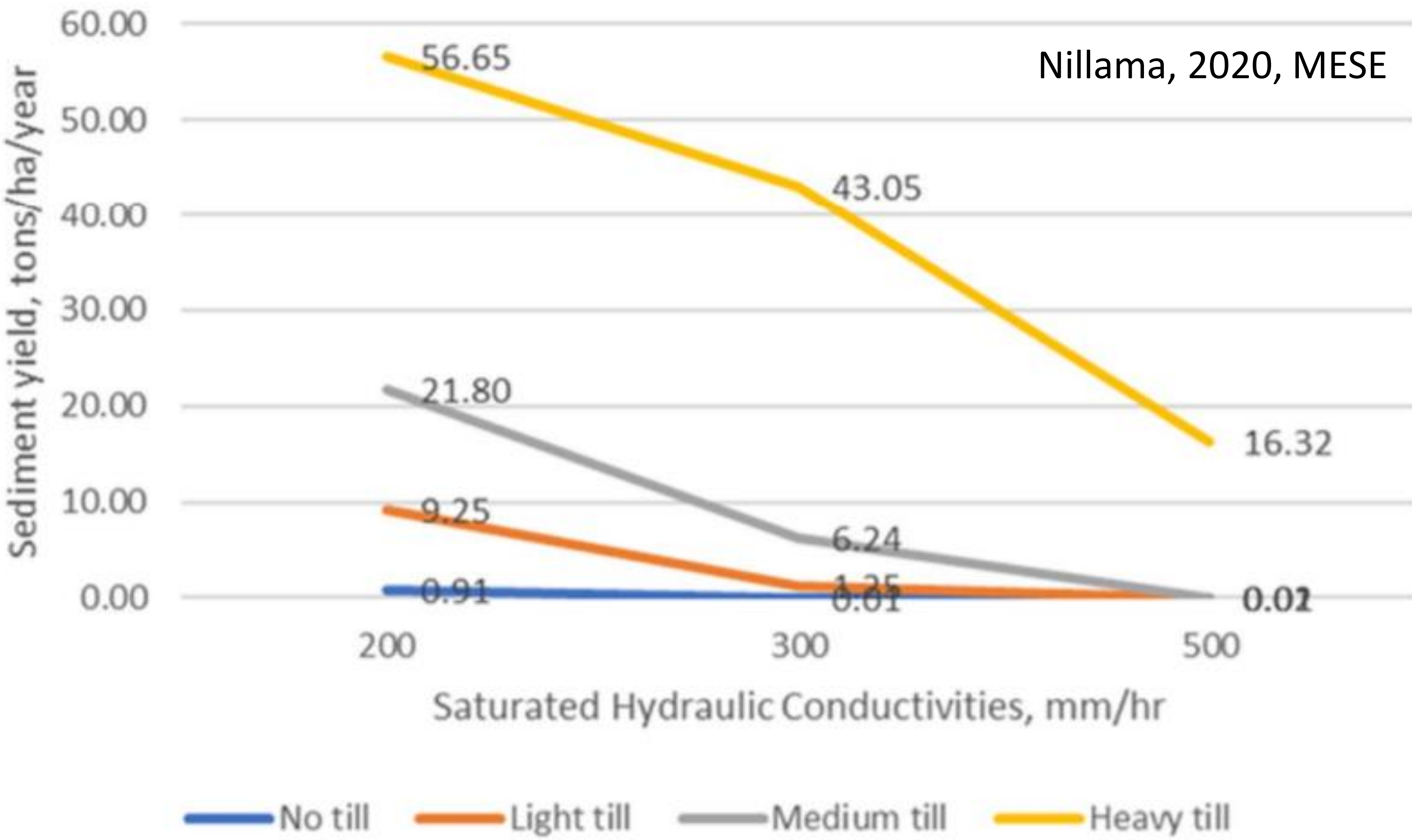
An example: wheat sowing date in Morocco

- The narrative description of the conditions to be fulfilled to perform the sowing event was provided by Moroccan stakeholders (E-AGRI project):
  - *The time window for sowing starts in October.*
  - *Tillage is performed at least a number of days after a precipitation event.*
  - *After tillage, when the amount of rainfall is larger than a percentage of cumulated potential evapotranspiration, then conditions are favorable for sowing.*
  - *Starting from this date, when soil water content in the first 10 cm is below a threshold, farmers usually sow wheat*

Start	Tillage	Climate	Soil water
Input	*Input*	*Input*	*Input*
- Day of the year	- Precipitation	- Precipitation	- Soil water content
	Parameters	- ETP	- Layer thickness
	- Threshold prec.	*Parameters*	*Parameters*
	- Number of days	- ETP %	- Percentage of FC

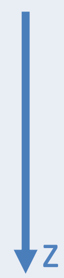
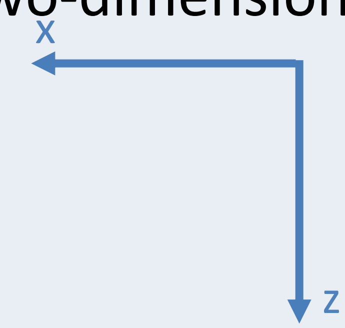
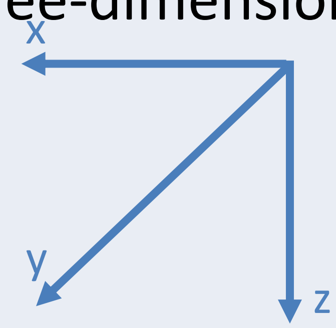
Modelling the impact of soil tillage

- A tillage event decreases soil bulk density, increases soil porosity, changes soil roughness and ridge height, destroys rills, increases infiltration, and changes erodibility parameters. A soil module in a cropping system model must be able to simulate these changes.



Simulations can be used to identify best management practices in dry and arid environments.
Identify trade-offs between runoff-erosion and system productivity.

Modelling water dynamics in the soil profile

Irrigation regime	Rainfall or uniform irrigation	Drip line irrigation	Localized irrigation with low flow rate
Cropping system			
Water soil gradient	One-dimensional 	Two-dimensional 	Three-dimensional 
Cascading approach (low parameterization)	Yes	No / Yes*	No
Richards' equation (high parameterization)	Yes	Yes	Yes

*considering the one-dimensional fluxes in the restricted volumes below the drip lines or plant rows (Ventrella et. 2019)

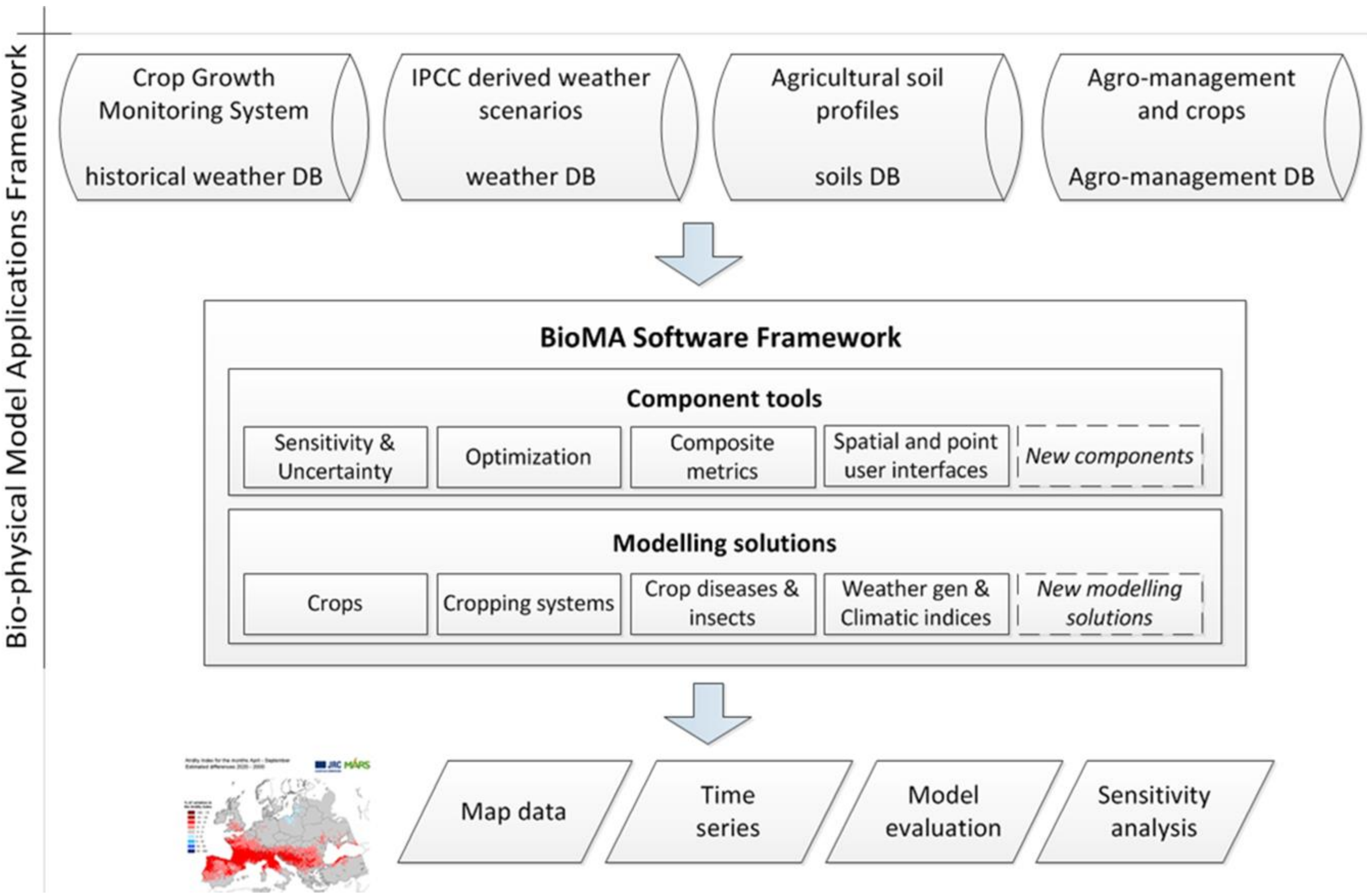
Preferential flow, as opposed to uniform flow, results in irregular wetting of soil profile as consequence of water moving faster in certain parts of the soil profile than in others.

Preferential flow is described with a variety of multi-porosity/permeability models

Simunek et al, 2003

Modelling frameworks to develop model tools

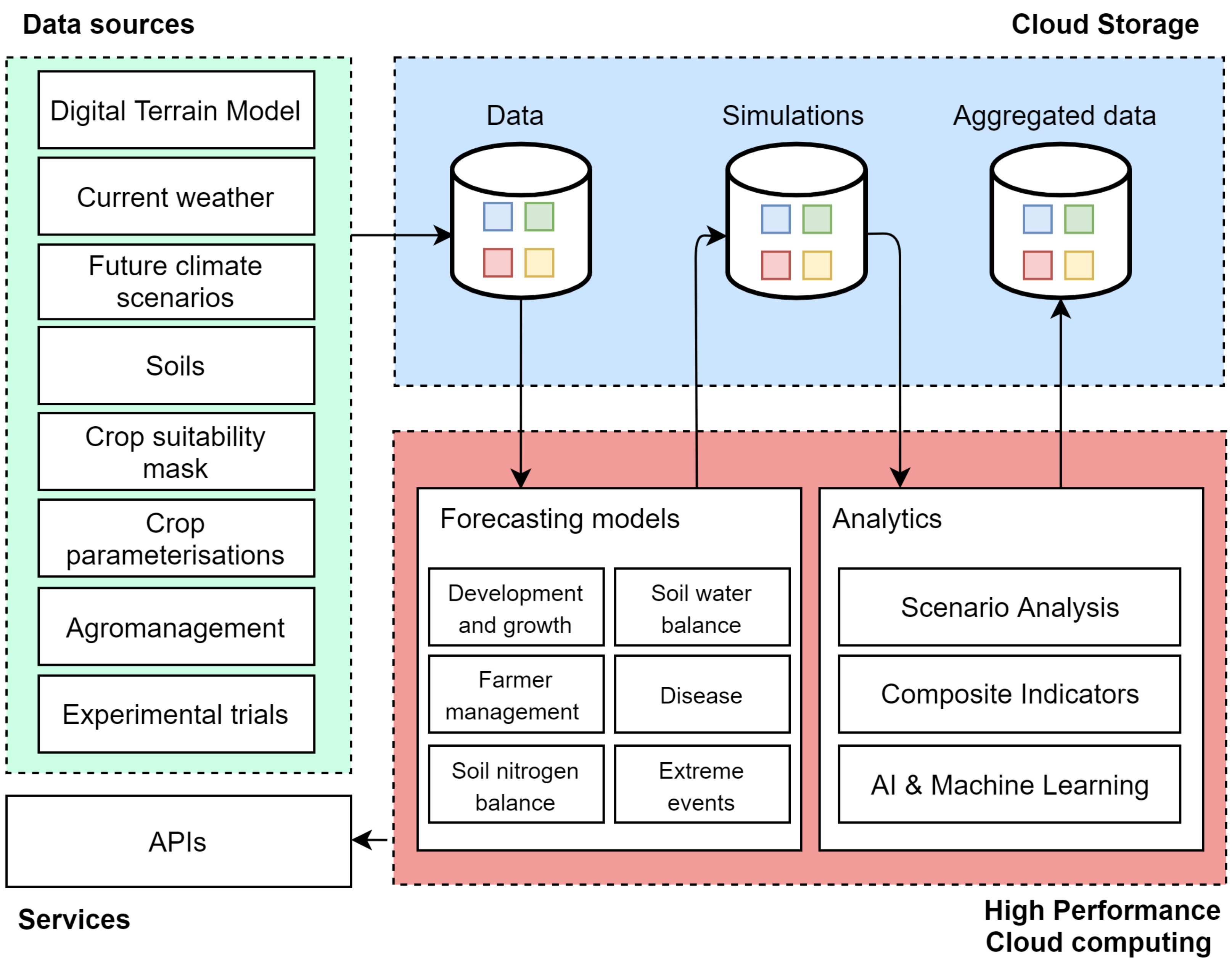
- Model frameworks enables to rapidly bridge from research to operational application of models via their modular structure. They facilitate cooperation across teams.
- APSIM (Australia), DSSAT (USA), RECORD (France) are examples of such frameworks which all have international contributors.



- BioMA (Biophysical Model Applications) is an open software framework designed for developing, parameterizing, analyzing and running modelling solutions based on biophysical models. Model libraries are being enhanced to improve the capability to simulate processes in arid environments.

BioMA models and cloud services

- The BioMA platform uses Microsoft Azure services with unlimited memory space and computing power linked to the parallelization of Azure Functions, facilitating data integration and process automation. The services include high computational power, storage, networking (secure connections) and analytics.



Conclusions

- The lack of ready to use libraries to build appropriate modelling solutions may limit the use of modelling techniques for scenario analyses in very dry environments and for some production enterprises.
- There is often a very limited knowledge about current *rules* to trigger management events in unattended simulations such us those of scenario analyses; this requires articulated interaction with scientists and agronomists operating in the target environment to develop feasible innovative agro-management plans.
- Adequate modelling solutions need to be built including relevant processes, while limiting excess in calibration of modelling tools. The development of ready-to-use libraries is on going at CREA, making model tools available to public users.
- International cooperation and interaction with scientists from the target area of possible applications is the key to increase reliability and operational capability of simulation tools.

Thank you for your attention

The Research at CREA
Agriculture and Environment

Macro-areas of research

- Expertise on agricutural systems analysis with respect to productivity, environmental impact, ecosystem services, adaptation and mitigation
- Advanced technologies on analytics, measures, and system simulation.