Modelling crop vulnerability and risk by applying the Decision Support System for Agro technology Transfer-Cropping System Model (DSSAT-CSM)

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Impacts on Agriculture, Forests and Ecosystem Services – IAFES Division

ClimaSouth Regional Workshop on Methods and Tools for Vulnerability Assessment

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Outline

- Climate change
  - Vulnerability of agricultural sector
- Tools for vulnerability assessment in agriculture
  - DSSAT-CSM
- Examples of agricultural model application:
  - Europe
    - Italy
      - Sub-Saharan Africa
        - Nigeria

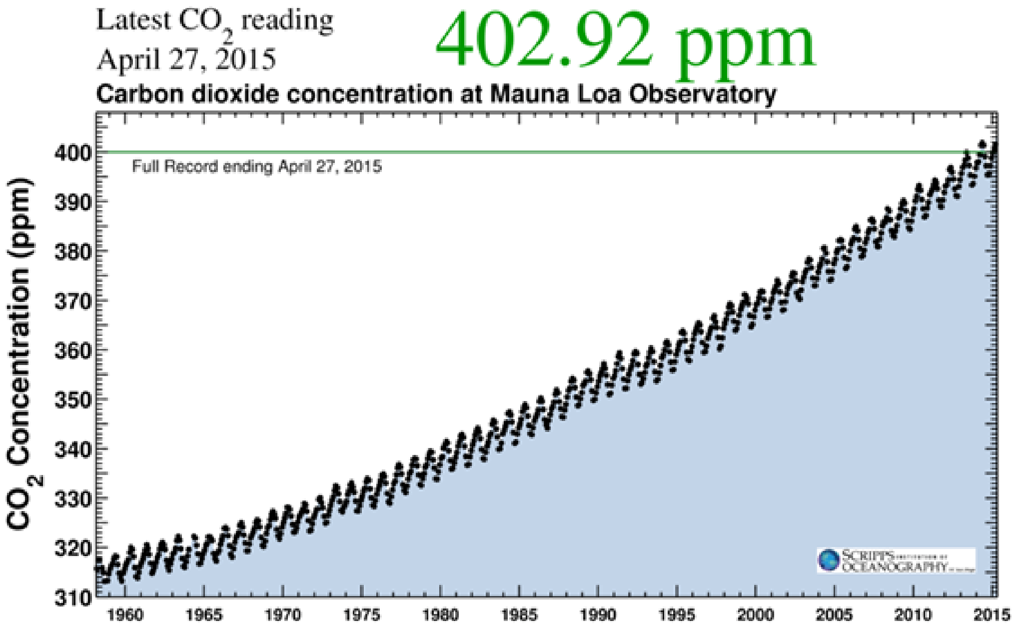
Evidences from AR5 (IPCC, 2013)

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.

- atmosphere and ocean have warmed
- sea level has risen
- the amounts of snow and ice have diminished
- concentrations of greenhouse gases have increased
- extreme events have increased

Human influence on the climate system is clear. This evidence for human influence has grown since AR4.

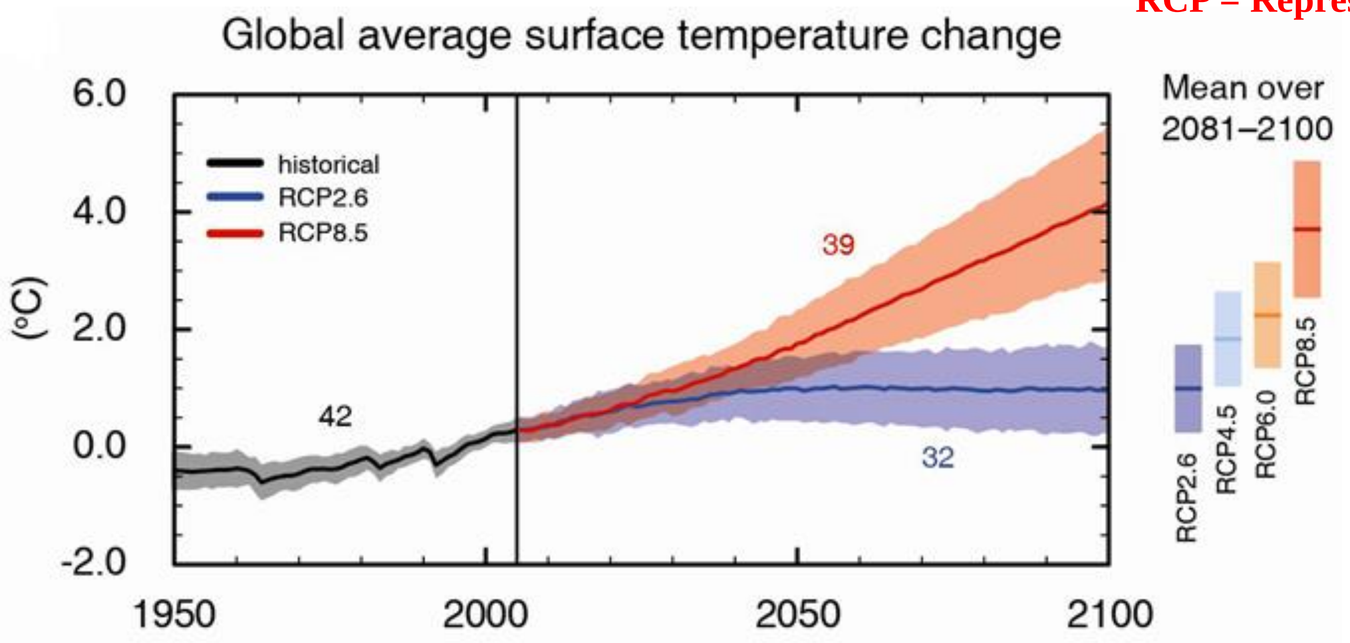
It is extremely likely *(> 95%)* that human influence has been the dominant cause of the observed warming since the mid-20th century.



http://www.ipcc.ch/

Future Projections from AR5

RCP = Representative Concentration Pathways



CO_2 concentration by 2100:

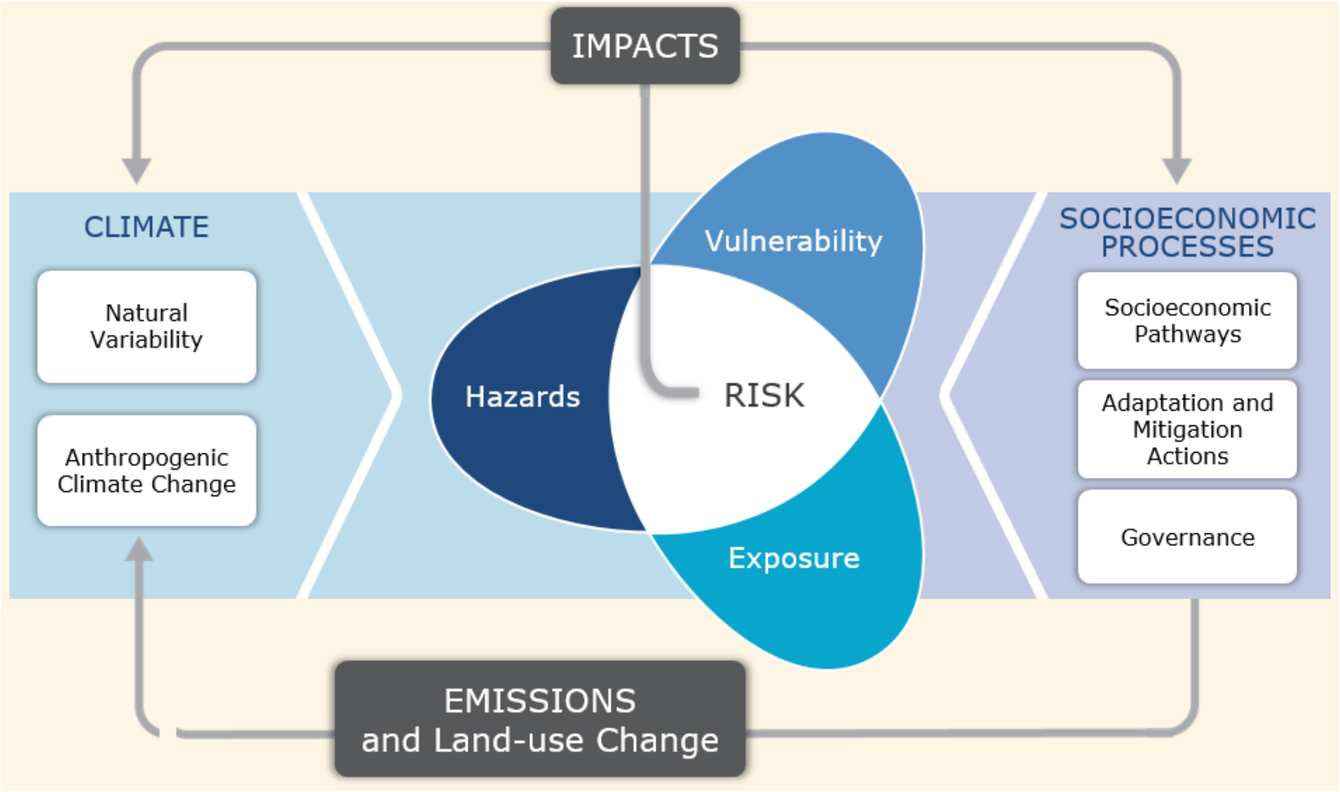
RCP2.6 = 421 ppm
RCP4.5 = 538 ppm
RCP6.0 = 670 ppm
RCP8.5 = 936 ppm

		2046–2065		2081–2100	
	Scenario	Mean	*Likely* range[c]	Mean	*Likely* range[c]
Global Mean Surface Temperature Change (°C)[a]	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8

http://www.ipcc.ch/

Vulnerability – Hazard - Exposure

Climate changes expose people, societies, economic sectors and ecosystems to risk. **Risk is the potential for consequences** when something of value is at stake and the outcome is uncertain, recognizing the diversity of values.

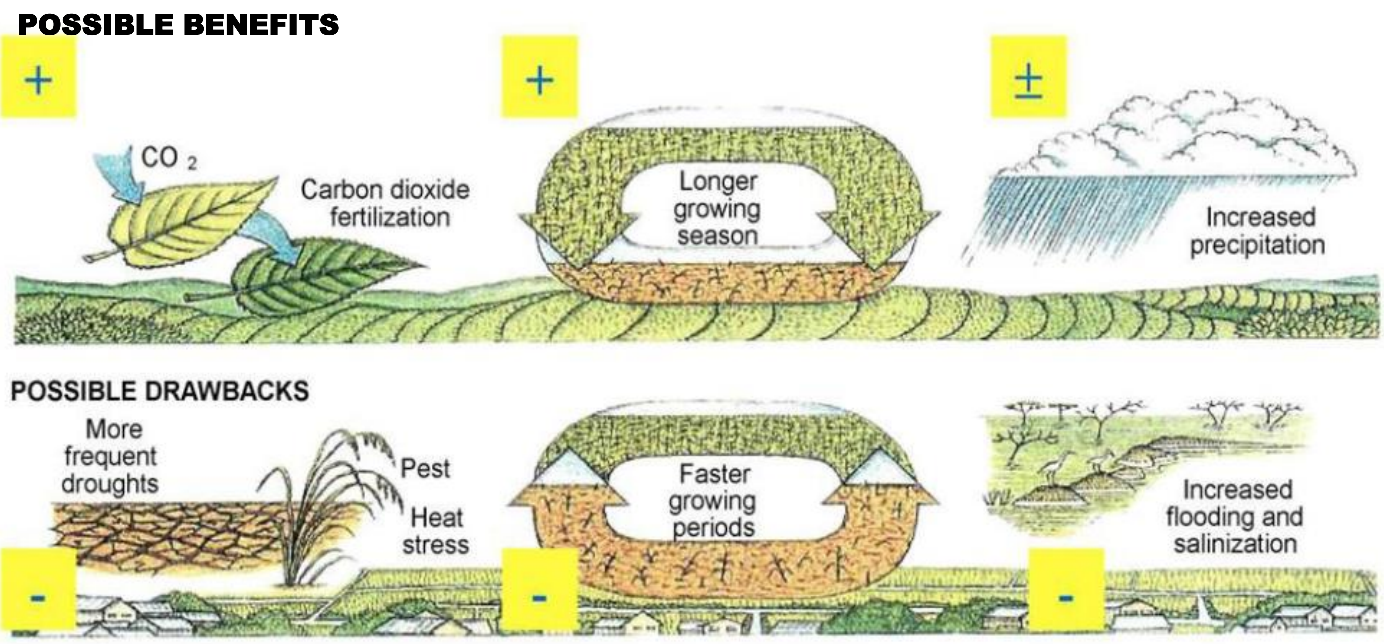


Risks from climate change impacts arise from the interaction between **hazard** (caused by an event or trend related to climate change), **vulnerability** (susceptibility to harm) and **exposure** (people, assets or ecosystems at risk).

Climate change and agriculture

Climate change is a significant risk for agricultural production

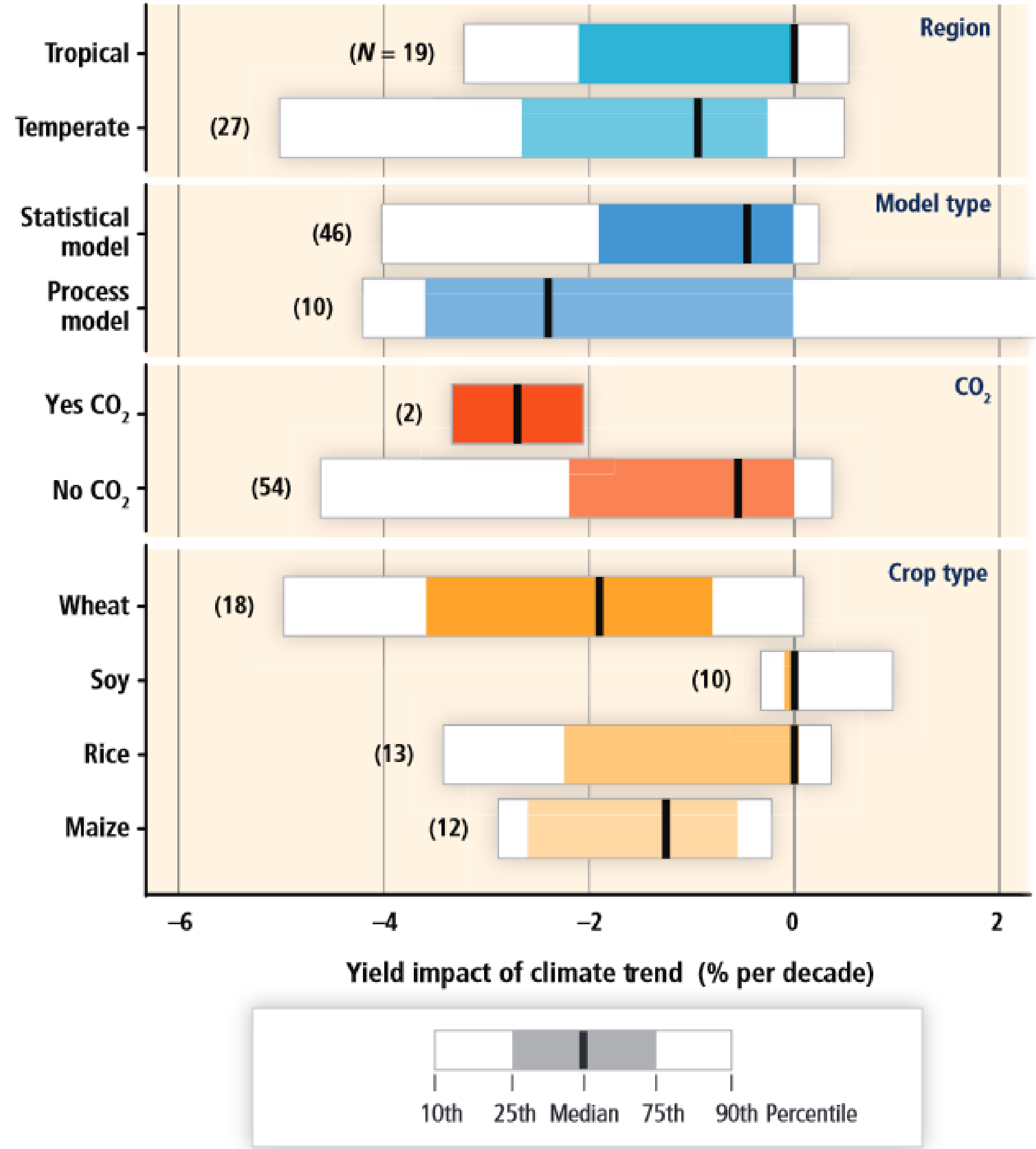
Even under optimistic scenarios for climate mitigation action, agricultural areas are likely to face significant **increases in temperature** in the coming decades, in addition **to changes in precipitation**, **cloud cover**, and **frequency and duration of extreme heat, drought, and flood events**.



Agro-ecosystem processes and a changing climate (from: Bongaarts, 1994).

Agricultural systems

CC without adaptation will have **a negative impact on the production of the main crops** (wheat, rice and corn), especially in **temperate regions**, as a consequence of a temperature increase of 2°C or more, above late-20th-century levels, although individual locations may benefit



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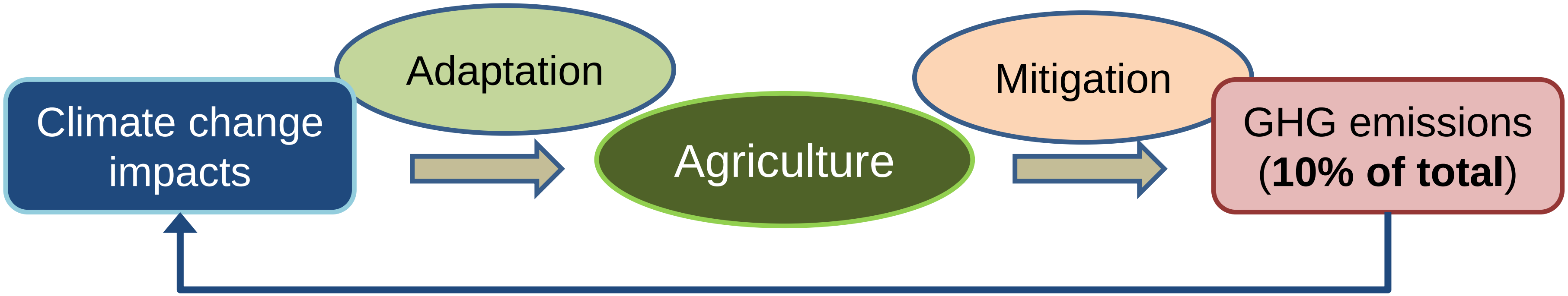
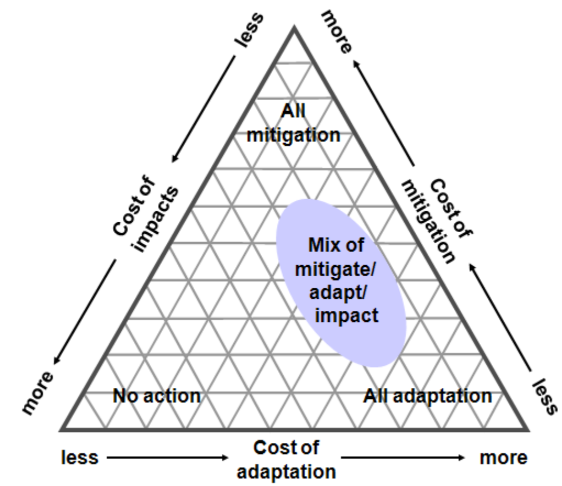
Adaptation/mitigation in agriculture



Global food production needs to be increased because of:



(Holdridge diagram)

- **Climate change impacts on agriculture** (IPCC, 2007, 2013)
- **World population growth** (FAO, 2009; UN, 2013)
- **Food security** Food availability - Food access - Food utilization (FAO, 1996)

Climate-Smart Agriculture

Agriculture that sustainably:

- **increases productivity and incomes**
- **increases resilience to climate change** (adaptation)
- **reduces and/or removes GHGs** (mitigation)

➢ achieve national food security and development goals

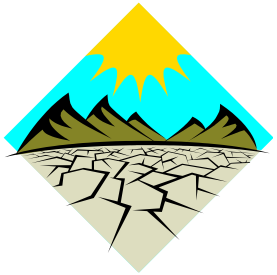
MITIGATION
Emission reduction (CH_4 and N_2O)
Increase of C sequestration
Energy production

ADAPTATION
Change in crop management system

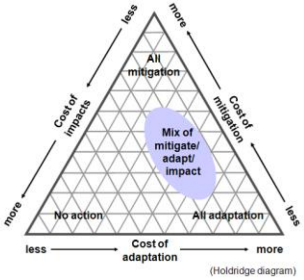
- Precision agriculture
- Conservation tillage
- Crop rotations
- etc..

Climate change and agriculture

We need **tools and methos** to estimate crop production depending on weather and climate, with the aim of:



- Identify the **most vulnerable areas to extreme events and climate change**
- Evaluate **the most effective management techniques** in terms of crop productivity and sustainable use of resources
- Identify **adaptation and mitigation strategies** specific for each region



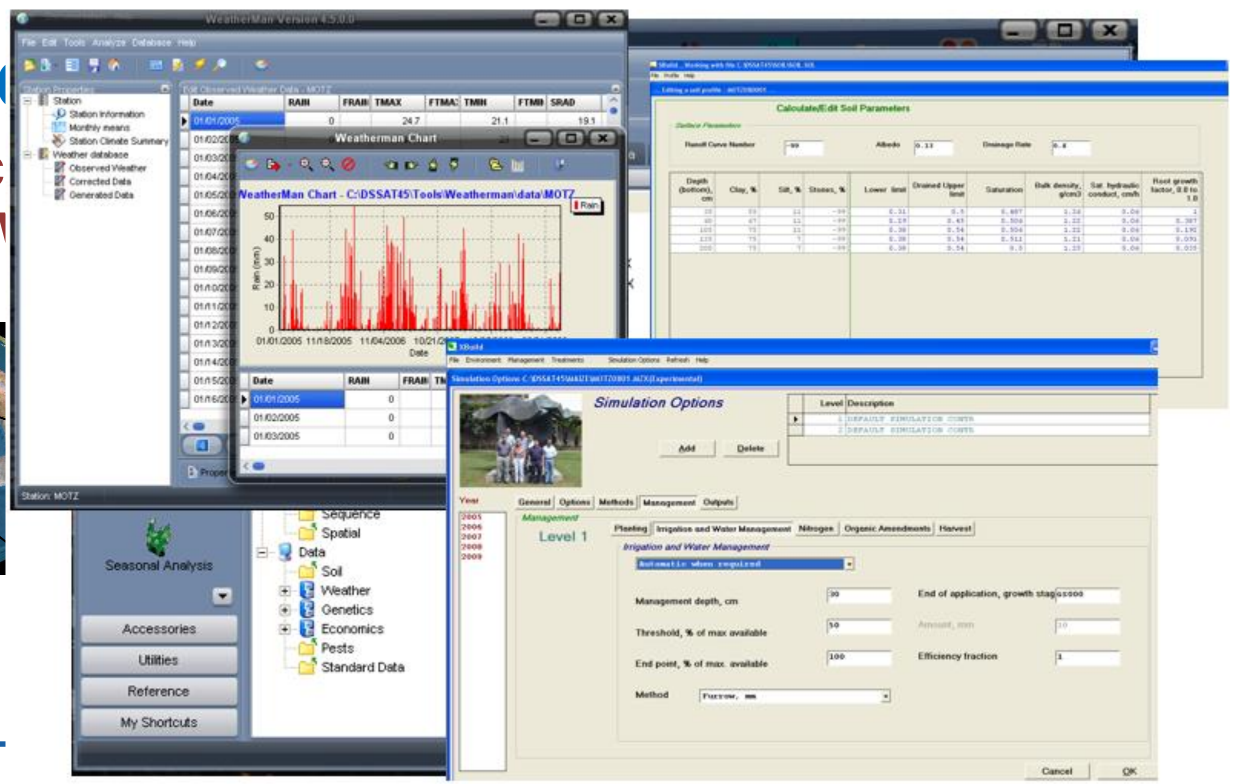
Risk and vulnerability analysis

Climate risk and vulnerability analysis

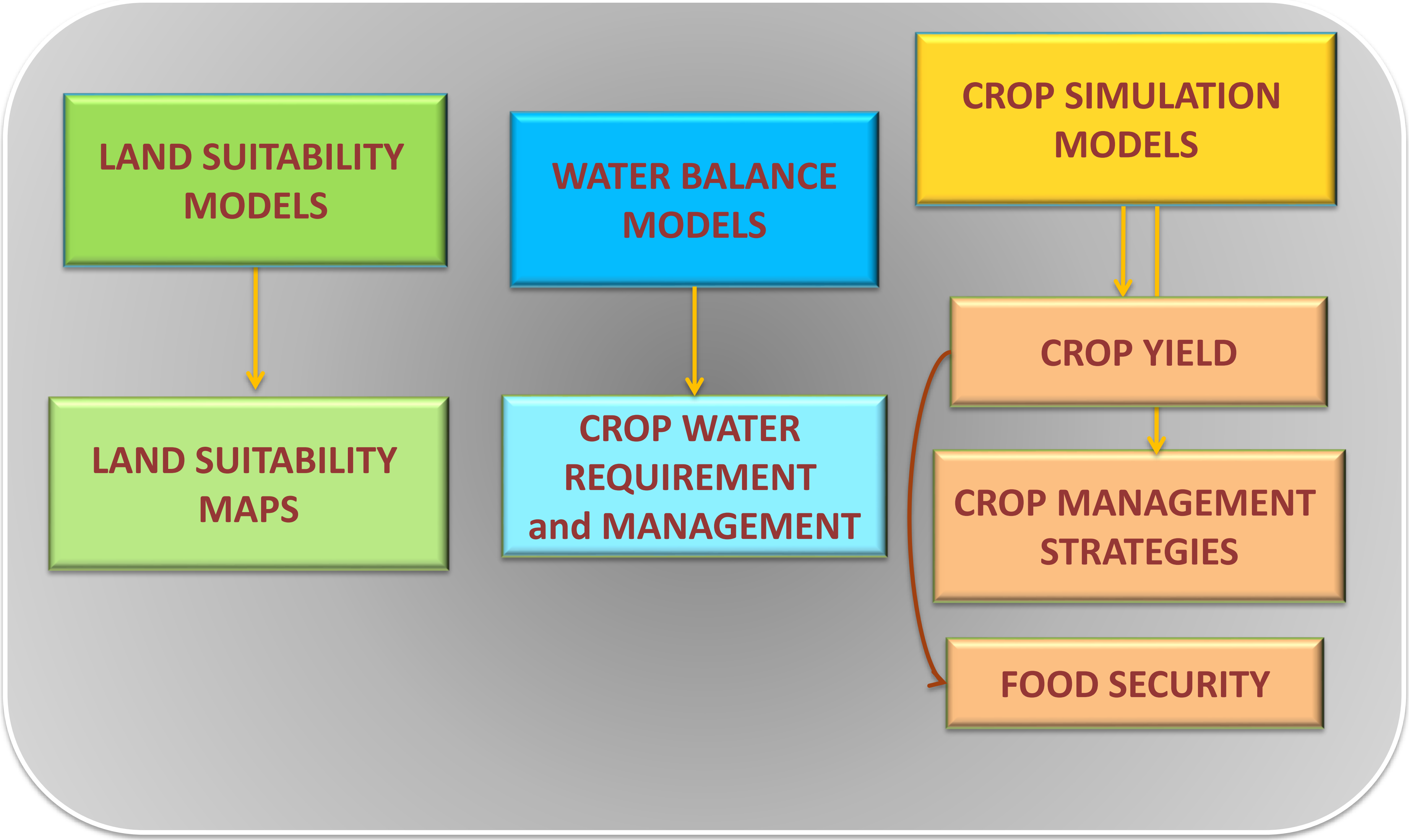
CLIMATE DATA

AGRICULTURAL MODELS

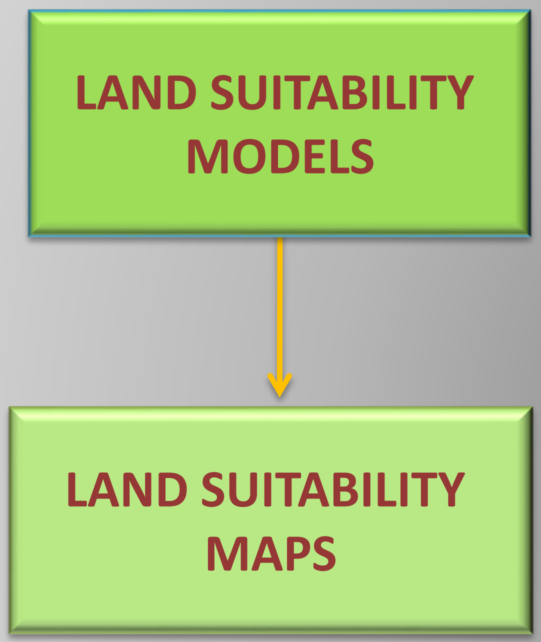
GCMs



Agricultural modeling



Agricultural modeling

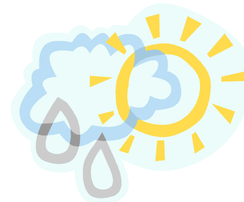


LAND CAPABILITY/ SUITABILITY

Land suitability analysis

- Characterize **climate, soil** and relevant land conditions (**optimal and limiting factors**) for the cultivation of a particular **crop/cultivar**

- Assess **suitability**, or the ability **of the land to meet the crop requirements**, in terms of water requirements, temperature, nutrients, workability, etc.

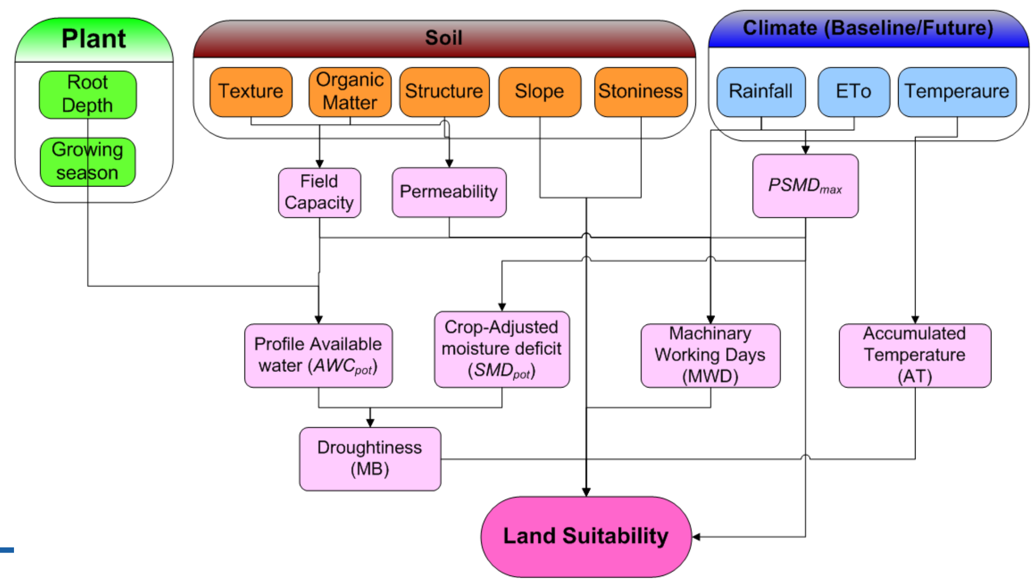


PRESENT CLIMATE

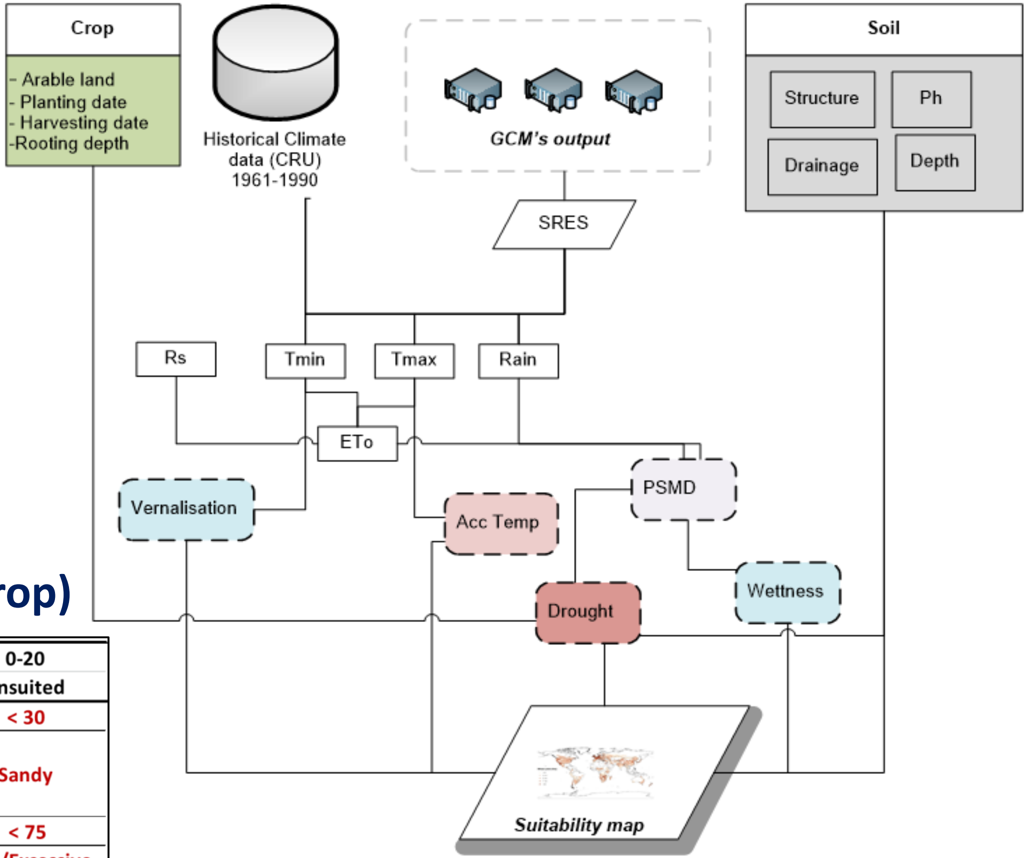
The crop today

CLIMATE CHANGE

The crop tomorrow



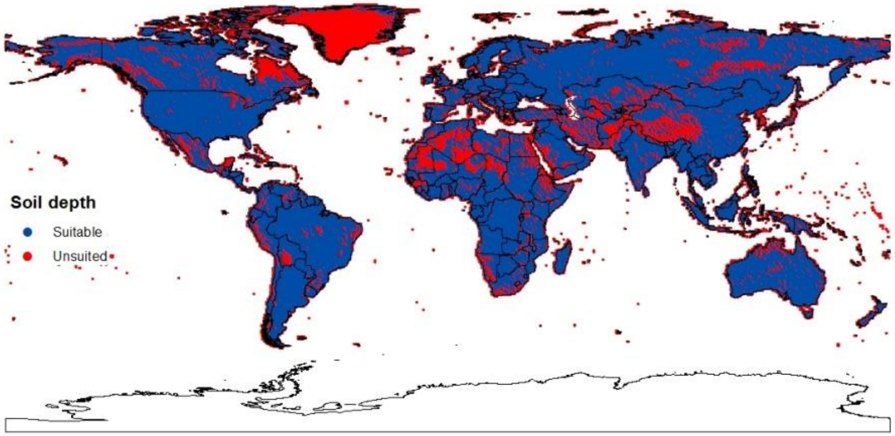
Flow chart of winter wheat land suitability model

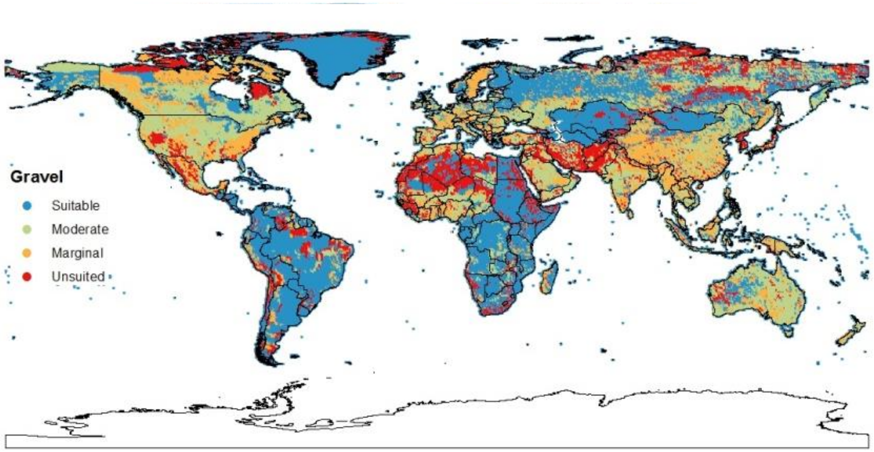


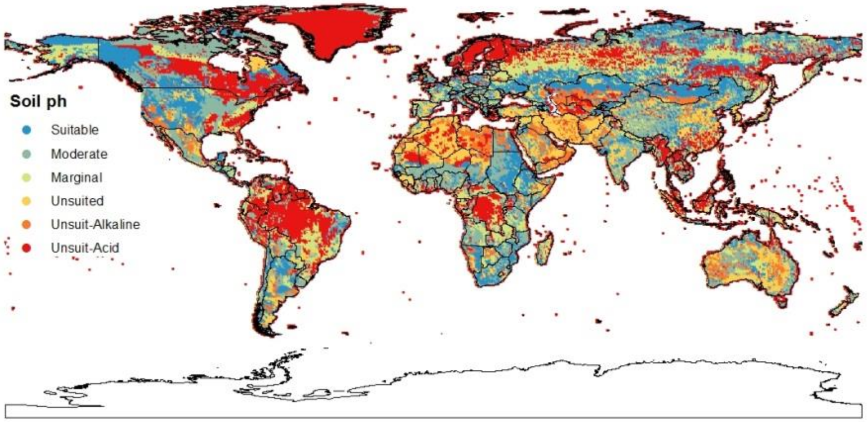
Classification parameters (winter wheat crop)

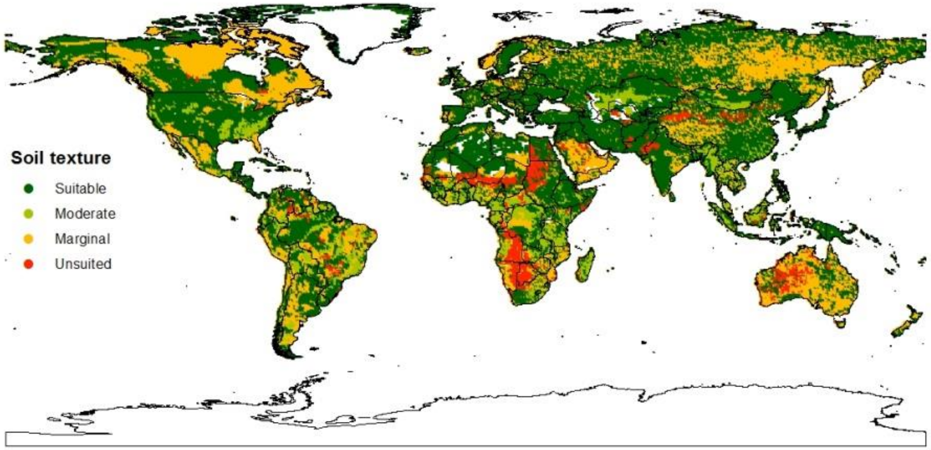
	Prod. Rating %	80-100	30-80	20-30	0-20
	Parameter	Suitable	Moderate	Marginal	Unsuited
Soil	Soil depth (cm)	> 120	120-100	100-50	< 30
	Soil texture	Other	Sandy clay; Sandy clay loam	Loamy sand	Sandy
	AWC (mm/m)	> 150	110-150	110-75	< 75
	Drainage	Well	Moderate	Imperfect	Poor/Excessive
Nutrient retention	pH	7.5-6.5	6.5-5.5	5.5-5	<5 or > 8
	CEC	> 24	16-24	8 - 16	< 8
	OM (%)	> 1.5	1.5-1	1-0.5	< 0.5
Mechanization	Gravel (%)	0-3	3 - 9	9 - 20	> 20
	Slope (%)	0 -2	2 - 4	4 - 8	> 8
Climate	Acc temp(C)	> 1750	1500-1750	1200-1500	< 1200
	Vernalization (^{o}C)	-4- 17			< -4 or > 17
	PSMDmax (mm)				< 75
	Droughtiness	> 0	0- -19	-19--30	< -30
	Tot. rain (mm)	> 450	350-450	250-350	< 250

Soil suitability





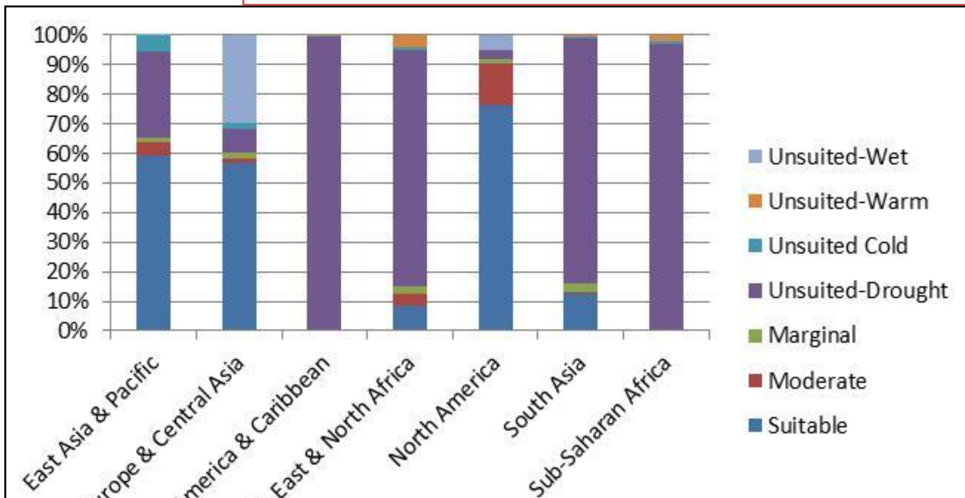




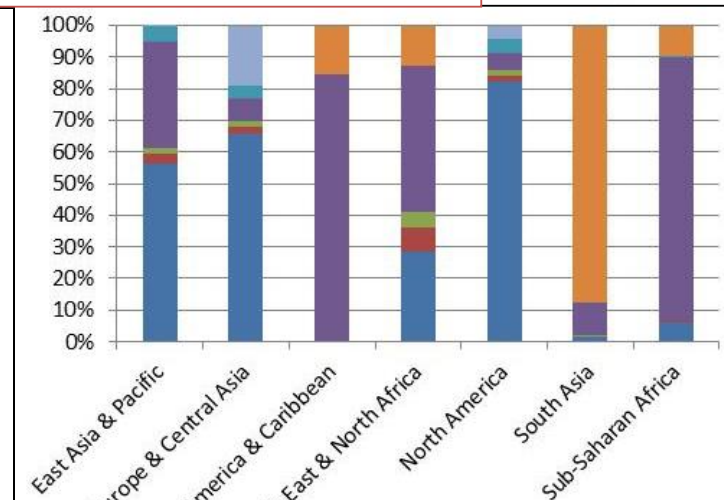
Baseline land suitability of winter wheat

Rainfed

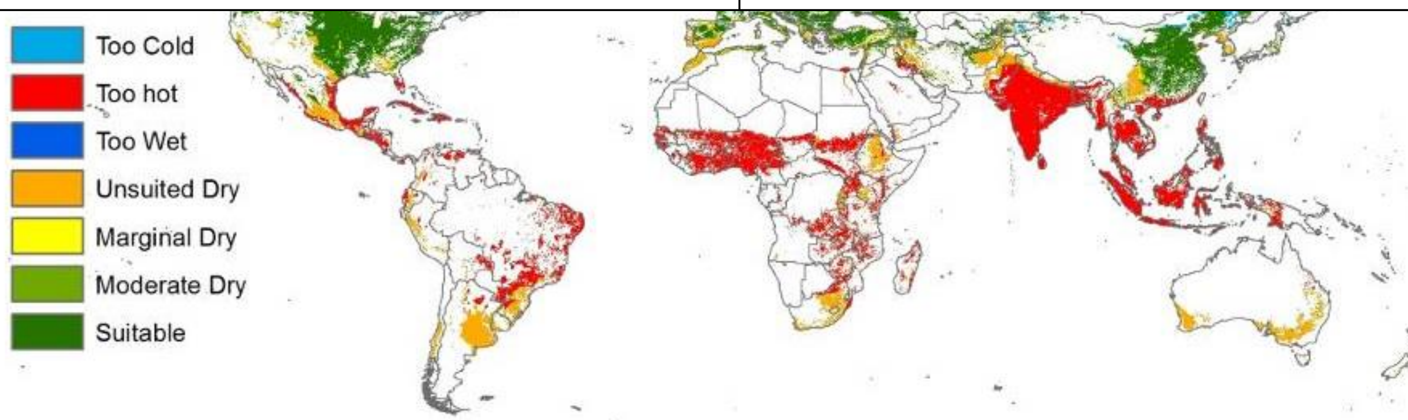
Percentage of area per land suitability class



(1961-1990)



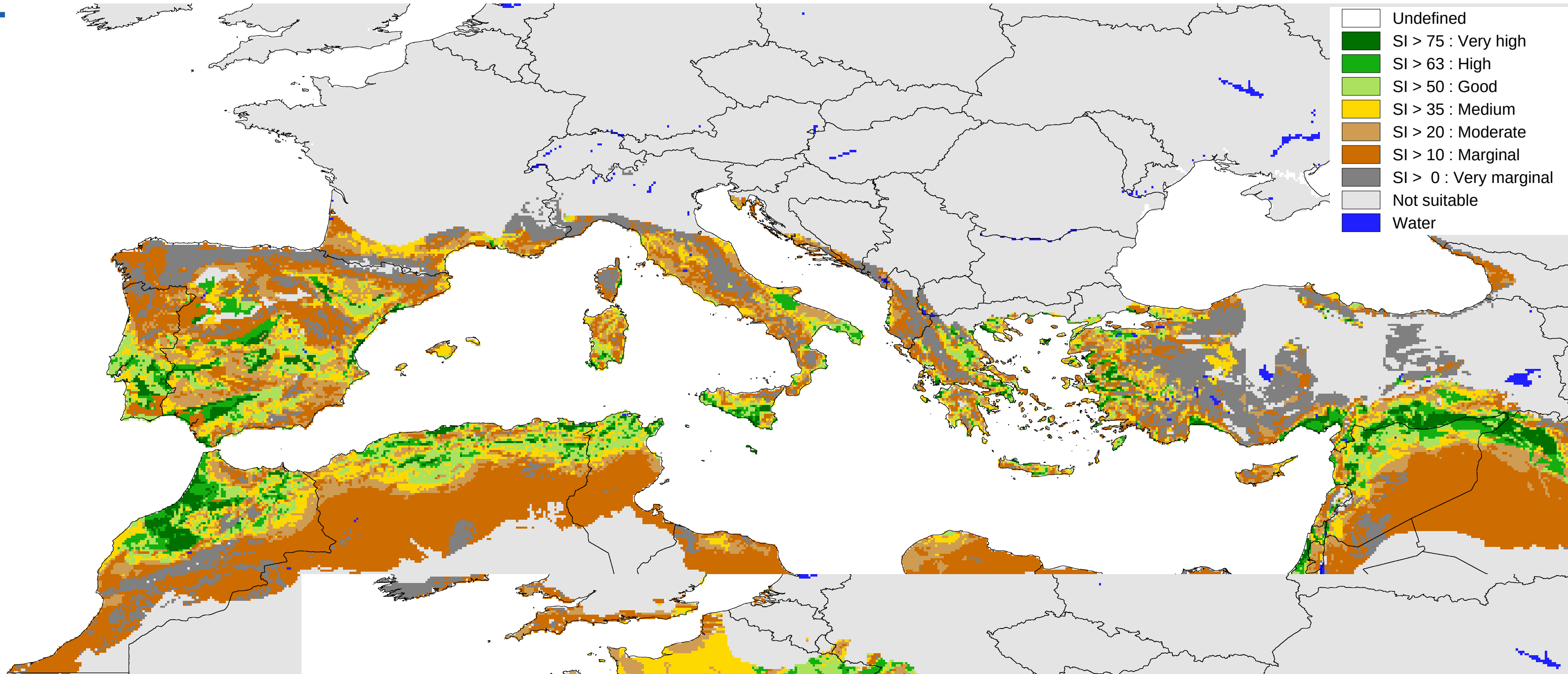
(2050)



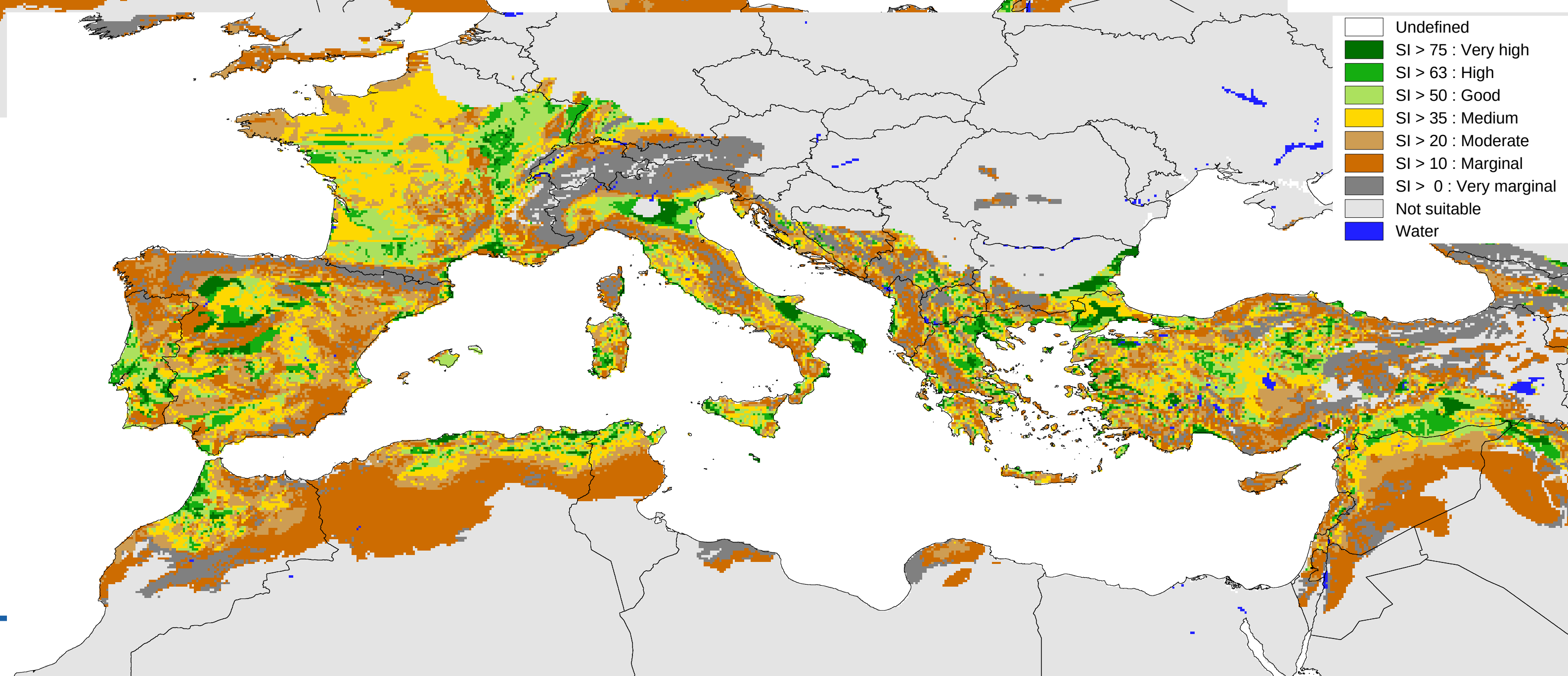
LAND CAPABILITY/ SUITABILITY

Land suitability for olive in Euro-Mediterranean Basin

Olive Present period (1990)



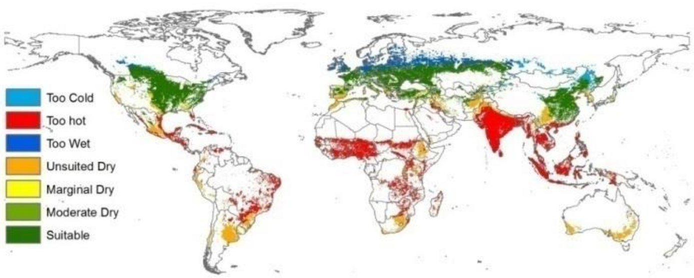
Olive – 2080 HadCM3 A2



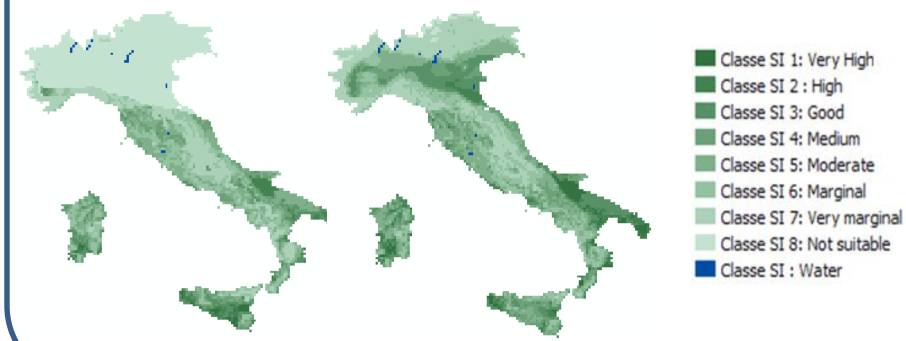
LAND CAPABILITY/ SUITABILITY

Spatial scales of application

Wheat - 2050

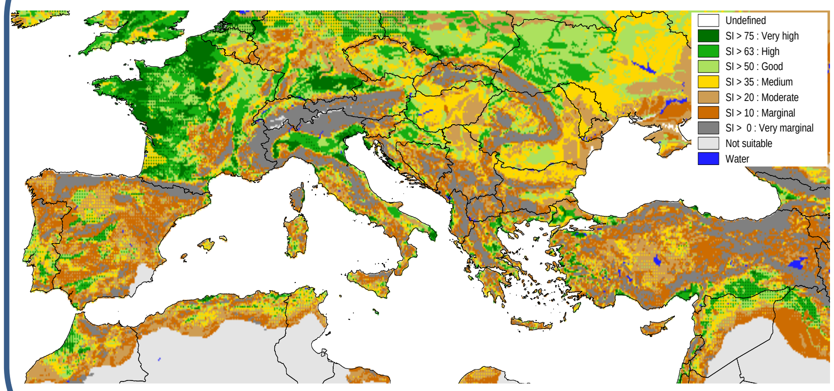


1990 2080 Olive

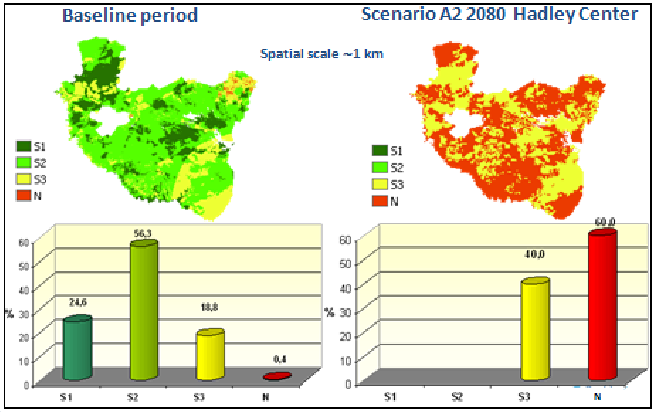


Global *Regional* *National* *Local*

Wheat – 2080



Wheat 1990 2080



Agricultural modeling

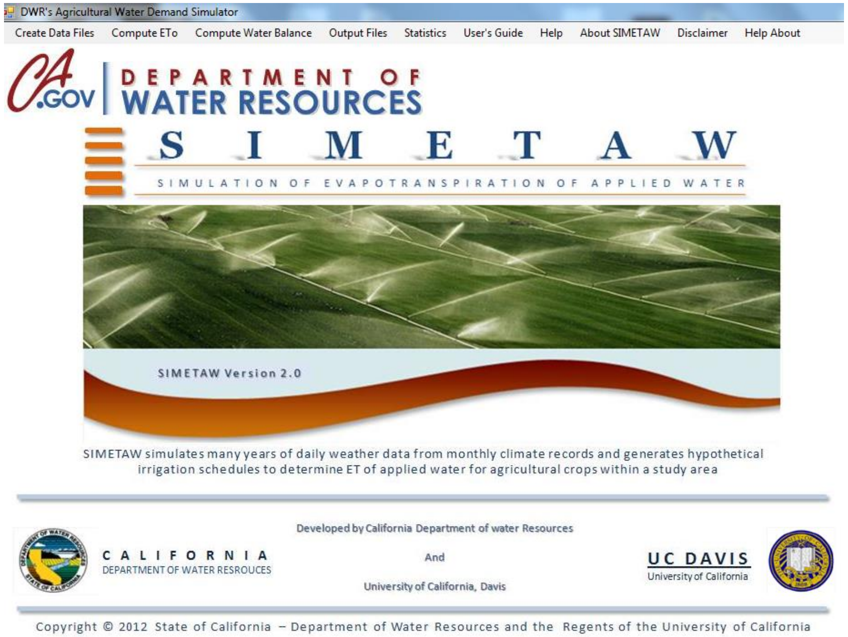
WATER BALANCE MODELS

↓

CROP WATER REQUIREMENT and MANAGEMENT

SIMETAW#

Simulation of Evapotranspiration of Applied Water (Snyder et al., 2004; Mancosu et al., 2015)



- user friendly
- daily soil water balance
- irrigation requirement

Agricultural water demand planning for the California Water Plan

ETaw

Evapotranspiration of Applied Water

Evapotranspiration of water that is diverted from streams and canals or pumped from ground water that is applied and contributes to seasonal crop evapotranspiration

$$ET_{aw} = \sum_{i=1}^{n} NA_{c,i}$$

SIMETAW# MODEL: INPUT DATA

climate data + soil information + crop & irrigation management

=

Irrigation Requirements by crop

- Observed or projected climate data
  - solar radiation (MJ m^{-2} day^{-1})
  - wind speed (m s^{-1})
  - dew point temperature (°C)
  - precipitation (mm)
  - max & min temperature (°C)
- Soil water holding characteristics
- Crop management
  - planting and ending date
  - hectares planted
  - maximum rooting depths
  - percentage shading of the ground
  - presence of cover crops
- Irrigation management
  - rain-fed or irrigated conditions (gravity, sprinkler, micro-sprinkler, drip)
  - irrigation frequency during the initial growth
  - percentage of the full irrigation requirement
  - system distribution uniformity

CALCULATIONS

FLUXES

- ✓ Kc corrections (near-bare soil evaporation, ETo, and % shading)
- ✓ ETo (under different CO_2 concentration levels)
- ✓ ETc and ETa

WATER BALANCE

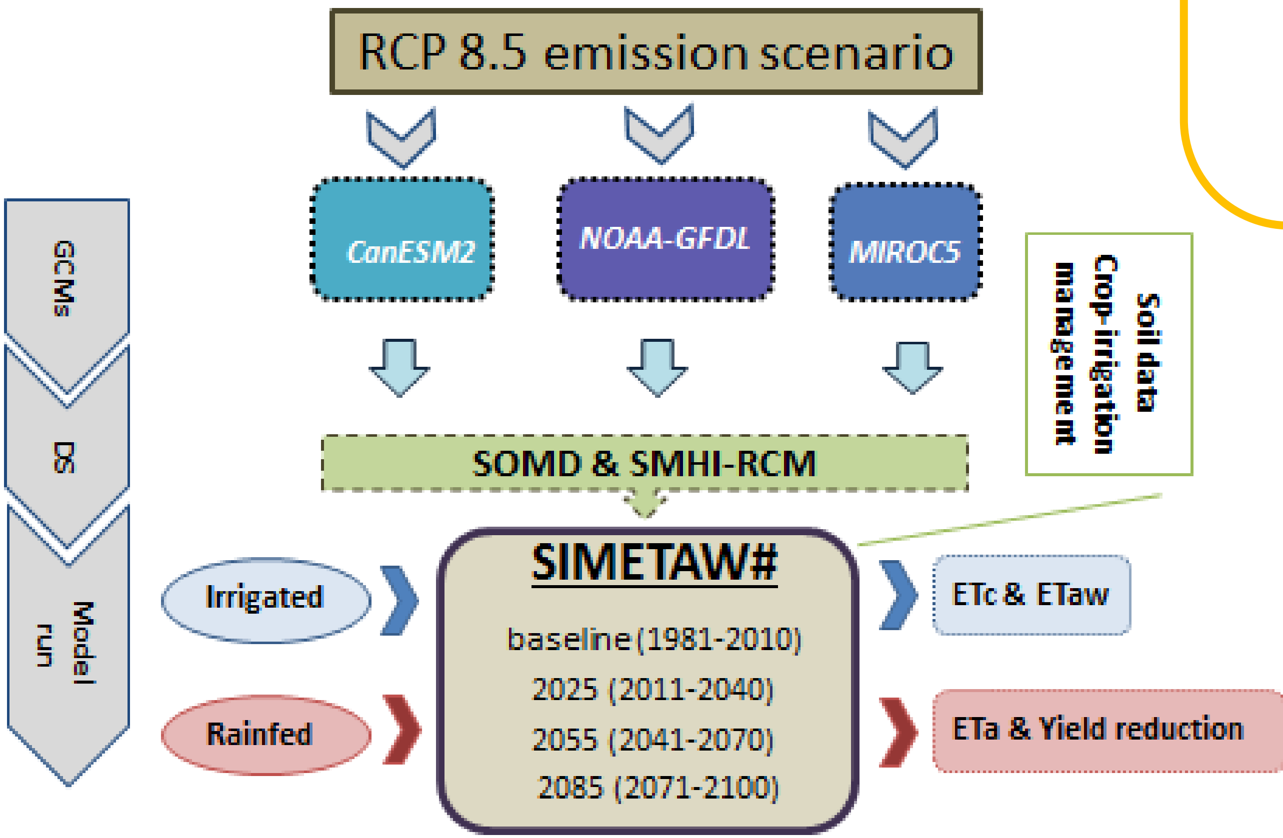
- ✓ Daily soil water balance
- ✓ Net irrigation application for event
- ✓ Numbers of irrigations

YIELD REDUCTION

- ✓ Stress coefficient (Ks) and yield reduction relative to full irrigation (deficit and rainfed conditions)

Application of SIMETAW in SSA

ClimAfrica



Crops

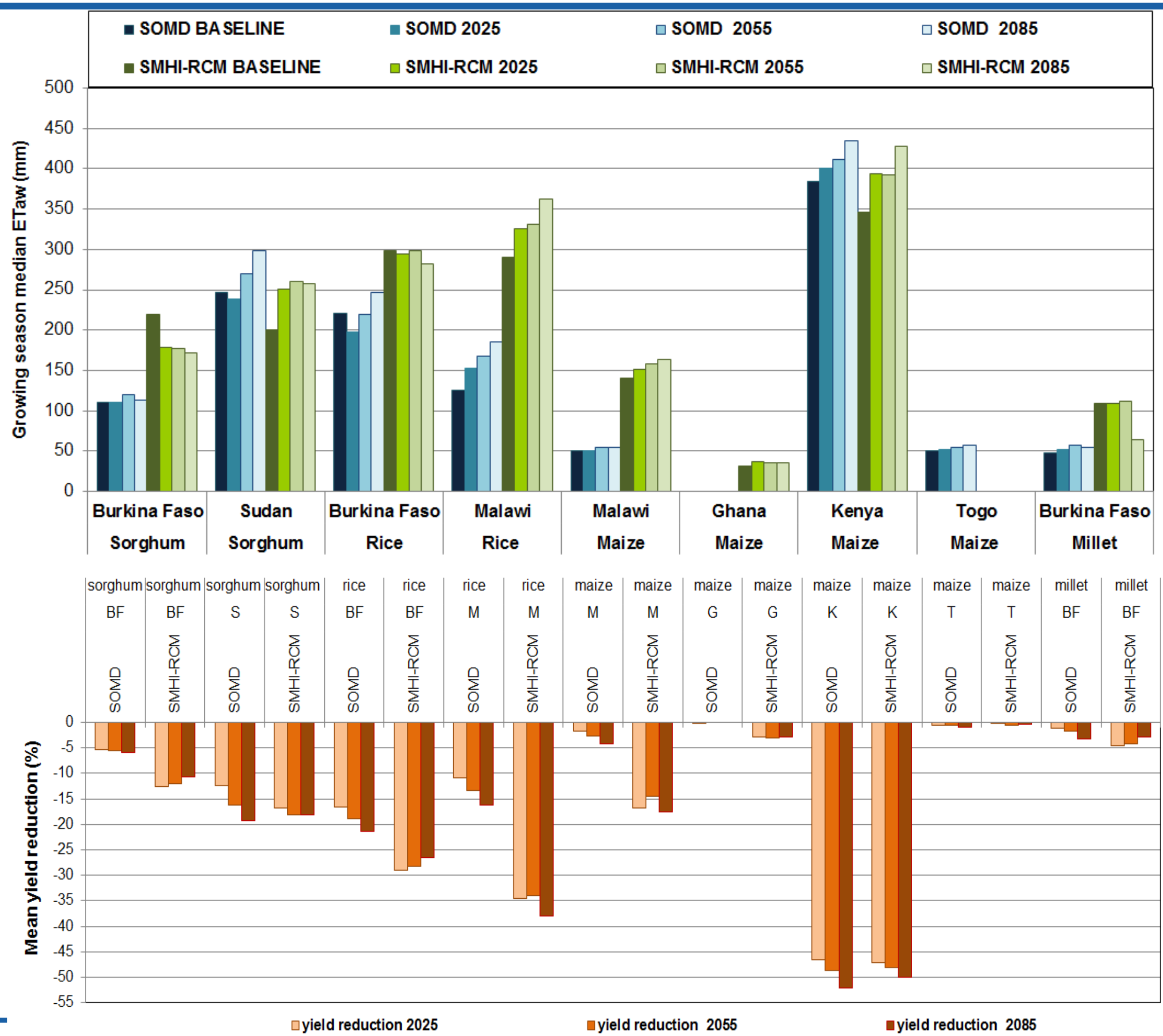
- ✓ Sorghum
- ✓ Maize
- ✓ Millet
- ✓ Rice

(Mancosu, 2014)

WATER BALANCE MODELS

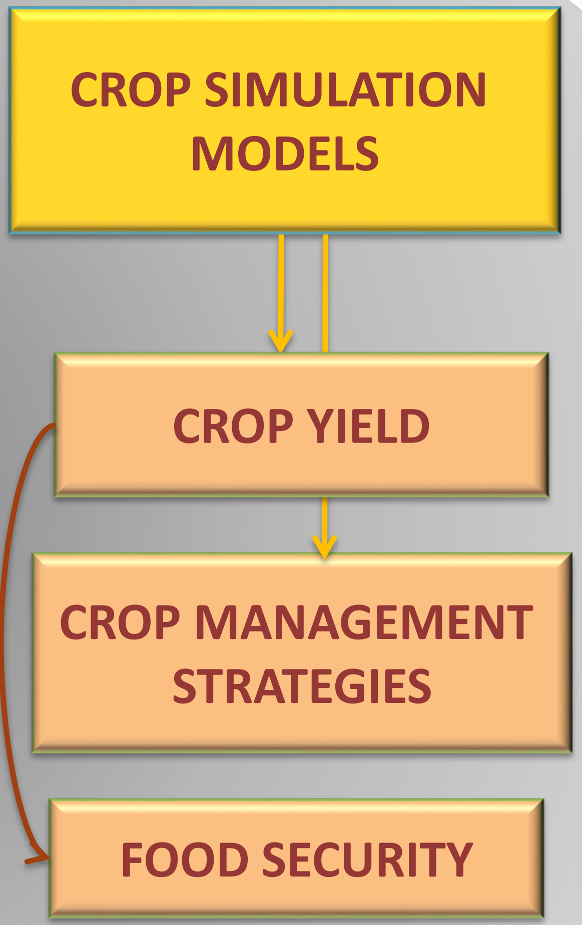
Climate change impacts on ETaw (irrigated) & Yield reduction (rainfed)

- ✓ Greater values for SMHI-RCM than SOMD
- ✓ NO uniform trend
- ✓ Kenya (Maize) highest irrigation requirements and yield reduction with both DS techniques
- ✓ No impacts in Ghana & Togo



(Mancosu, 2014)

Agricultural modeling



Issues for Agriculture in the 21st Century

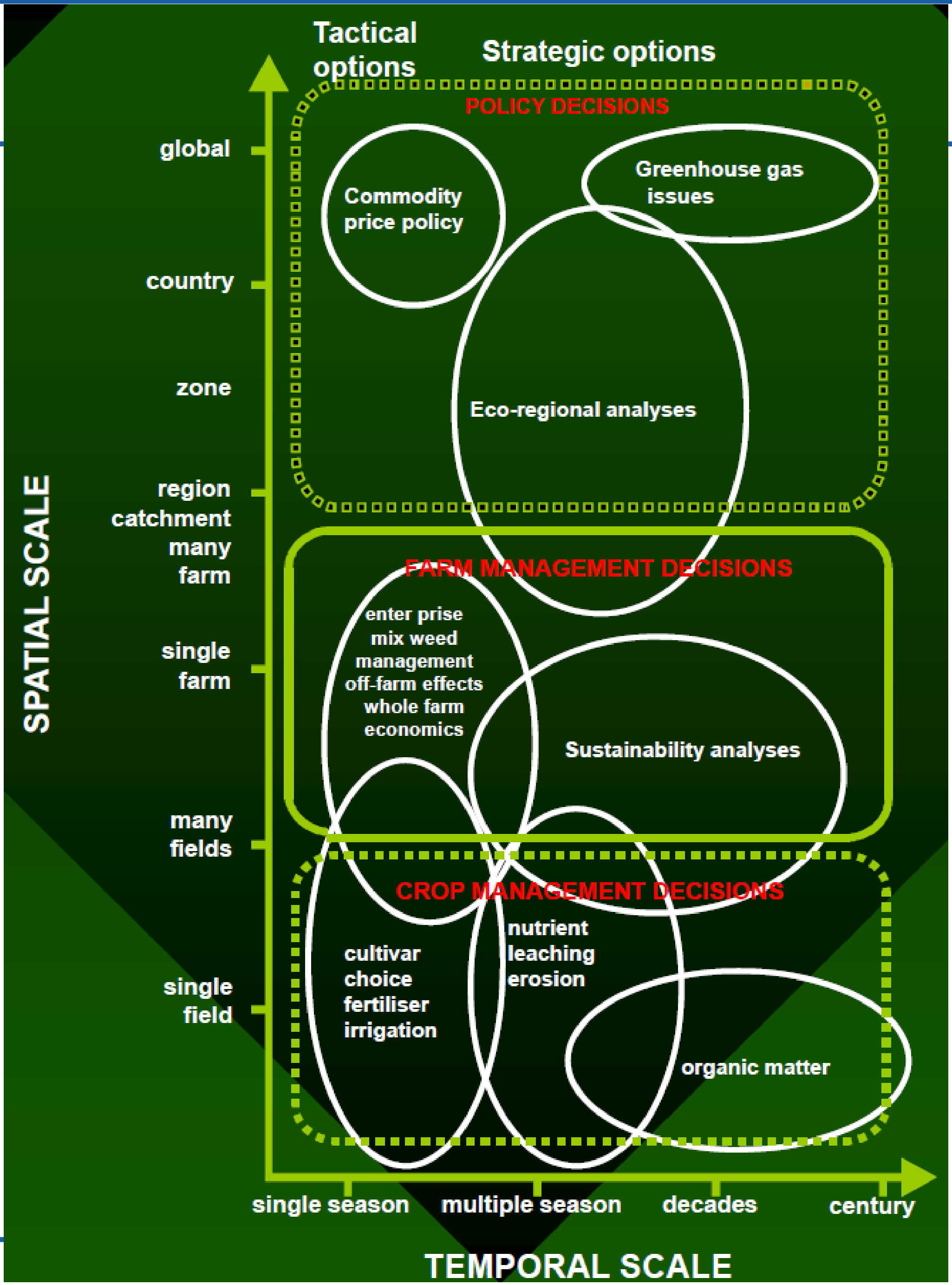
- **Food security**
- **Climate related risks** (climate change and variability)
- Increased demands for agricultural products
- Increased pressures on **natural resources, as water**
- Rapid changes in technology
- Information needed for **decision making**
- Gap between information needed and that created by traditional agronomic research
- High and increasing **costs of field experimentation**
- Need for **integration of knowledge**

AGRICULTURE

▪ Spatial and Temporal Issues

The agricultural system is a **complex** system that includes many interactions between biotic and abiotic factors

- Some of these factors can be modified by farmer interactions and intervention, while others are controlled by nature



Modelling agricultural systems

- A model is a mathematical representation of a real world system

- The use of models is very common in many disciplines, but the use of models in agricultural sciences traditionally has not been very common

Crop Simulation Models

- integrate the current state-of-the art scientific knowledge from many different disciplines

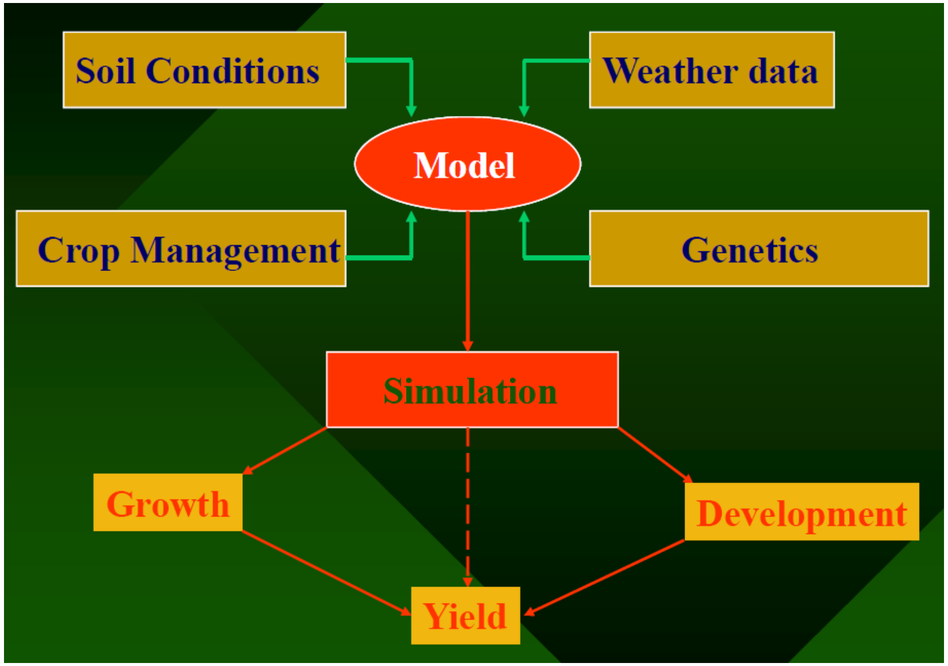
(crop physiology, plant breeding, agronomy, agrometeorology, soil physics, soil chemistry, soil fertility, plant pathology, entomology, economics, …)

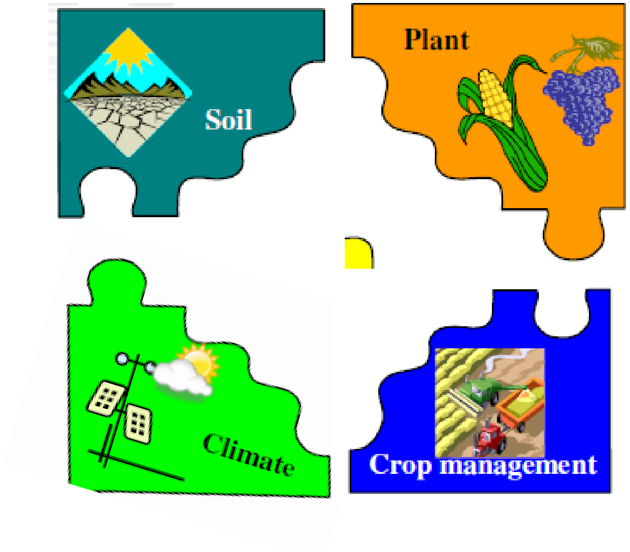
- have been developed for various purposes:

irrigation management, pest management, precision agriculture, yield forecasting, crop rotation analysis, nutrient management, land use planning, climate change assessment, economic risk,…

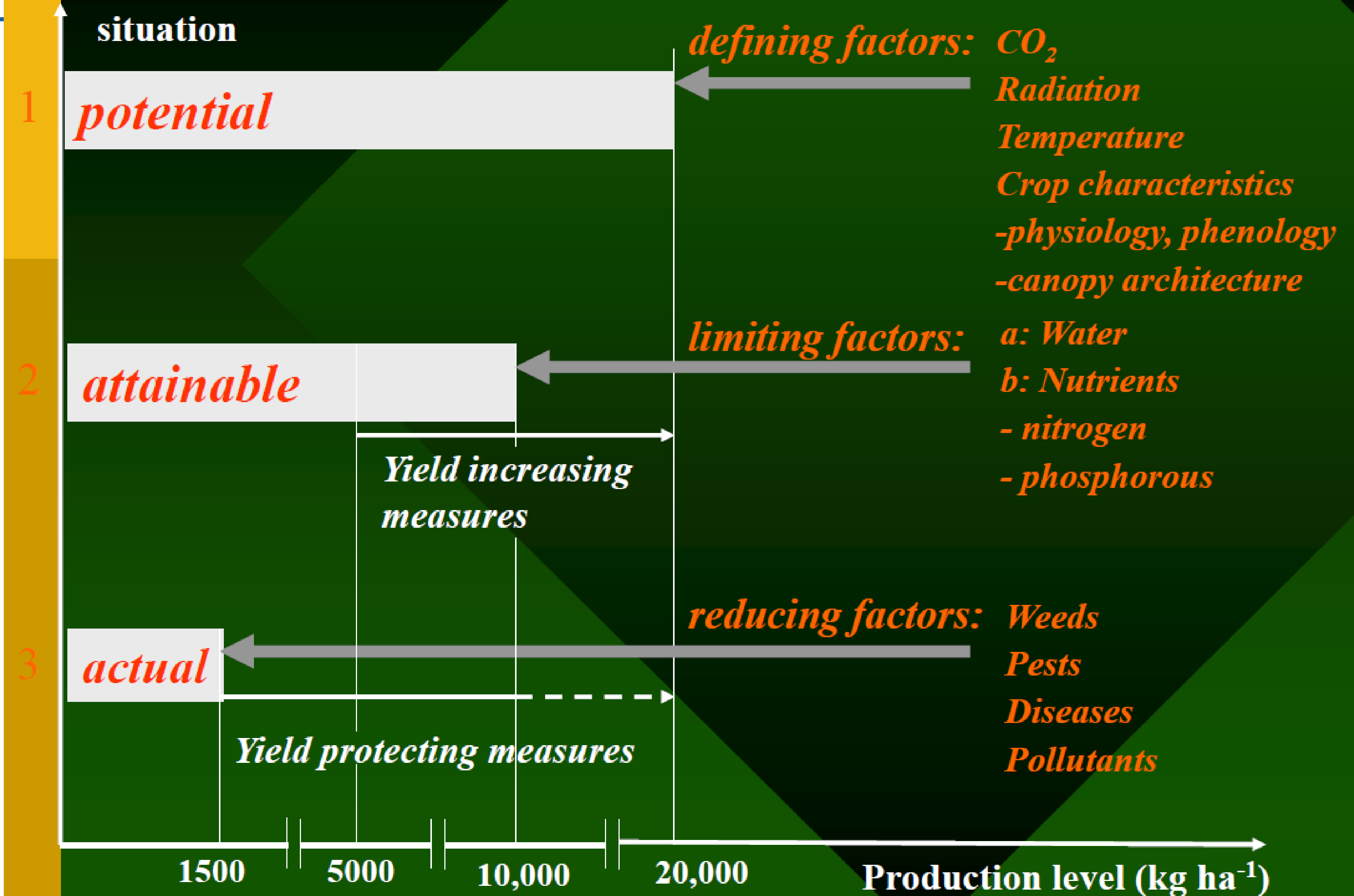
Crop simulation models

- Calculate or predict ***crop growth and yield*** as a function of:
  - soil conditions
  - weather conditions
  - crop management
  - genetics





Crop Model Concepts



Source: World Food Production: Biophysical Factors of Agricultural Production, 1992.

Crop simulation models

What if…?

Applications

- Diagnose problems (Yield Gap Analysis)
- Precision agriculture
  - -Diagnose factors causing yield variations
  - -Prescribe spatially variable management
- Irrigation management
- Soil fertility management
- Plant breeding and Genotype * Environment interactions
- Yield prediction for crop management
- Adaptive management using climate forecasts
- Climate variability
- Climate change
- Soil carbon sequestration
- Targeting aid (Early Warning)

DSSAT-CSM

CROPSYST

STICS

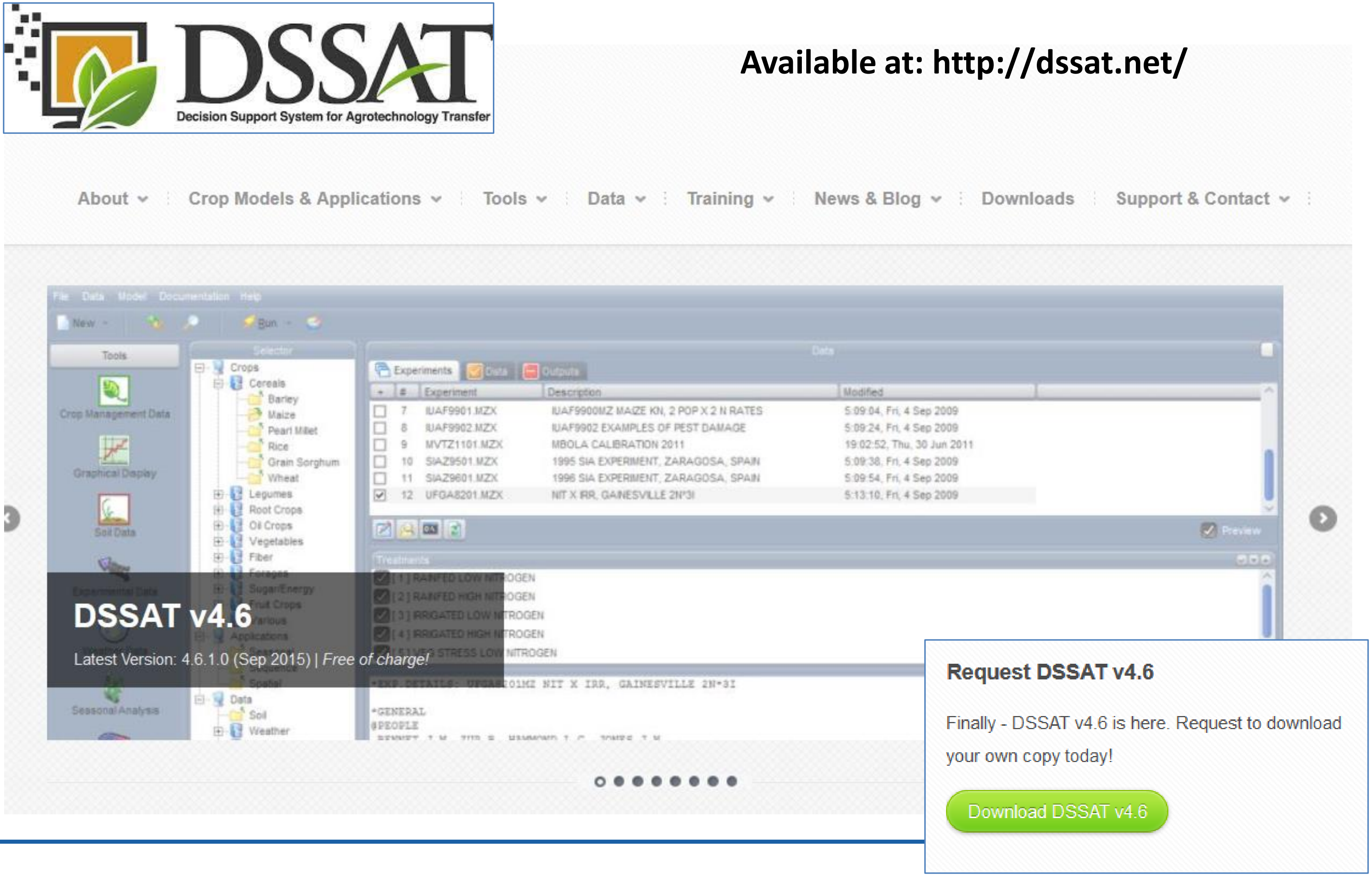
APSIM

SIRIUS

WOFOST

DSSAT

Available at: http://dssat.net/



DSSAT

- Decision Support System for Agrotechnology Transfer (DSSAT) is a software application program that comprises **crop simulation models for over 42 crops** (as of v4.6).

- DSSAT is supported by **data base management programs** for **soil, weather, and crop management and experimental data**, and by utilities and application programs.

- The crop simulation models in DSSAT **simulate growth, development** and **yield** as a function of the soil-plant-atmosphere dynamics

- DSSAT has b
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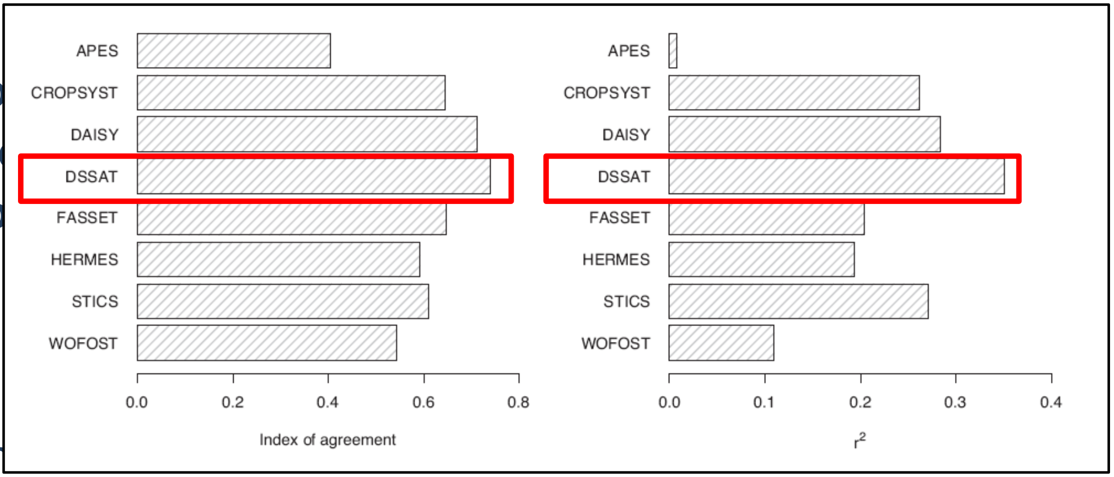
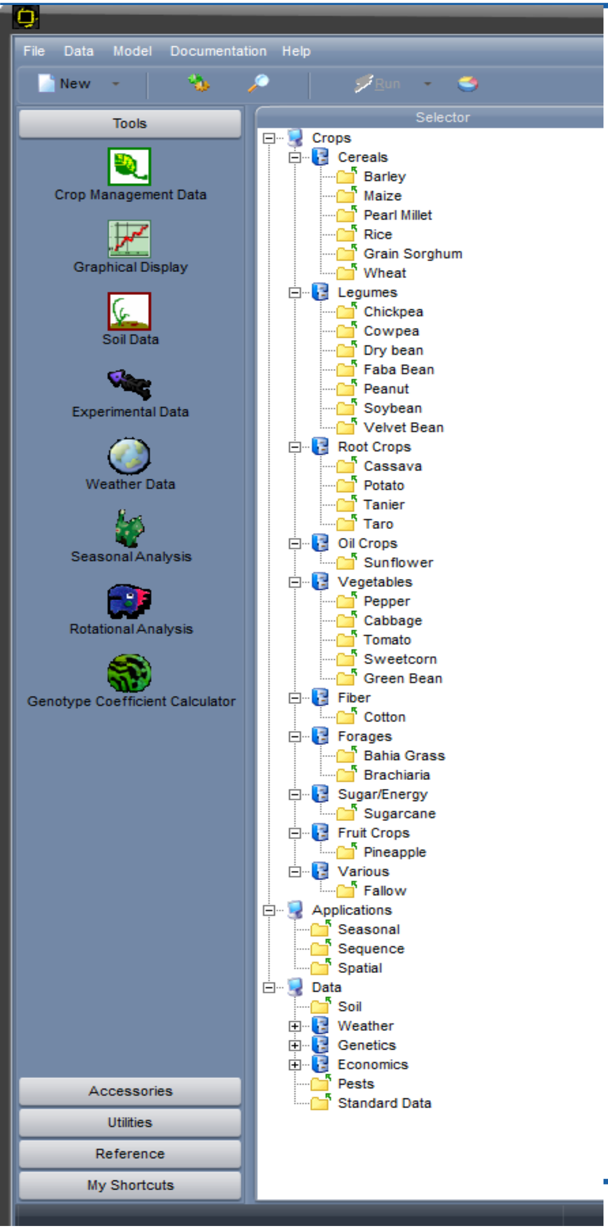
the impact o

- It is one
applications
performing r



Source: Palosuo et al., 2011

DSSAT Cropping System Model

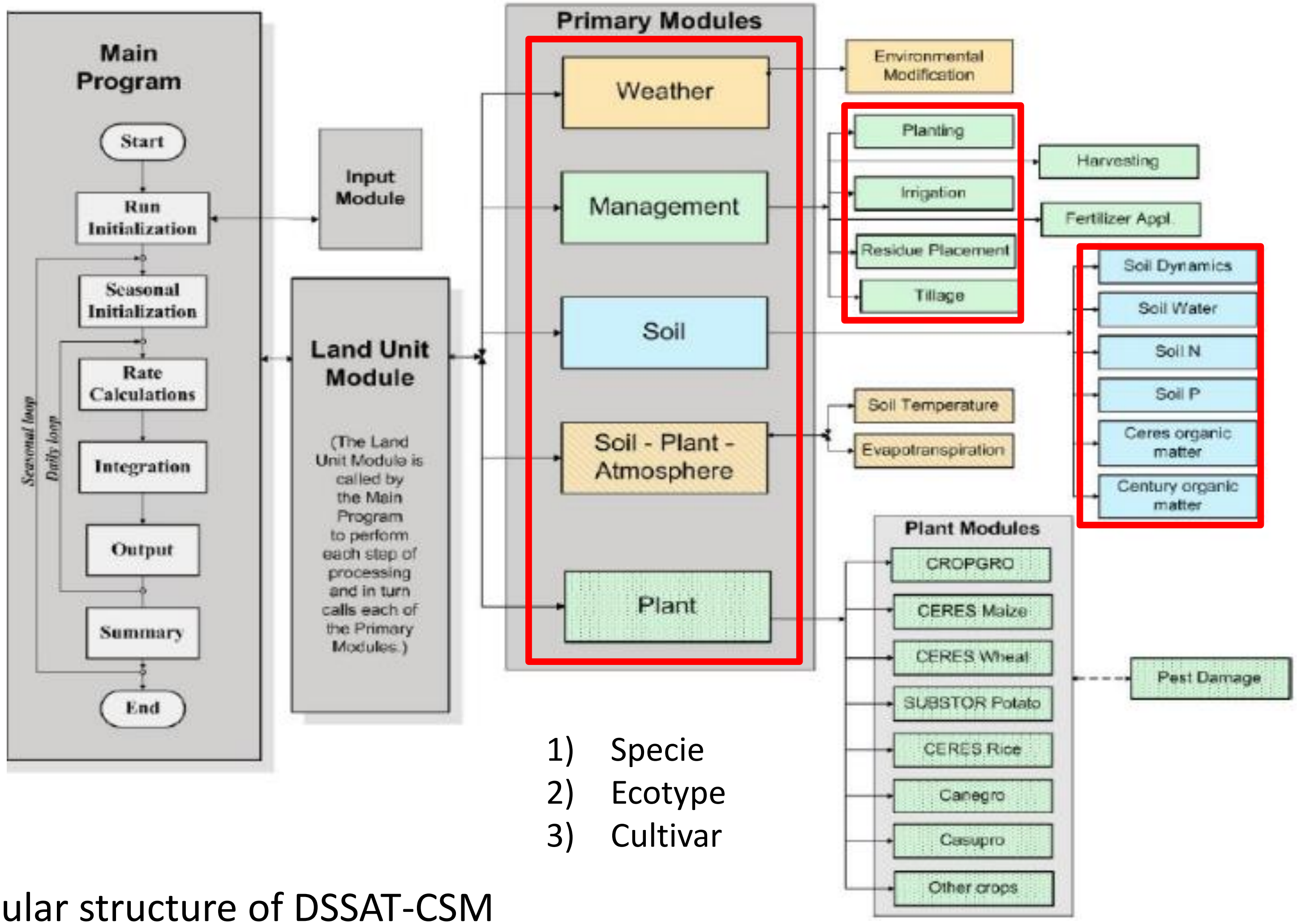


- CERES
  - Maize
  - Wheat
  - Sorghum
  - Rice
  - Barley
  - Millet
- [Other crops]
  - Potato
  - Sweetcorn
  - Sugarcane
  - Cassava
  - [Sunflower]
  - [Forages]

- CROPGRO (Legumes)
  - Soybean
  - Peanut
  - Common bean
  - Faba bean
  - Chickpea
  - Cowpea
  - Velvet bean
- CROPGRO (Other)
  - Cotton
  - Tomato
  - Bell Pepper
  - Cabbage
  - Green bean

DSSAT-CSM

- Based primarily on agronomic objectives
- Modularity
- Simulation of various processes
- Several operation modes
- Three genotype levels



1) Specie
2) Ecotype
3) Cultivar

Components and modular structure of DSSAT-CSM (Jones et al., 2003; Hoogenboom et al., 2010).

Cropping System Model (CSM) – Genetic Coefficients

- **Species parameters and functions**

Defines the response of a crop to environmental conditions, including temperature, solar radiation, CO_2 and photoperiod, as well as plant composition and other functions and parameters

- **Ecotype coefficients**

Defines coefficients for groups of cultivars that show similar behavior and response to environmental conditions.

- **Cultivar coefficients**

Cultivar and variety specific coefficients, such as photothermal days to flowering & maturity, sensitivity to photoperiod, seed size, etc.

DSSAT

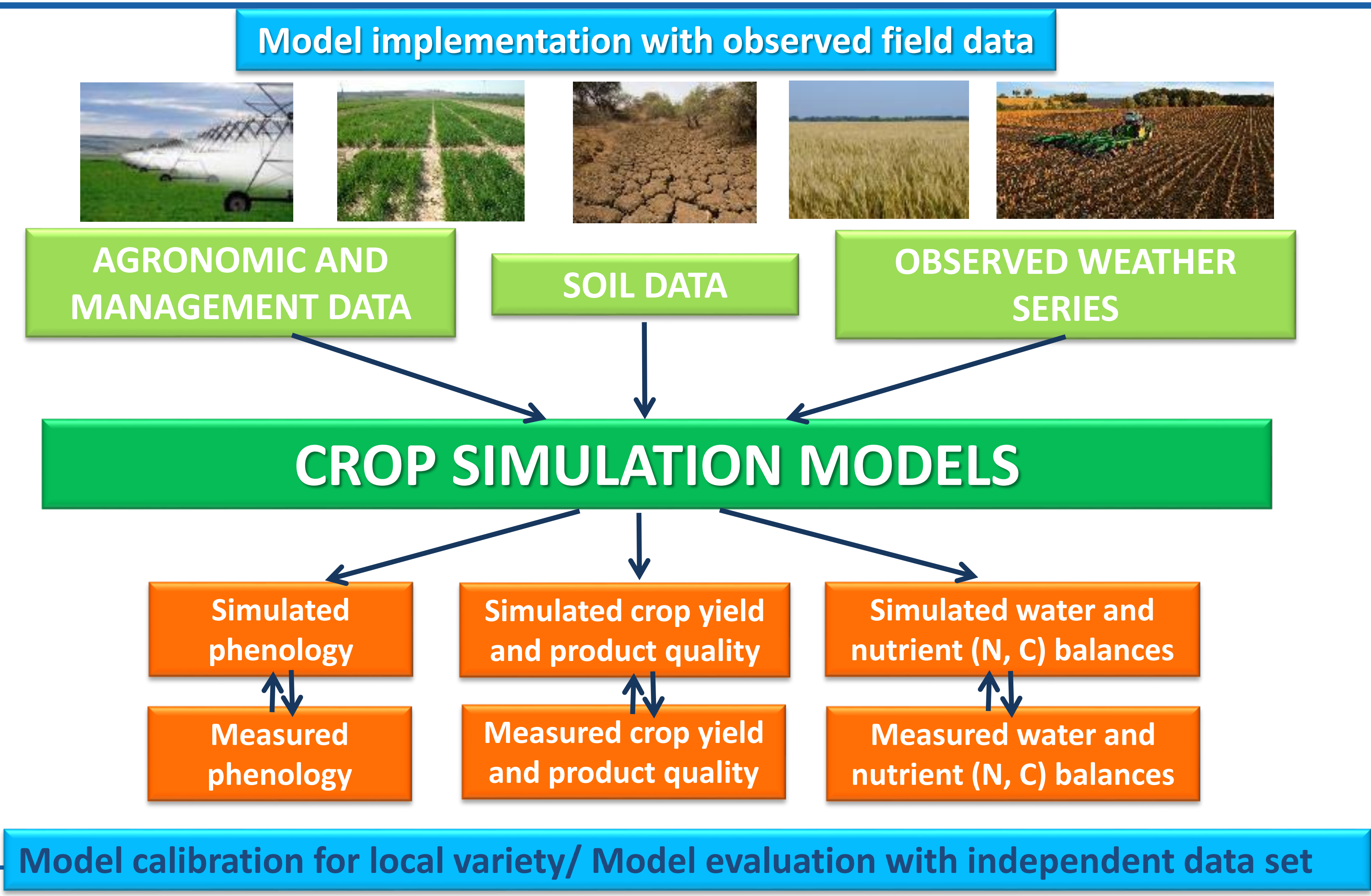
Minimum Data Set

- Level 1 - Operate crop simulation models
- Level 2 - Evaluate model performance
  - Calibrate, estimate parameters
- Level 3 - Develop models (Maximum)

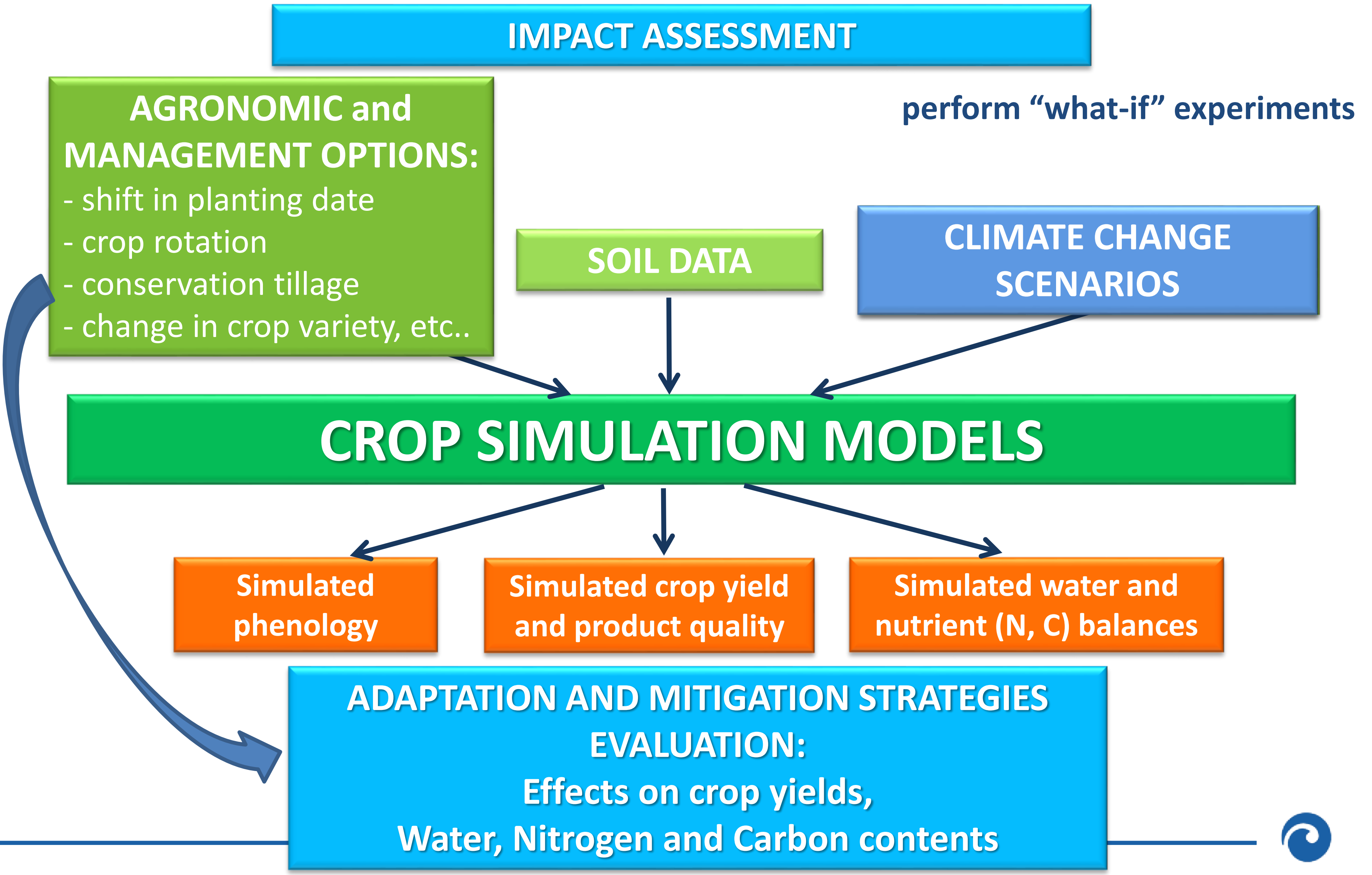
Crop data for model operation
•**Cultivar name and type** •**Initial conditions:** previous crop/crop residue •**Planting/sowing date and depth; row spacing, plant population** •**Irrigation and water management, dates, methods and amounts or depths** •**Fertilization types, quantities and date** •**Tillage type and date** •**Harvest schedule**

Crop data for model evaluation
•**Historical observed crop data:** - data of emergence - data of flowering - data of physiological maturity - canopy height at maturity - yield of appropriate economic unit (e.g. kernels) in dry weight terms - harvest product individual dry weight (e.g. weight per grain, weight per tuber) - damage level of pest infestation •**Initial conditions:** previous crop/crop residue •**Planting/sowing date and depth; row spacing, plant population** •**Irrigation and water management, dates, methods and amounts or depths** •**Fertilization types, quantities and date** •**Tillage type and date** •**Harvest schedule**

Methodology – model parameterization



Methodology – impact, adaptation, and mitigation



Assessment and prediction of

➢ AGRO-CLIMATIC Indexes

- Length of growing cycle
- Prec during the growing season
- ETc

➢ CROP YIELD and QUALITY

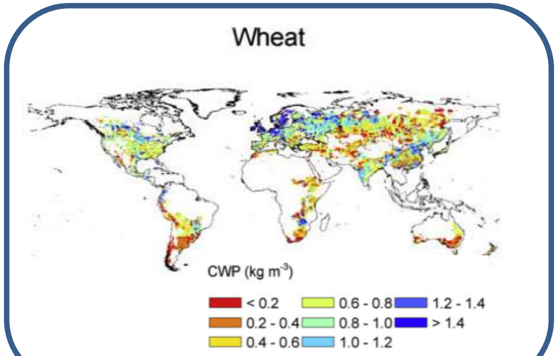
- Yield and product components

➢ WATER, CARBON and NITROGEN balances

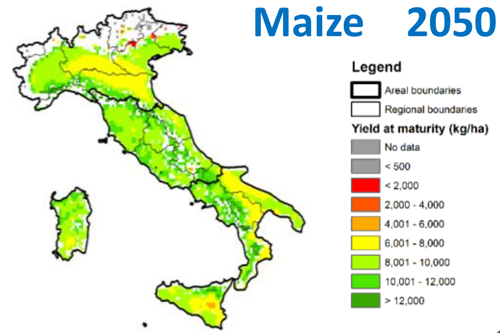
- Irrigation requirements
- Fertilization management
- Carbon sequestration

CROP SIMULATION MODELS

Crop models can be applied at different scales

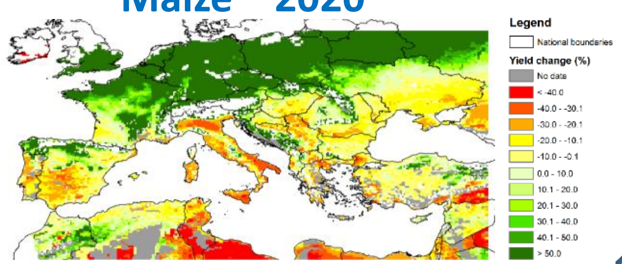


Maize 2050

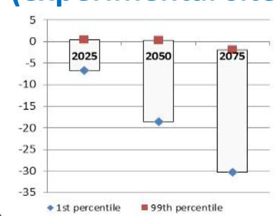


Global — Regional — National — Local

Maize 2020



Wheat (yield changes %)
(experimental site in Sardinia, Italy)



Mereu et al., 2010; 2014
Gallo et al., 2014

DSSAT applications:

For science
For consultancy

Local scale
National scale

ITALY and EUROPE *Wheat, Maize*

NIGERIA *Maize, Sorghum, Millet, Rice, Cassava*

SUB-SAHARIAN AFRICA *Maize, Sorghum, Millet*

Field scale - climate change impact assessment on wheat

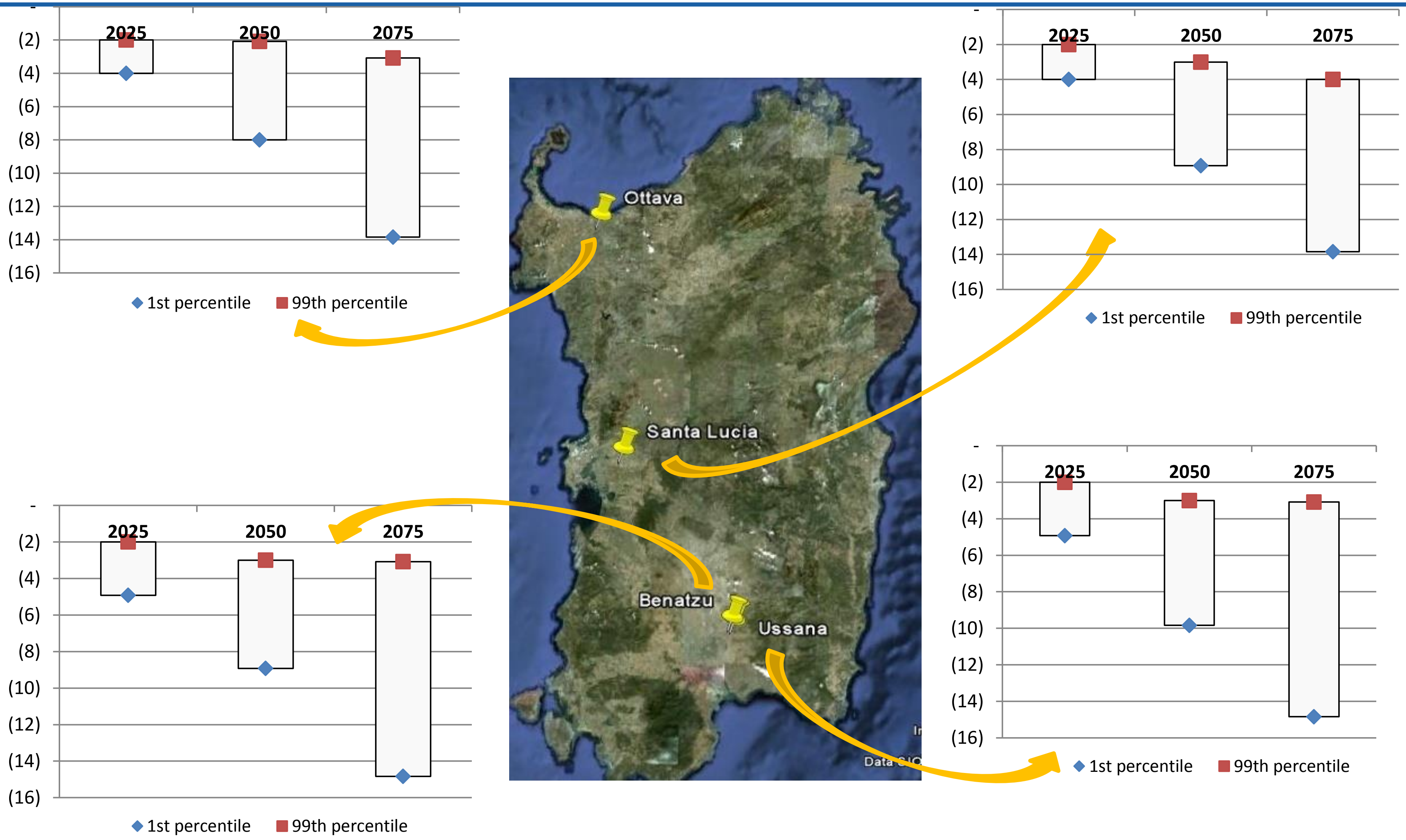
- For each experimental site, 27 climate change scenarios (statistical downscaling):
  - **3 GCMs**: HadCM3, ECHAM5 and NCAR
  - **3 versions**: low, middle and high
  - **3 future periods**: 2025, 2050, 2075

- Evaluation of *"direct"* and *"indirect"* effect of increased CO_2 concentration

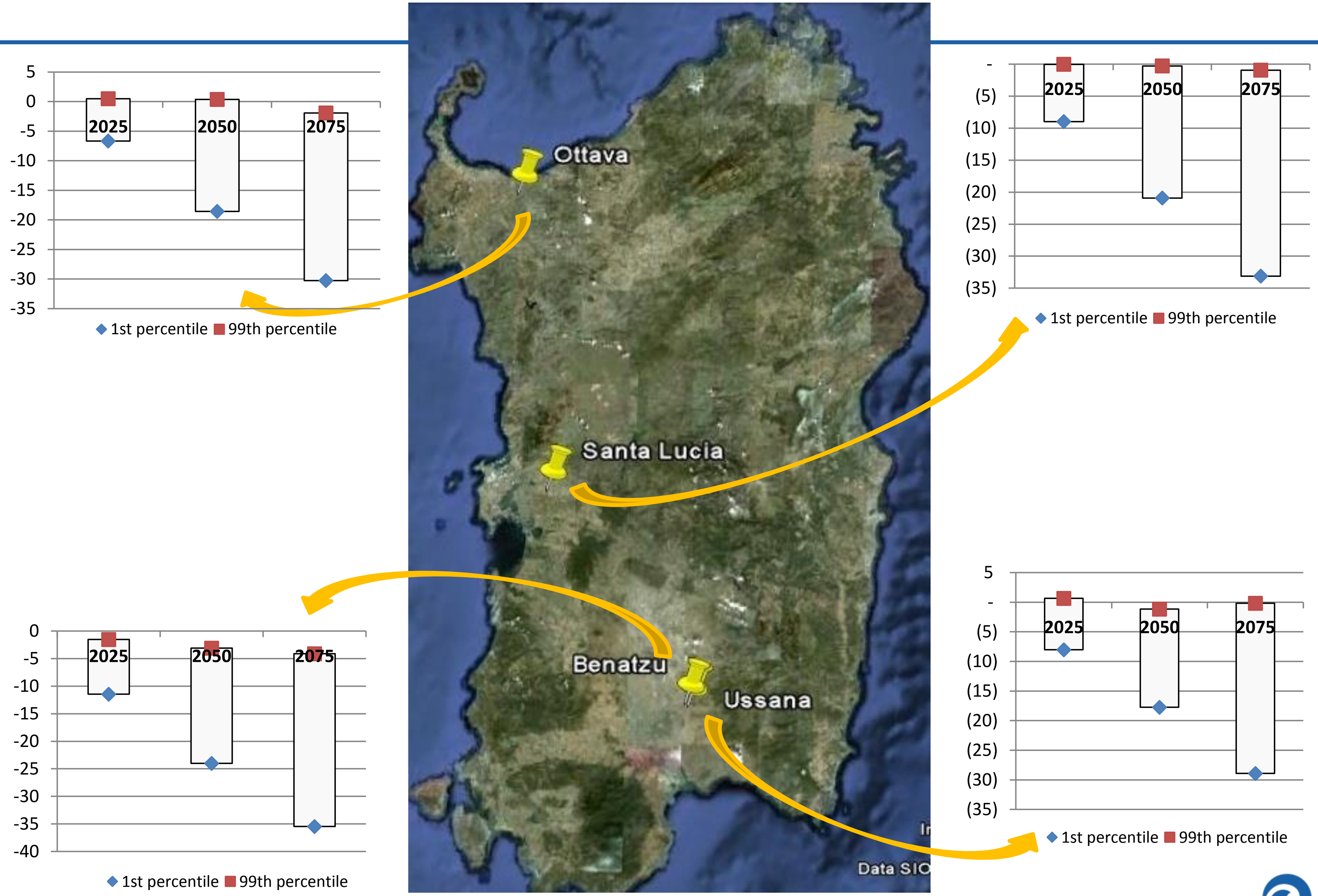
"indirect" effect of increased CO_2 concentration on climate conditions

"direct" effect of increased CO_2 concentration on plant photosynthesis and transpiration

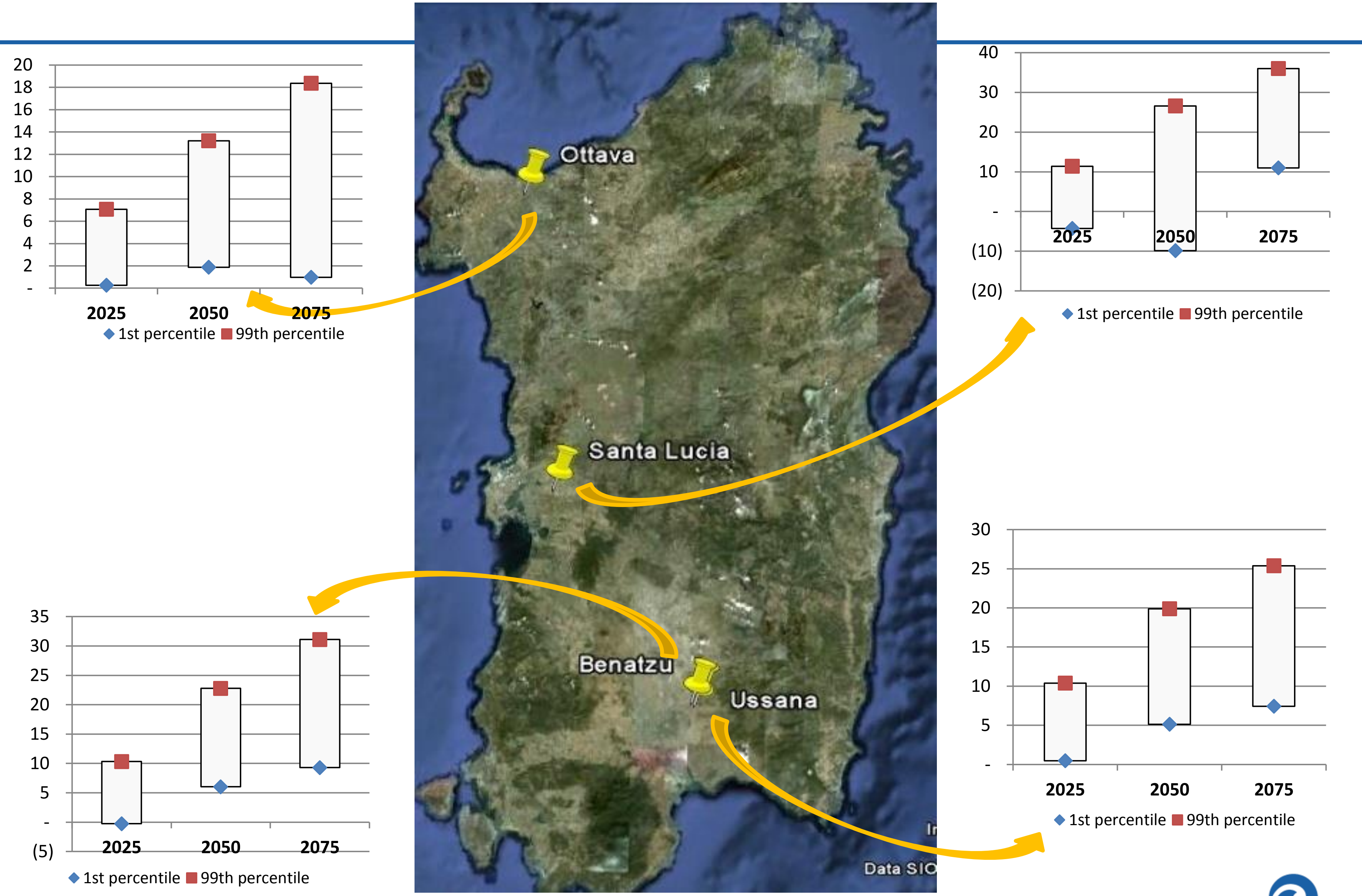
Climate change impact assessment on anthesis (dap)



Changes in wheat yield (%) without CO_2 direct effect



Changes in wheat yield (%) with CO_2 direct effect

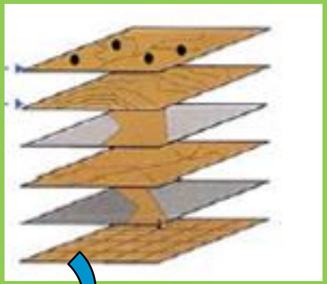


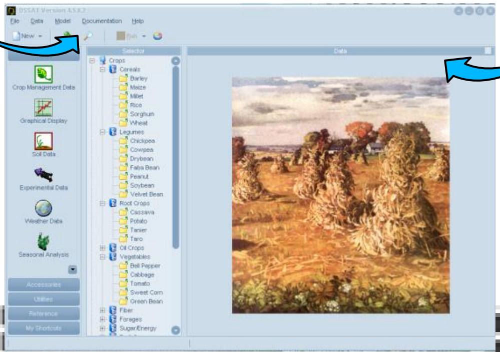
Crop simulation models - The DSSAT 4.5 - CSM

Site-specific inputs:
- CLIMATE
- SOIL
- CROP MANGEMENT
- CROP characteristics

....

Input maps (Netcdf):

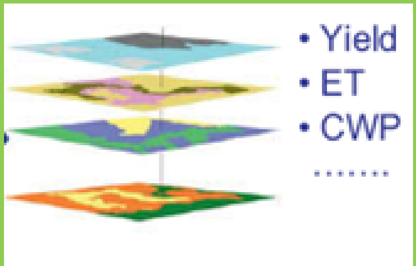


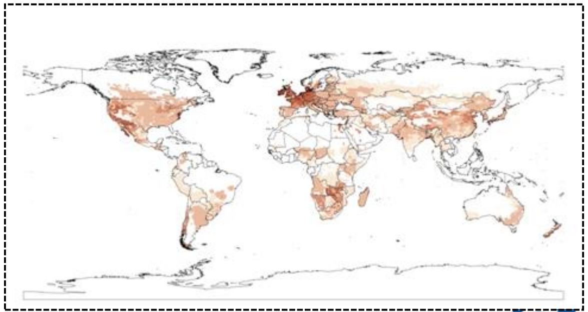


Site-specific outputs:
- Crop yield
- Crop phenology
- ET, CWP
- C, N, and water balance

....

Grid-base output maps (Netcdf):





From local to national/regional scale

Local scale

National/regional scale

1. Input data collection, analysis and processing to fit crop model requirements

2. Model parameterization for each crop/variety, considering the ordinary crop management, for each area considered

3. Scripts for iterative model simulation, to obtain output in each grid point (Trabucco *et al.* - linking DSSAT-CSM with GIS)

Methodology

REANALYSES

COSMO-CLM (RCM)
RCP 4.5 and 8.5

8 km (Italy)

14 km (Europe)

CROP SIMULATION MODELS

AGROCLIMATIC INDEXES

CROP WATER REQUIREMENTS

PHENOLOGY

CROP PRODUCTION

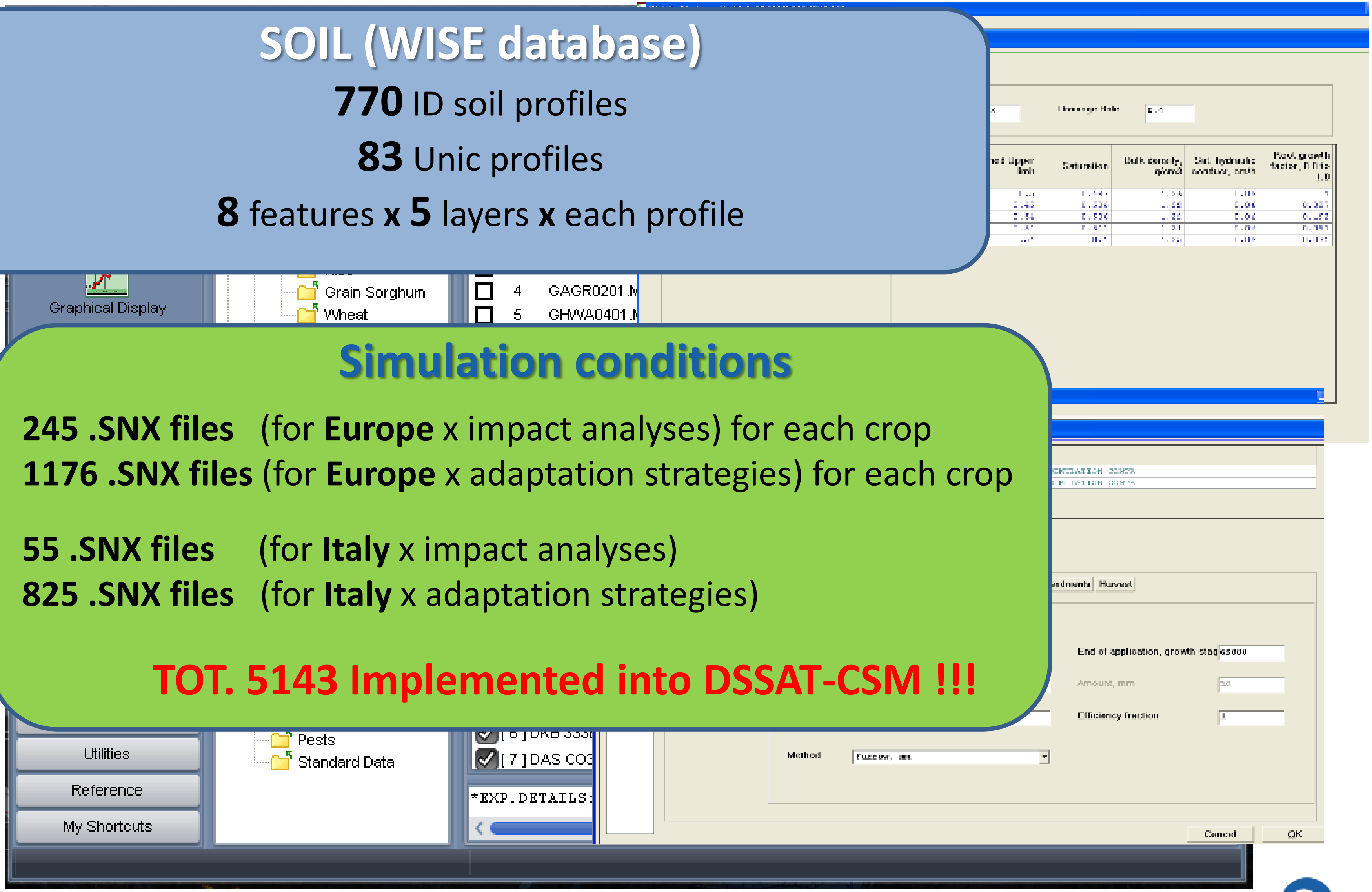
- Effects of crop rotation, conservation tillage on crop yields and soil carbon contents

Durum wheat

Common wheat

Maize

Data processing to fit crop models requirements



SOIL (WISE database)

770 ID soil profiles

83 Unic profiles

8 features **x 5** layers **x** each profile

Simulation conditions

245 .SNX files (for **Europe** x impact analyses) for each crop
1176 .SNX files (for **Europe** x adaptation strategies) for each crop

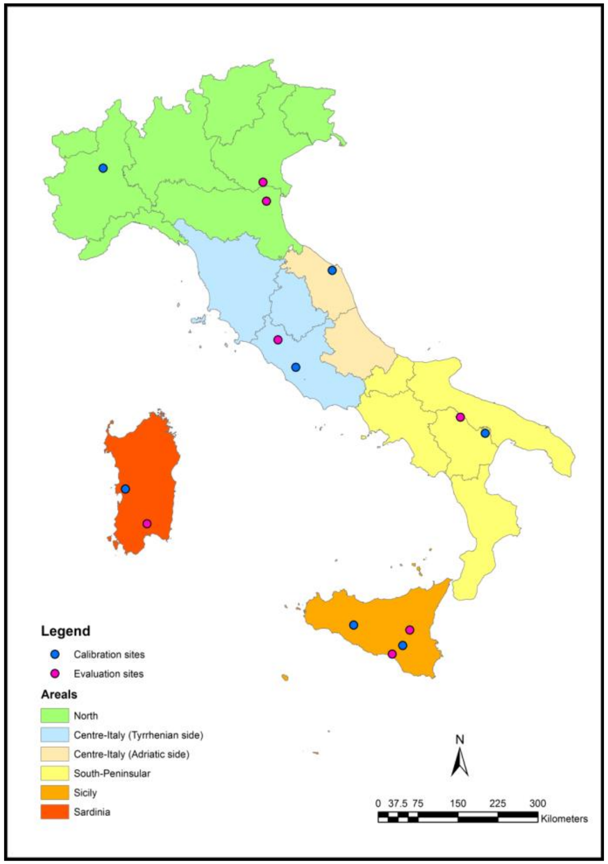
55 .SNX files (for **Italy** x impact analyses)
825 .SNX files (for **Italy** x adaptation strategies)

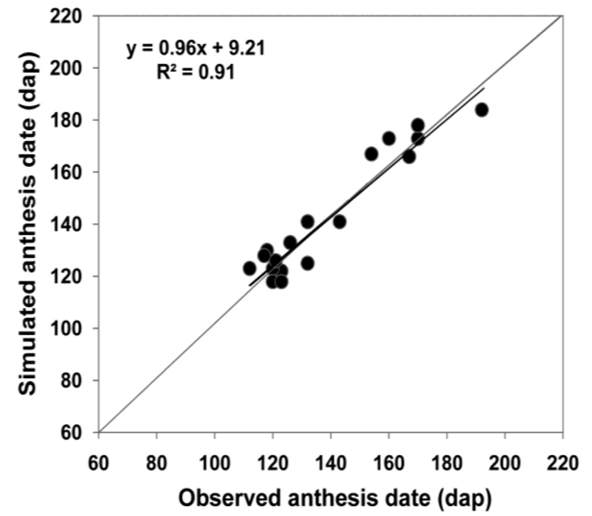
TOT. 5143 Implemented into DSSAT-CSM !!!

(Gallo et al., 2014 in preparation)

2. Model parameterization for each crop/variety, considering the ordinary crop management, for each area considered

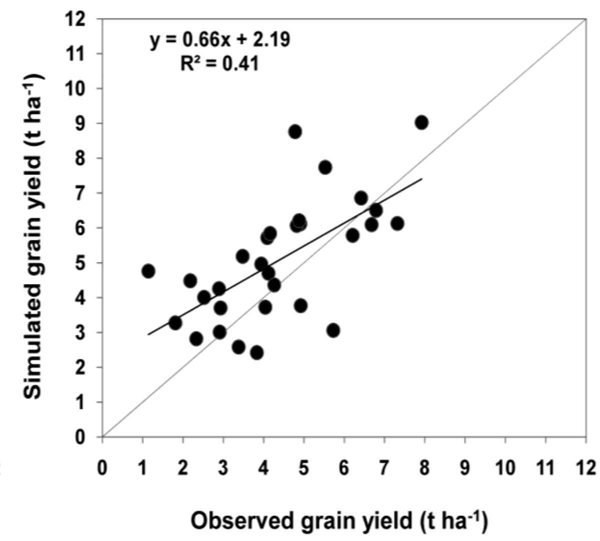
Durum wheat





Anthesis date evaluation

N = 19
r = 0.95***
RMSE = 7.73
CRM = -0.02
d-Index = 0.97



Grain yield evaluation

N = 30
r = 0.64***
RMSE = 1.59
CRM = -0.16
d-Index = 0.77

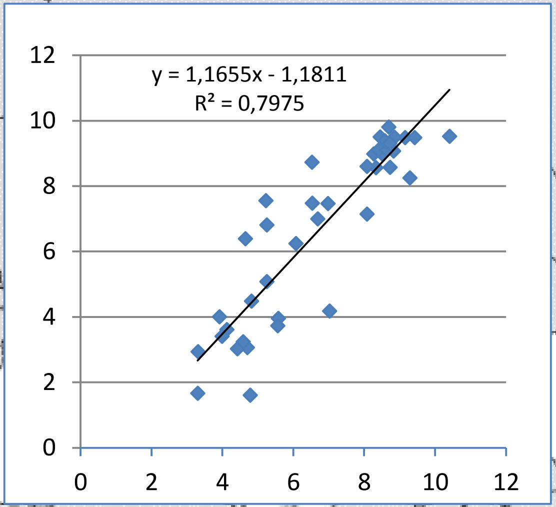
***$p \leq 0.001$

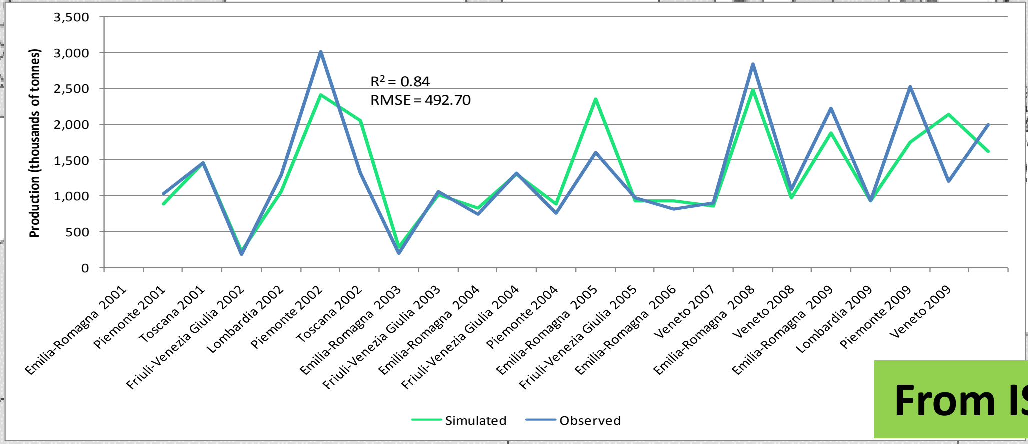
Results

Model evaluation for crop types

MAIZE	Mean yield (2000-2009) t/ha		Max yield (2000-2009) t/ha		Min yield (2000-2009) t/ha	
	SIM	OSS	SIM	OSS	SIM	OSS
Francia	8.6	8.7	9.3	9.5	8.1	7.2
Italia	8.4	9.1	10.4	9.8	6.5	7.5
Ungheria	5.8	5.8	7.0	7.6	4.6	3.7
Romania	4.2	3.1	4.8	4.5	3.3	1.6

From EUROSTAT





From ISTAT

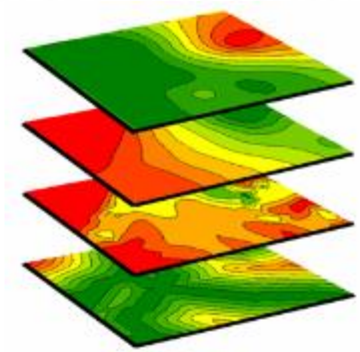
(Gallo et al., 2014 in preparation)

3. Develop a tool for iterative model simulation, to obtain output in each grid point

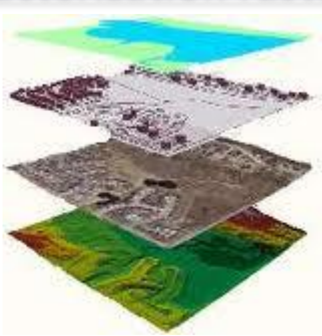
Tool written in R to integrate DSSAT with large scale environmental datasets

GIS-DSSAT Spatial platform

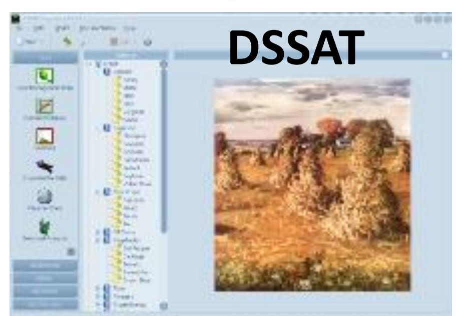
Input - Daily Climate NETCDF time series:



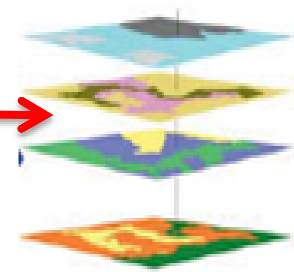
Input - soil/agronomic characterization raster:



Data structure/value verification & flagging for inconsistencies



Output - Spatial crop modelling (NETCDF):



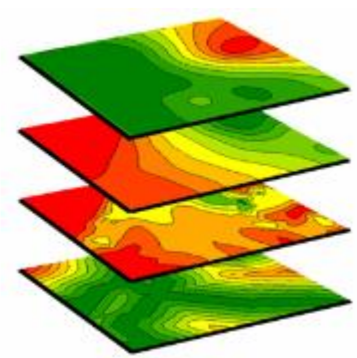
Data Validation

(Trabucco A., Gallo A., Mereu V., Spano D., 2014)

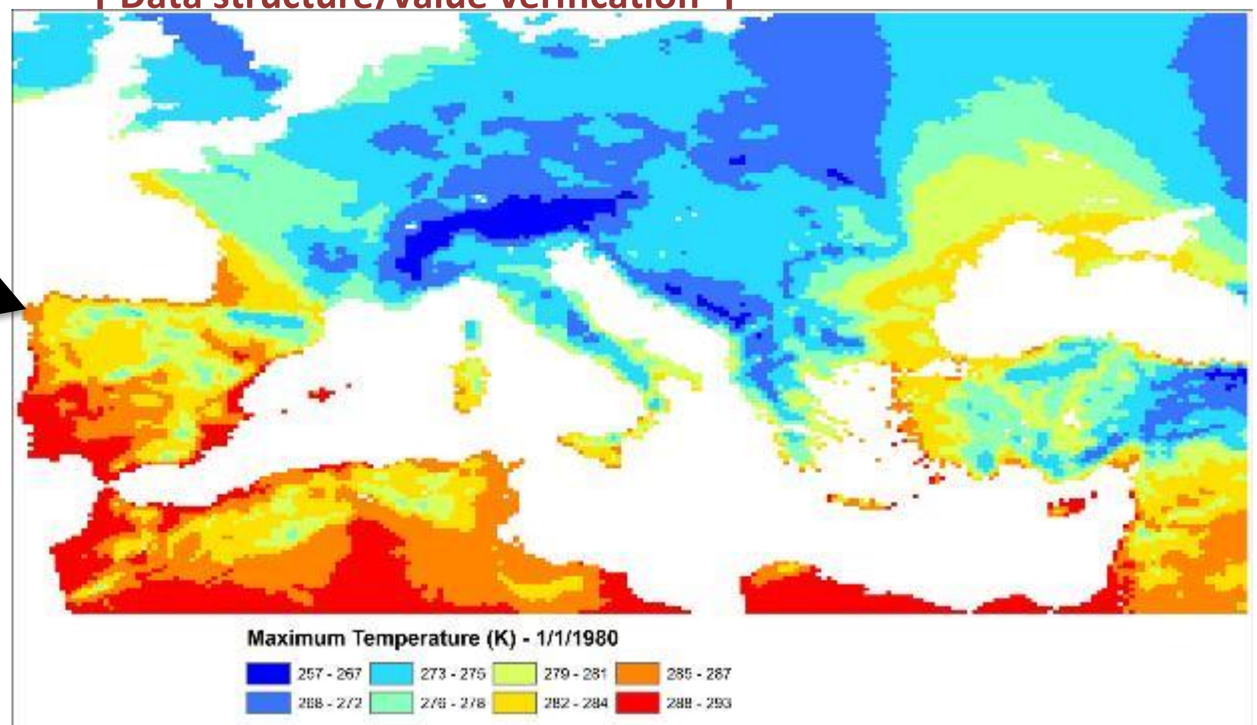
GIS-DSSAT tool

Fully integrated with climate model netcdf geo-datasets and up-to-date large scale socio-environmental geo-datasets

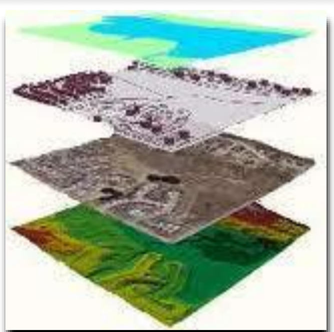
Input - Daily Climate NETCDF time series:



Data structure/value verification



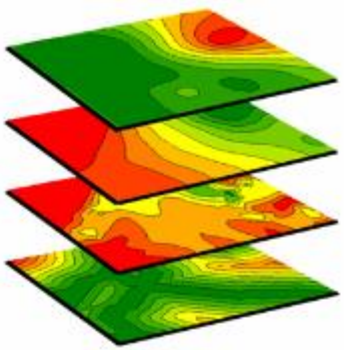
Input - soil/agronomic characterization raster:



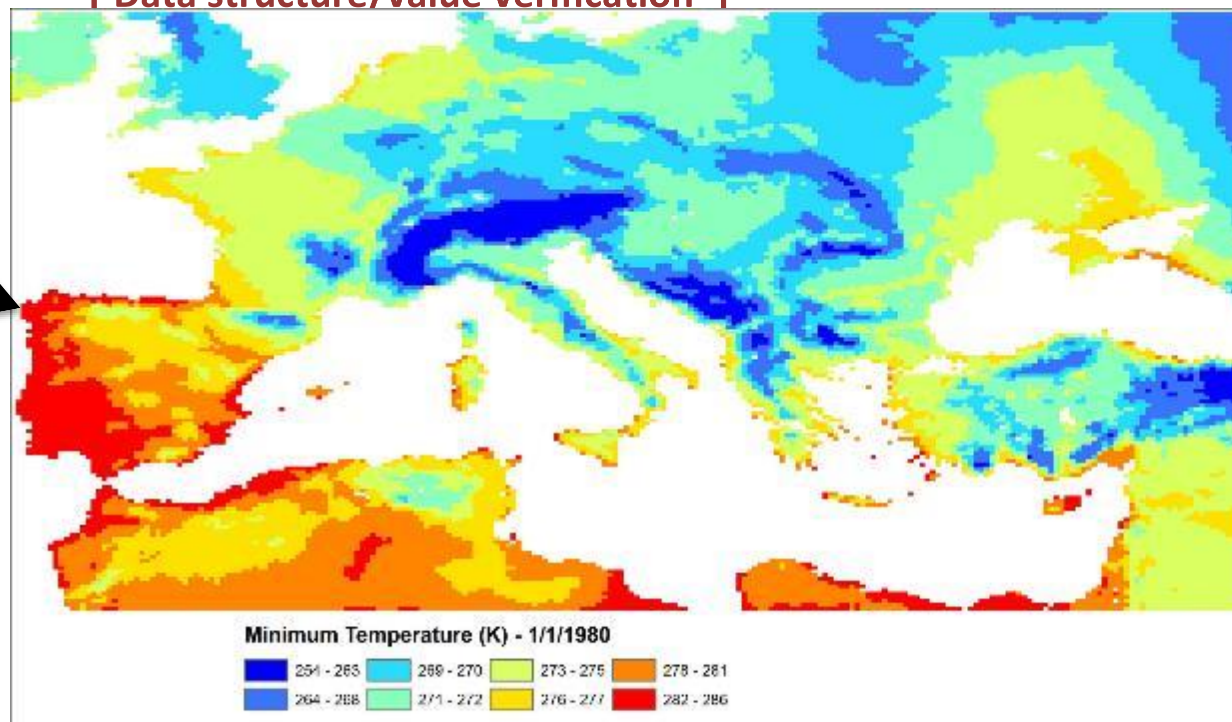
GIS-DSSAT tool

Fully integrated with climate model netcdf geodatasets and up-to-date large scale socio-environmental geodatasets

Input - Daily Climate NETCDF time series:



Data structure/value verification



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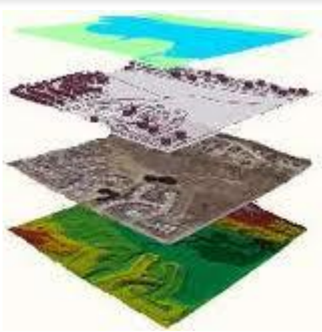

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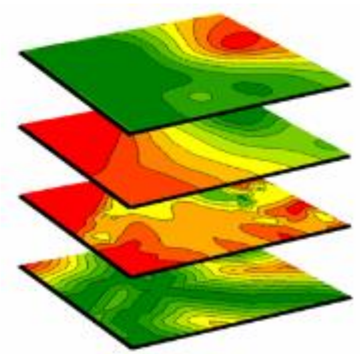
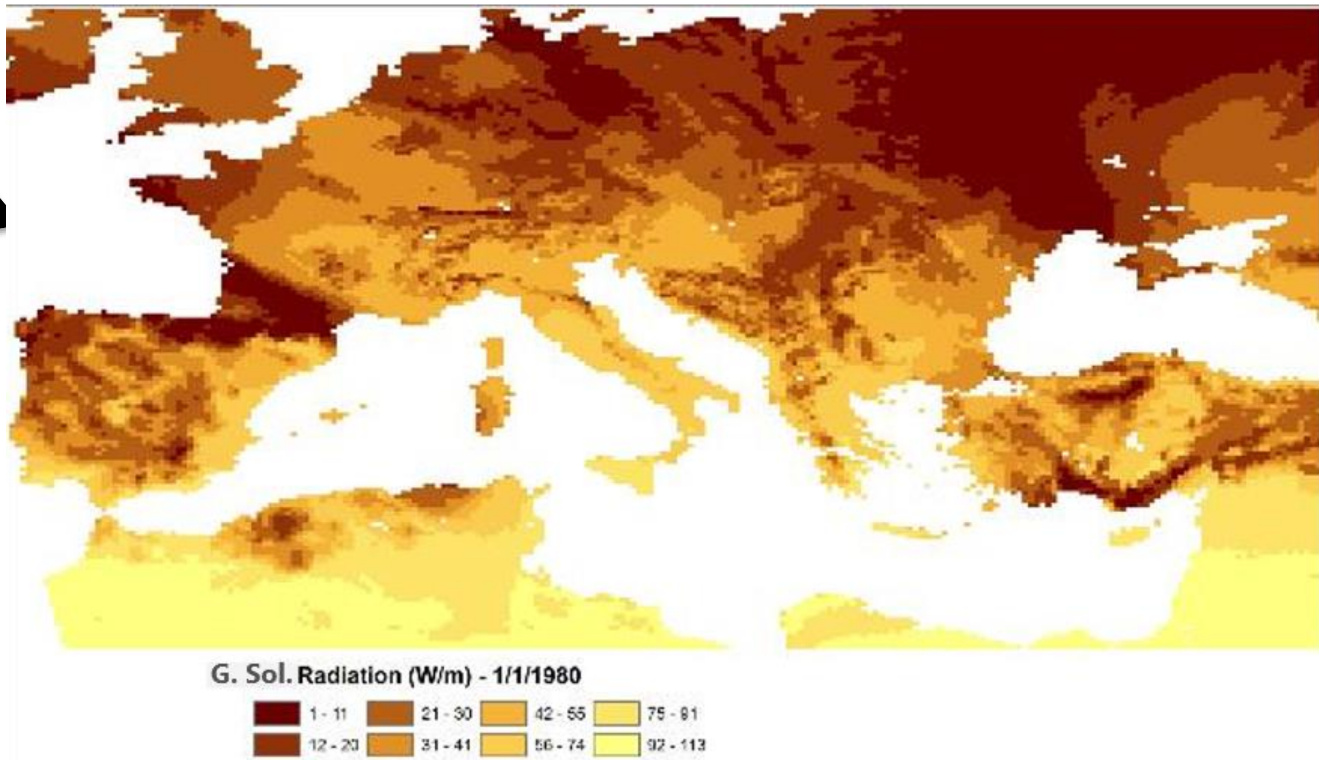


Data structure/value verification & flagging for inconsistencies



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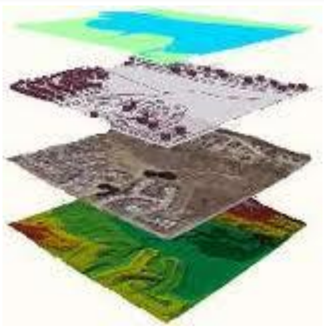

GIS-DSSAT tool

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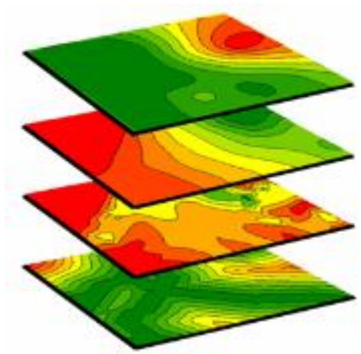
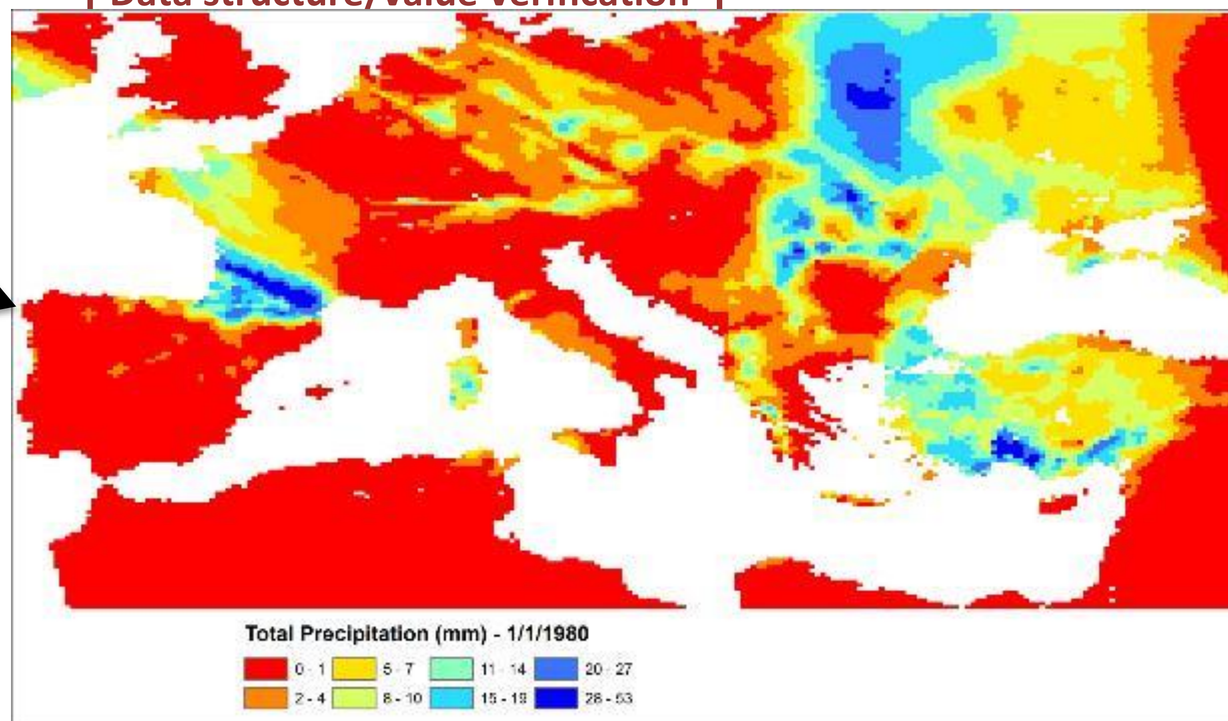


Data structure/value verification



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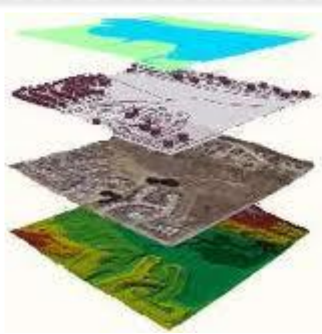

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Fully integrated with climate model netcdf geodatasets and up-to-date large scale socio-environmental geodatasets

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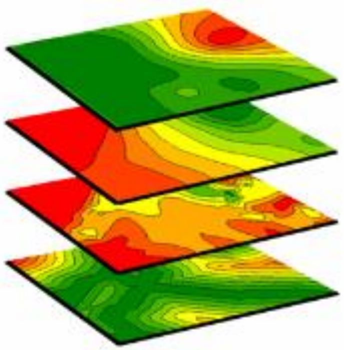
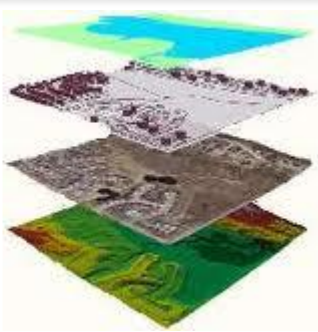
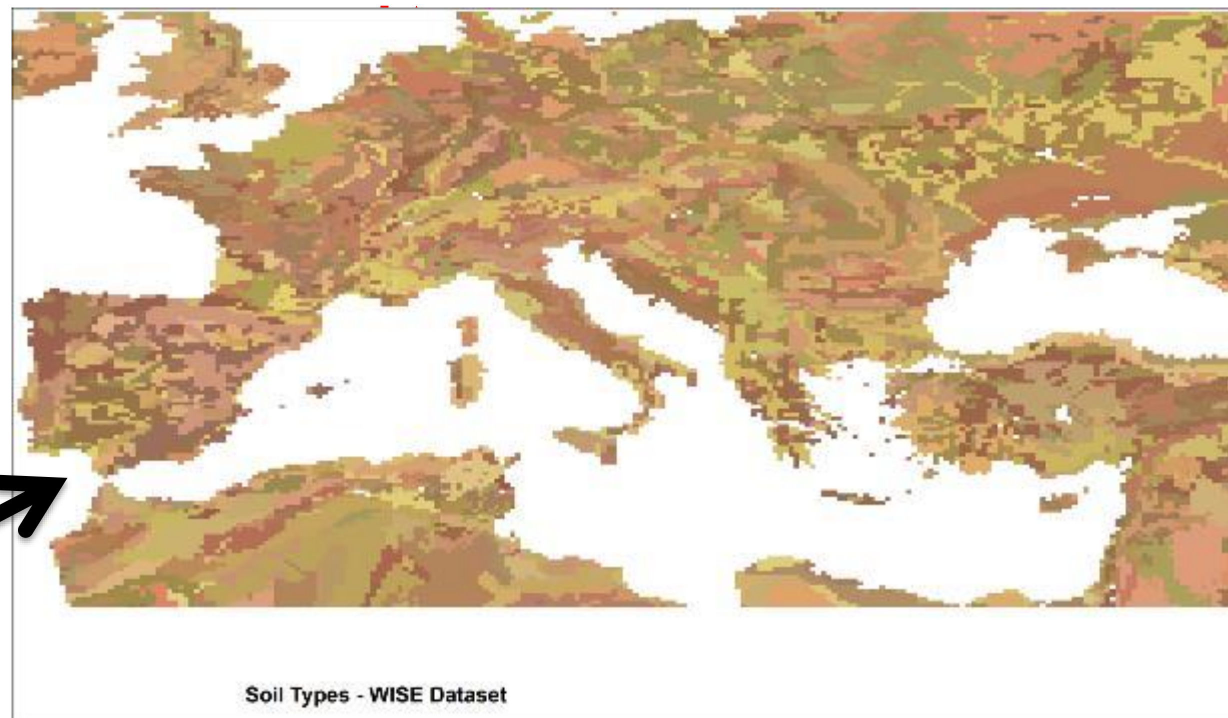


Data structure/value verification & flagging for inconsistencies

Input - soil/agronomic characterization raster:





GIS-DSSAT tool

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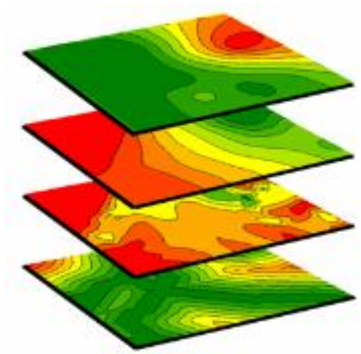

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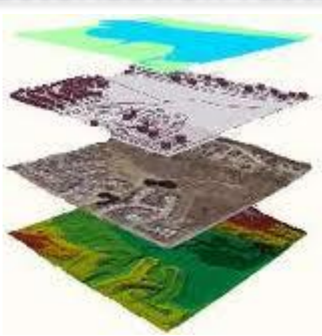
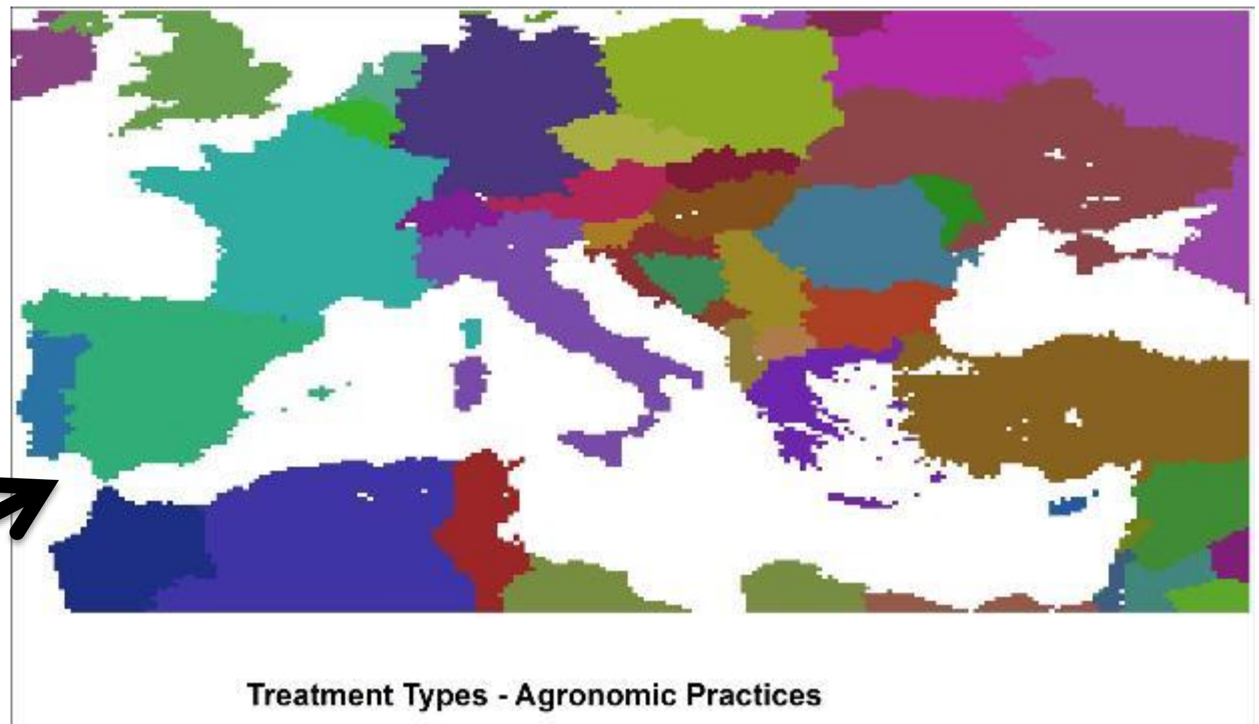


Data structure/value verification & flagging for inconsistencies



GIS-DSSAT tool

Fully integrated with climate model netcdf geodatasets and up-to-date large scale socio-environmental geodatasets

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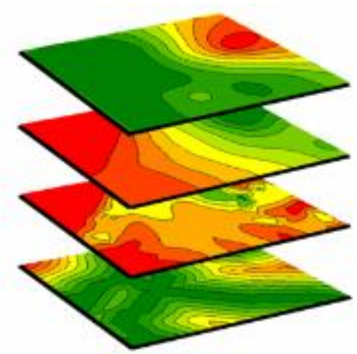
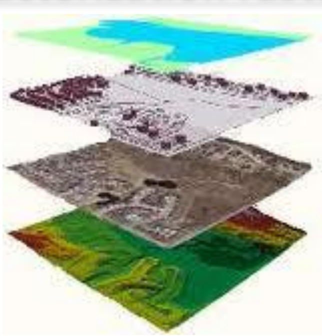
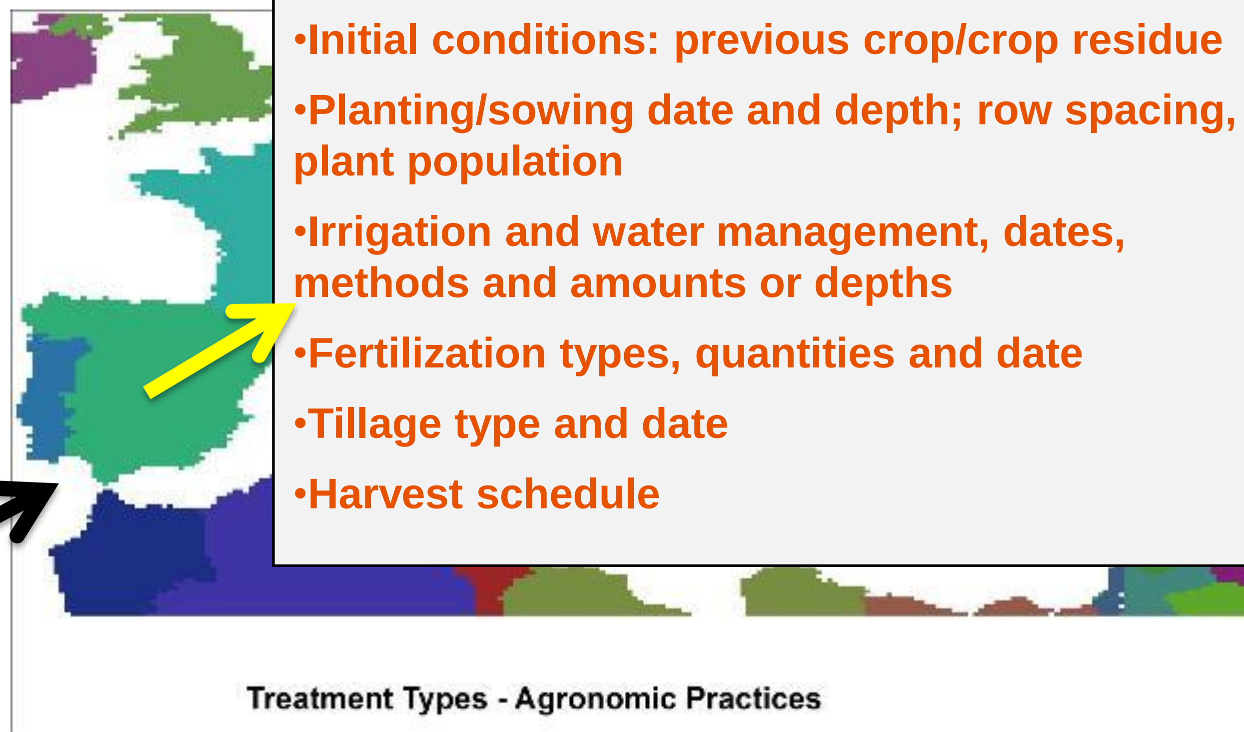


Input - soil/agronomic characterization raster:



Data stru
& flaggin

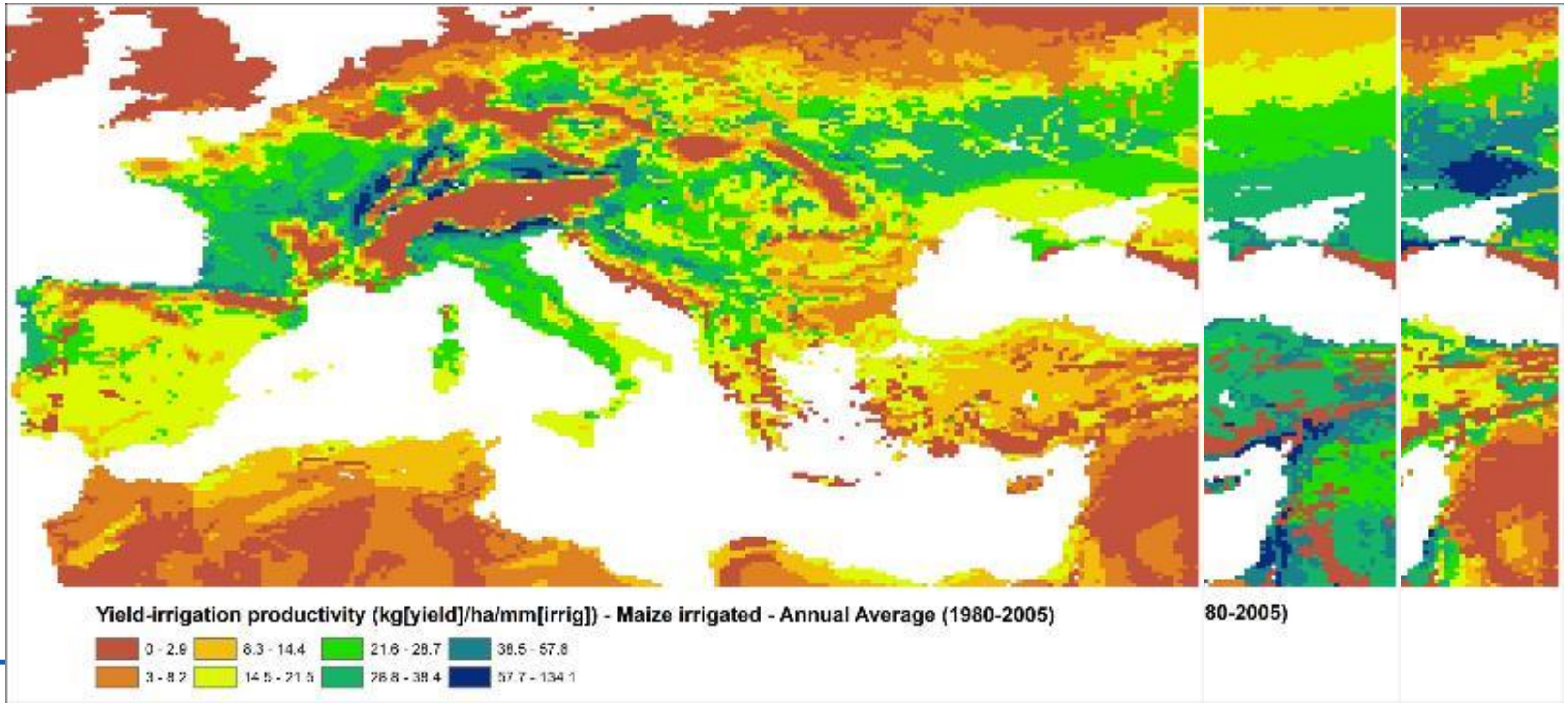


Crop data for model operation

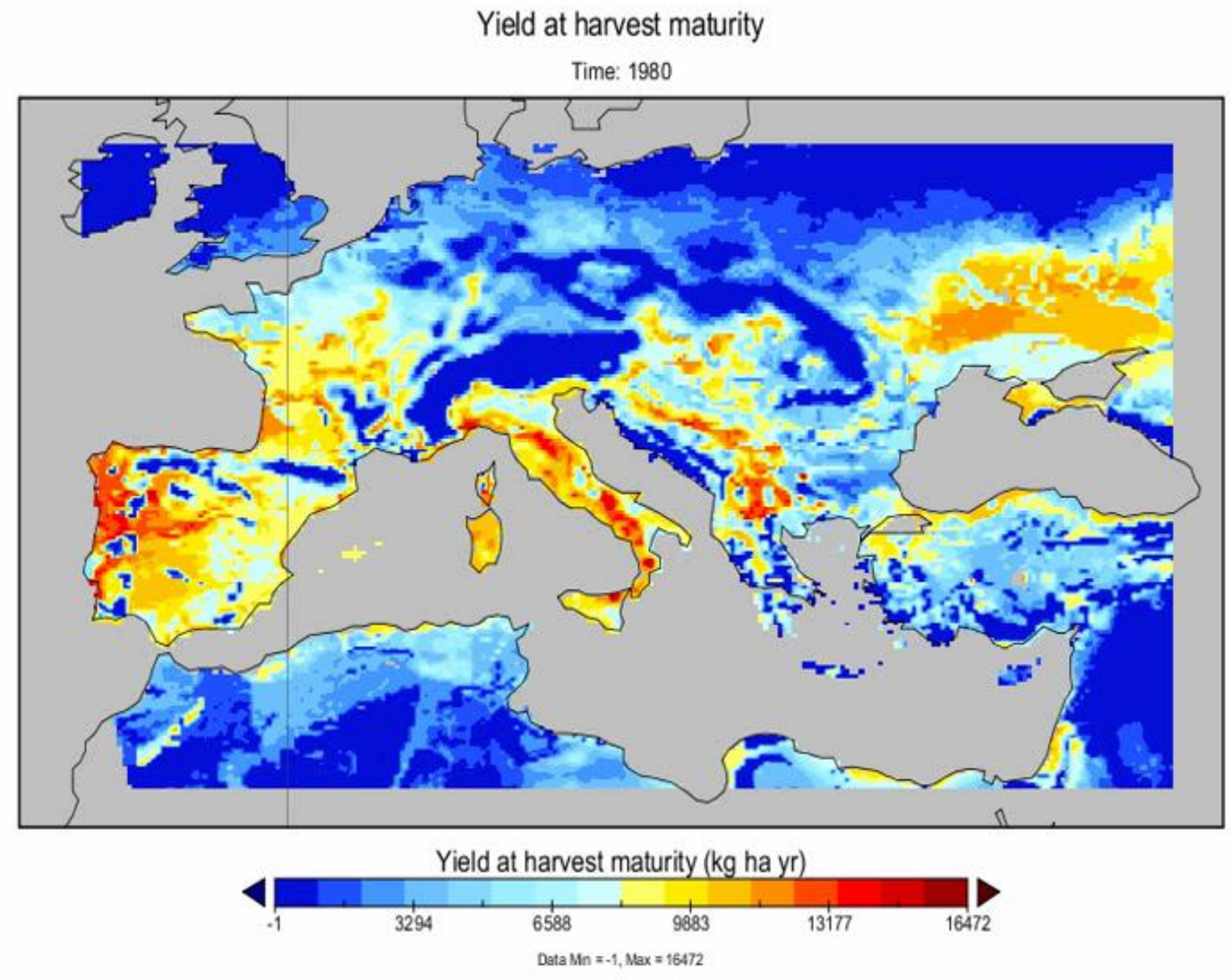
- Cultivar name and type
- Initial conditions: previous crop/crop residue
- Planting/sowing date and depth; row spacing, plant population
- Irrigation and water management, dates, methods and amounts or depths
- Fertilization types, quantities and date
- Tillage type and date
- Harvest schedule

GIS-DSSAT tool

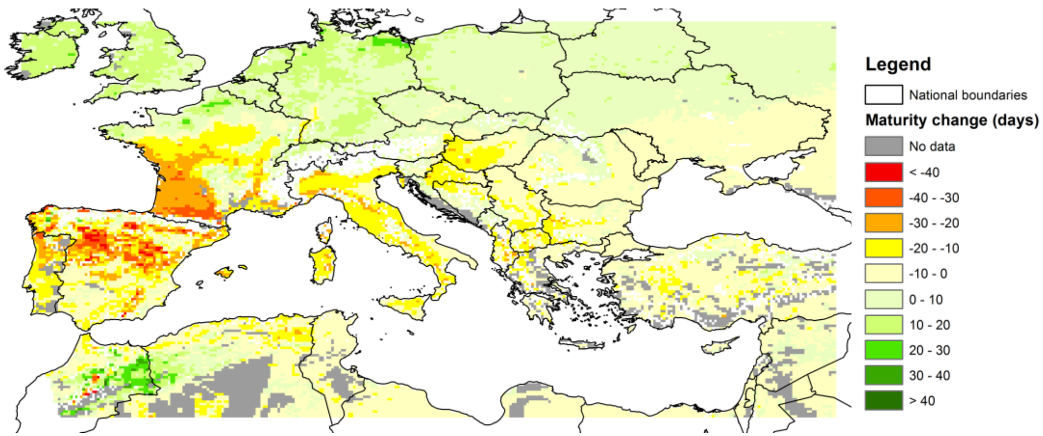
- Various data check are applied to verify for data error and masking
- Outputs of crop growth performances (e.g. Yield, growing season), water use/needs (and efficiency) of maize and wheat have been produced (Euro-Med 14km and Italy at 8km)



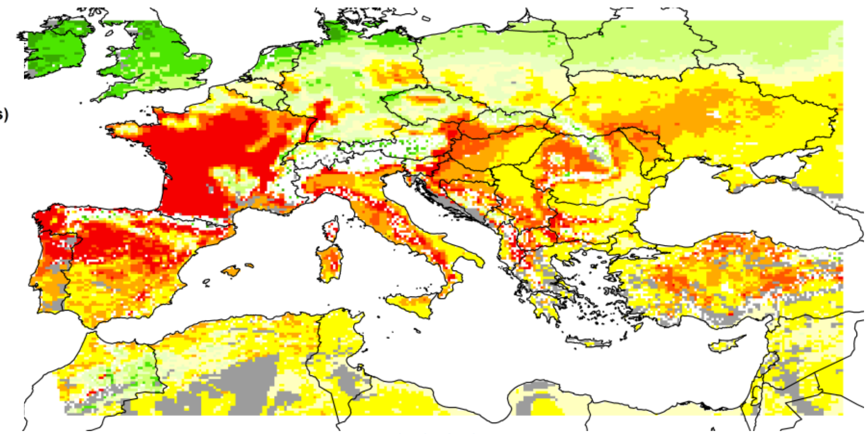
GIS-DSSAT tool



Changes in maturity period for maize (days after planting)



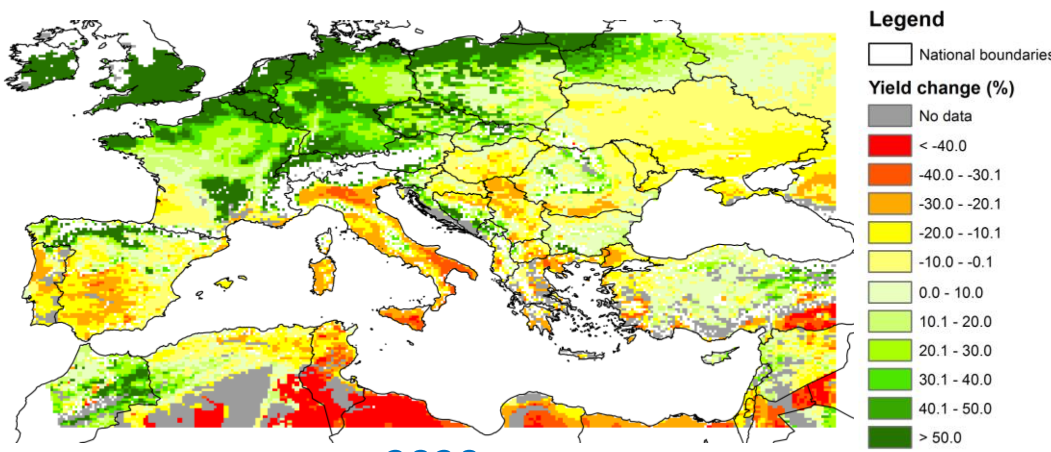
2020



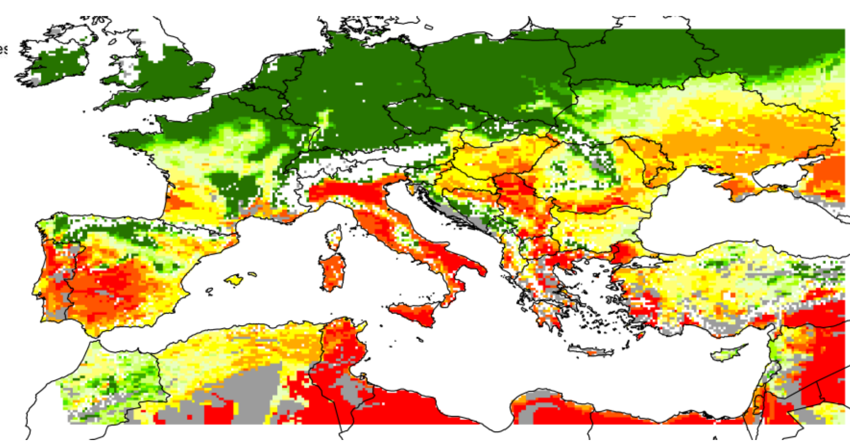
2080

RCM: COSMO-CLM
RCP4.5 (14 km)

Changes in maize yield (%)



2020

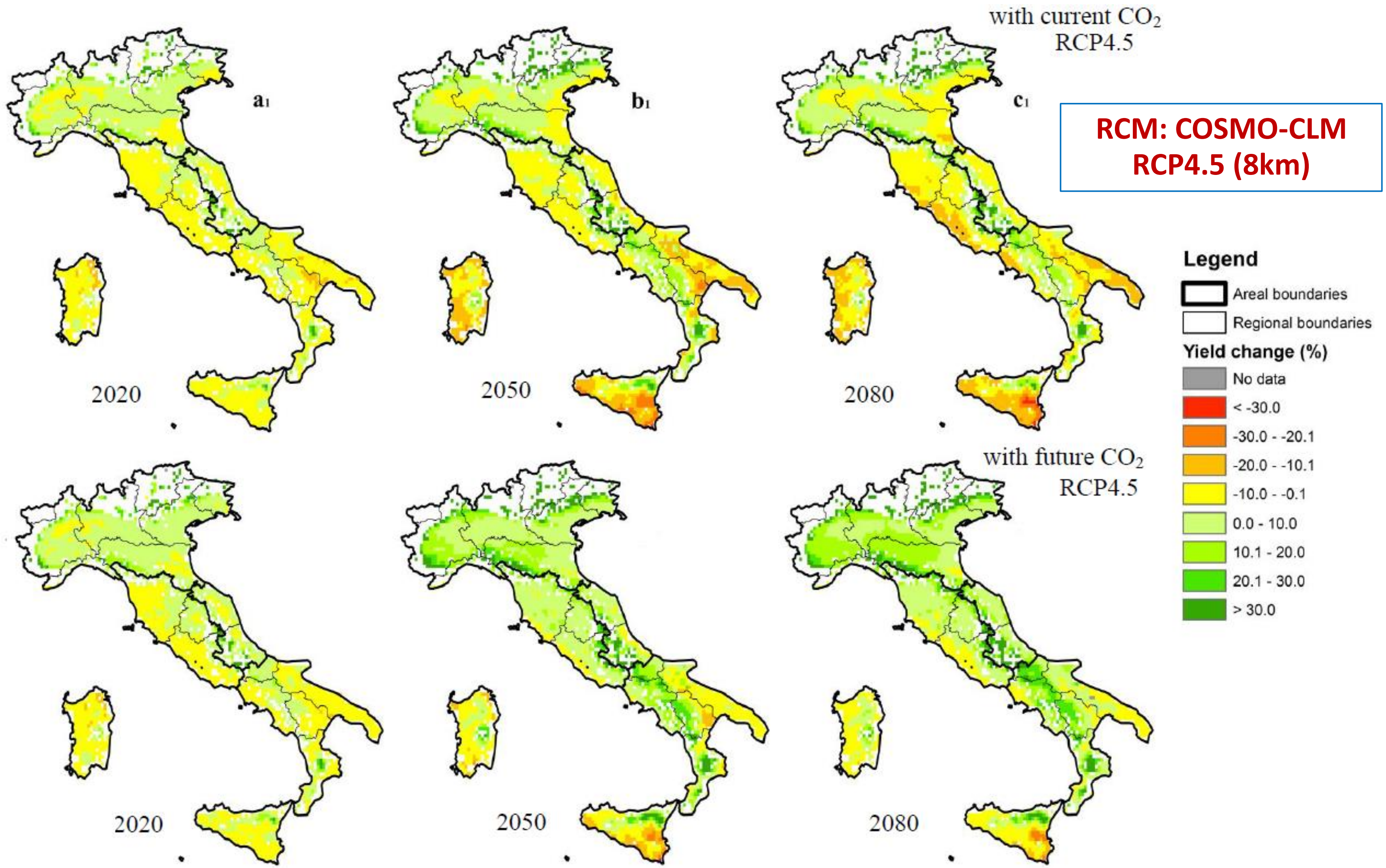


2080

(Mereu et al., 2014 in preparation)

Durum wheat yield changes (%)

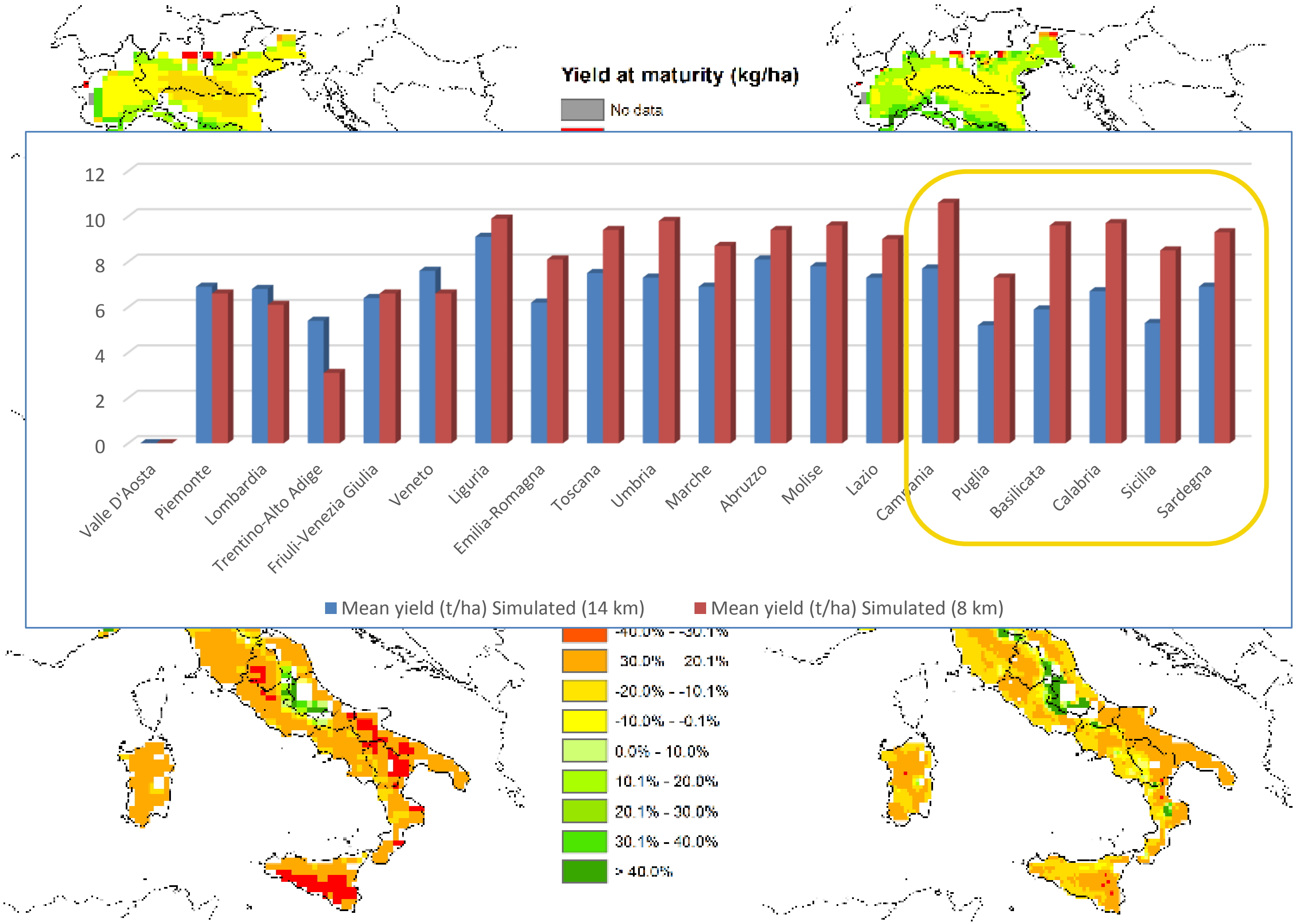
RCM: COSMO-CLM
RCP4.5 (8km)



Gallo et al. 2014

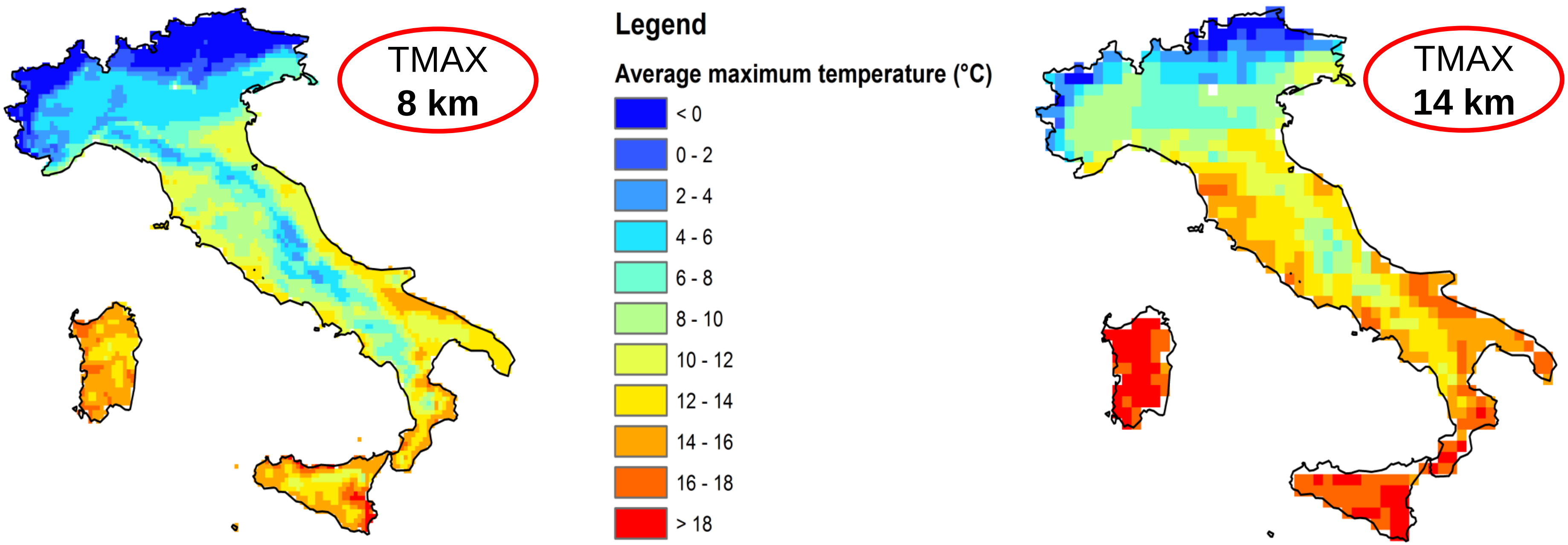
14 km *vs* 8 km   2050   RCP 4.5

Average maize yield (kg/ha)



(Mereu et al., 2014 in preparation)

Uncertainty analysis associated with different climate data resolutions



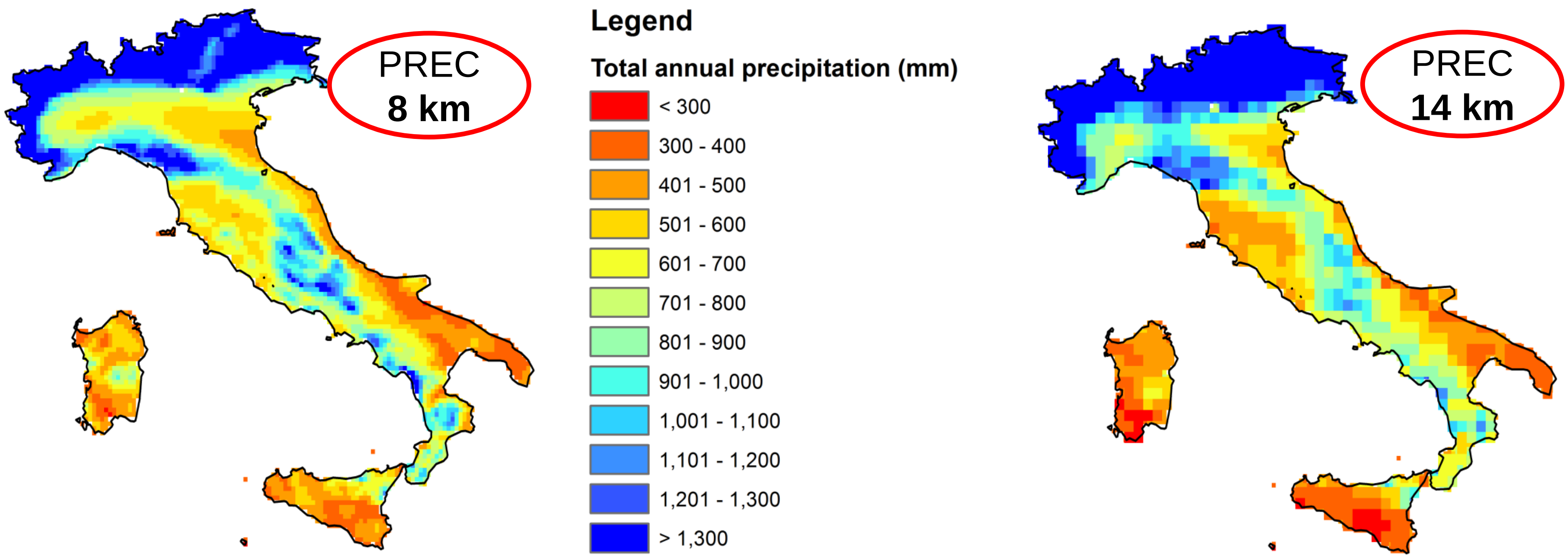
results

Maturity date

Grain yield

(Gallo , 2015)

Uncertainty analysis associated with different climate data resolutions



results

Maturity date

Grain yield

(Gallo , 2015)

Uncertainty analysis associated with different climate data resolutions

Average grain yield (t ha^{-1})

Durum wheat			
Area	**Observed**	**Simulated (8 km)**	**Simulated (14 km)**
North	5.5	**5.3**	4.6
Centre-Italy (Tyrrhenian side)	4.9	5.6	**4.8**
Centre-Italy (Adriatic side)	4.8	**5.1**	3.8
South-Peninsular	3.8	4.8	**4.0**
Sicily	3.8	**3.4**	2.7
Sardinia	5.2	**4.5**	4.2
Common wheat			
Area	**Observed**	**Simulated (8 km)**	**Simulated (14 km)**
North	6.0	**4.5**	4.1
Centre	5.2	**4.4**	**4.4**
South-Peninsular	3.1	**3.1**	3.0
Maize			
Area	**Observed**	**Simulated (8 km)**	**Simulated (14 km)**
North	11.1	**8.0**	7.2

(Gallo , 2015)

Uncertainty analysis associated with different climate data resolutions

Annual average maturity date (dap)

Period	Area					
	North		Centre		South-Islands	
	8 km	14 km	8 km	14 km	8 km	14 km
1990	160**	159**	174***	160***	157***	139***
2020	147***	141***	160***	139***	145***	122***
2050	135***	141***	146***	139***	134***	122***
2080	131***	124***	142***	122***	129***	110***

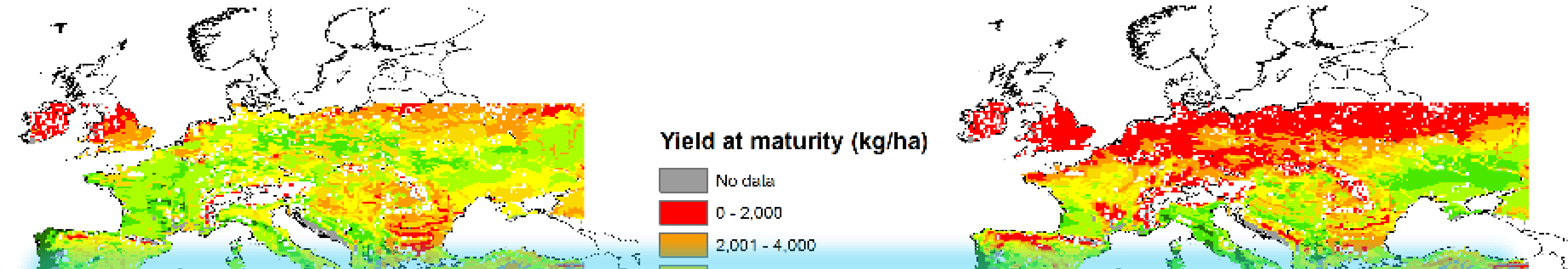
Annual average grain yield (t ha^{-1})

Period	Area					
	North		Centre		South-Islands	
	8 km	14 km	8 km	14 km	8 km	14 km
1990	4.9***	4.2***	10.6ns	10.7ns	10.7***	10.5***
2020	9.1***	8.0***	10.5***	9.1***	9.8***	7.6***
2050	8.2***	7.0***	9.8***	7.8***	9.0***	6.6***
2080	7.8***	6.6***	9.4***	7.3***	8.2***	6.1***

Student's t-test *P≤0.05; **P≤0.01; ***P≤0.001; ns=not significant

(Gallo , 2015)

Average maize yield (kg/ha)



- **Bias correction** of GCMs/RCMs
- **Resolution** of dynamical/statistical **downscaling**
- Considering **a wide range of GCMs and scenarios**

Agriculture in Sub-Saharan Africa

- Agriculture drives the economy of many Sub-Saharan African countries
- It is the main economic activity in terms of employment share
- Smallholder farmers
- Rain-fed agriculture (98%) used for subsistence
- Most vulnerable continent to climate change/variability
- Low adaptive capacity of the continent due to increasing in population, persistent poverty, and other social factors
- Substantial decrease of crop yields due to increasing temperatures, changed precipitation patterns, and more frequent droughts

Reanalysis (1979-2009)

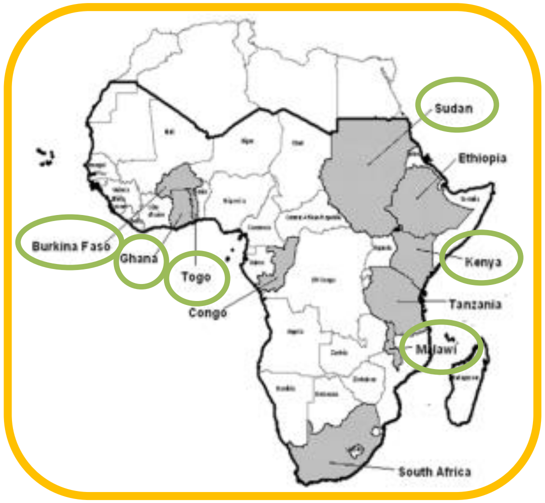
GCMs : GFDL, MIROC5, CanESM2 RCP 8.5 (1961-2100)

Dinamically downscaled (CORDEX) ~50km

Statistically downscaled (from CMIP5) ~50km

Crop simulation models

crop phenology and yield
crop water requirements
crop management effects



FARMERS | **POLICY MAKERS** | **ECONOMIC MODEL**

ClimAfrica

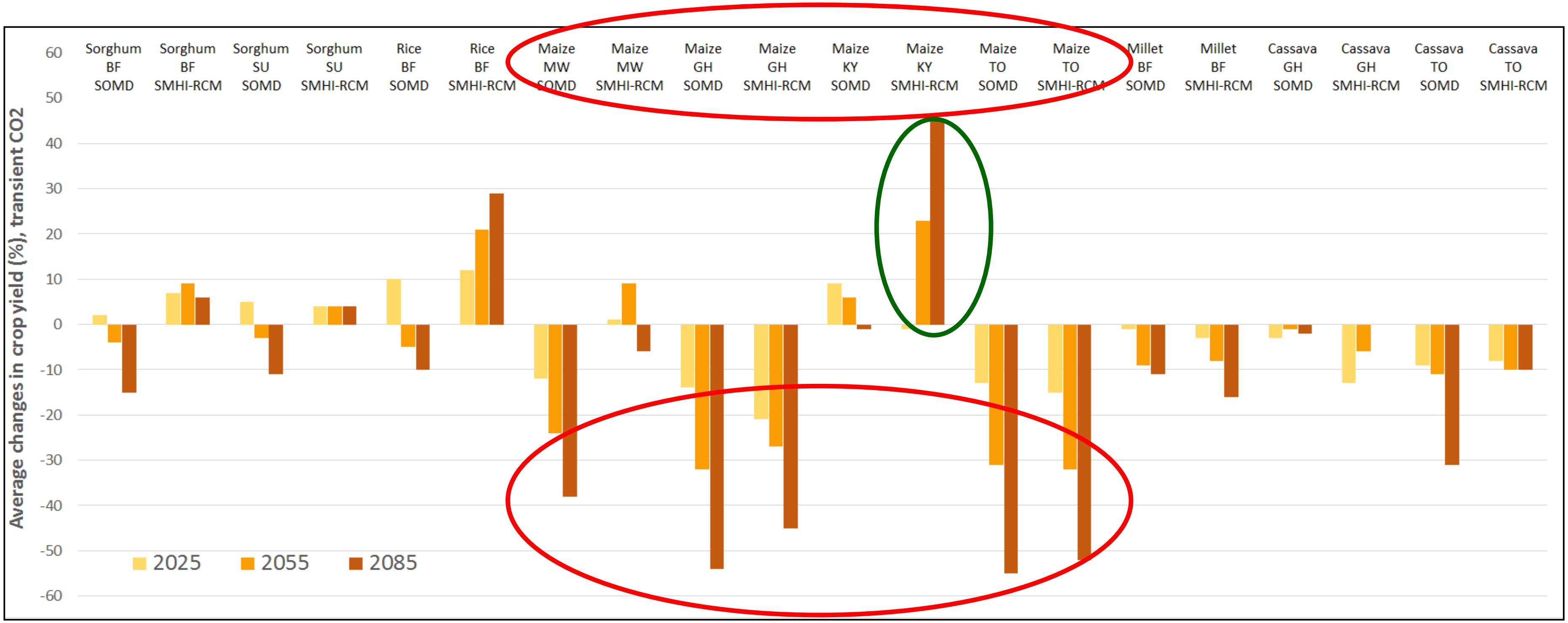
Average simulated changes in maturity (days) respect to baseline (1981-2010) with two downscaling methods in each case study area.

Crop	SOMD 2025	SOMD 2055	SOMD 2085	SMHI-RCM 2025	SMHI-RCM 2055	SMHI-RCM 2085
Sorghum (Burkina Faso)	-3	-7	-10	-4	-7	-11
Sorghum (Sudan)	-2	-5	-8	-3	-7	-9
Rice (Burkina Faso)	-7	-10	-14	-10	-19	-19
Maize (Malawi)	-8	-16	-23	-6	-16	-26
Maize (Ghana)	-3	-7	-12	-5	-10	-16
Maize (Kenya)	-6	-10	-15	-9	-17	-27
Maize (Togo)	-3	-8	-12	-5	-10	-15
Millet (Burkina Faso)	-4	-10	-15	-6	-11	-15
Cassava (Ghana)	-11	-7	+20	-30	-44	-30
Cassava (Togo)	-9	0	+48	-21	-23	-12

Shortening of the growing season

(Mereu et al., in submission)

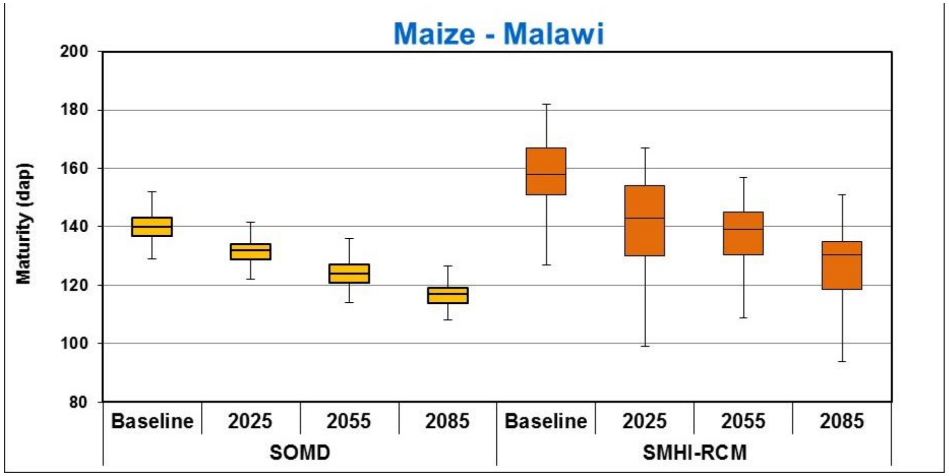
Average changes in crop yield (%) for a selection of crops and sites – simulated using the site based DSSAT model (transient CO_2)

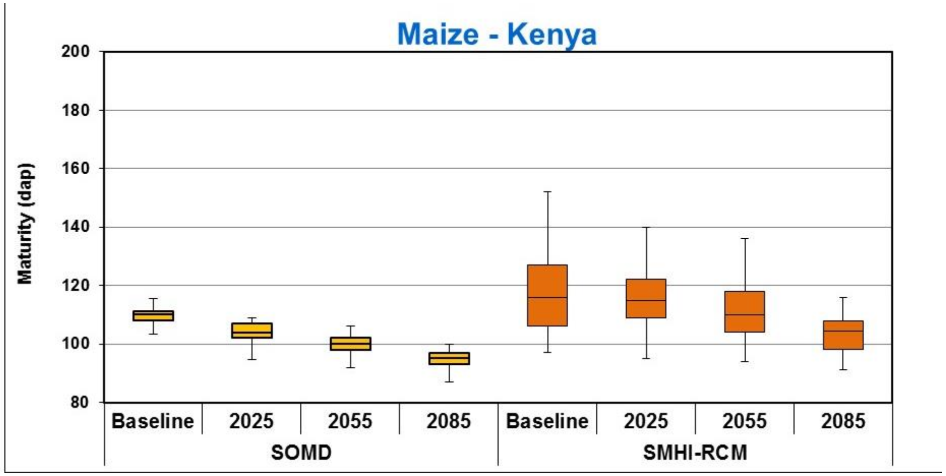


- DSSAT predicts a decrease in crop yield, especially for 2055 and 2085.
- The largest **yield declines** are projected for maize (with up to -55% in Ghana and Togo).
- A **positive trend of yield** projections in Kenya (due to increased precipitation) even if the increase in crop yield is high in % terms, but small in absolute terms.

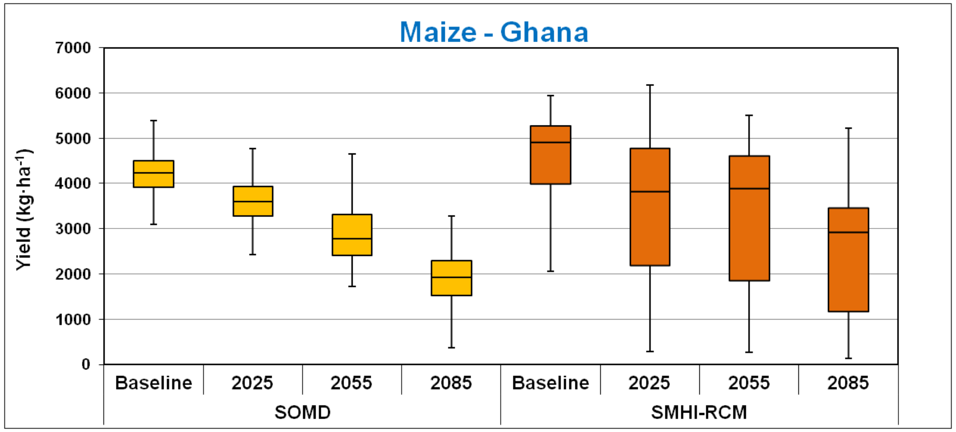
(Mereu et al., in submission)

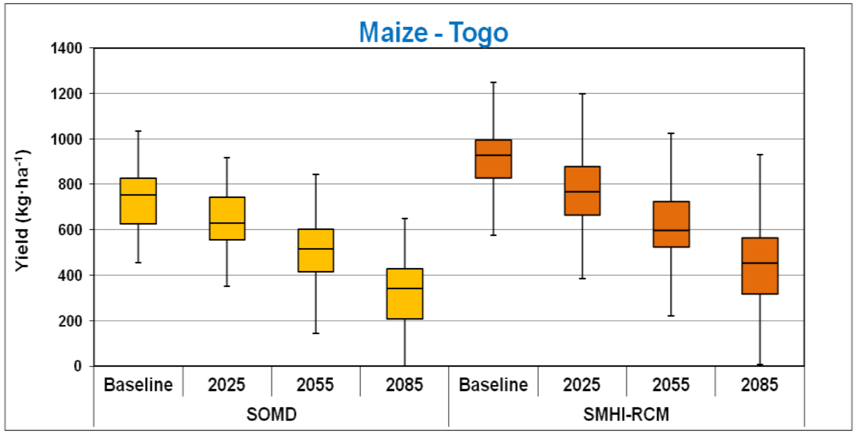
Climate change impacts on crop maturity period (dap)





Climate change impacts on crop yield (kg/ha) (CO_2 according to RCP 8.5) - rainfed





- Higher yield reductions projected with statistically downscaled data
- Higher uncertainties in the projections with dynamically downscaled data

(Mereu et al., in submission)

ClimAfrica

Climate risk analysis in Nigeria

Climatic Change
DOI 10.1007/s10584-015-1428-9

Impact of climate change on staple food crop production in Nigeria

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Andrea Gallo[1] **· Raffaello Cervigni**[4] **· Donatella Spano**[1,2]

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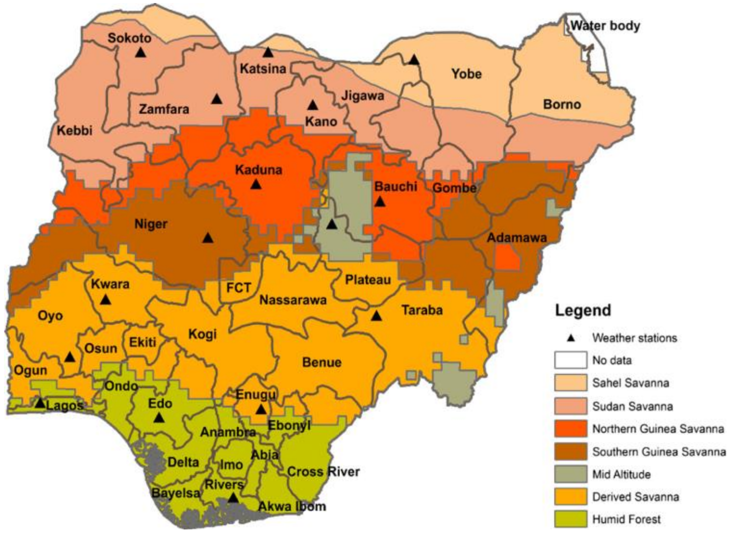
Abstract Climate change impact on the agricultural sector is expected to be significant and extensive in Sub-Saharan Africa, where projected increase in temperature and changes in precipitation patterns could determine sensible reductions in crop yields and concerns for food security achievement. This study presents a multi-model approach to analysing climate change

Climate risk analysis in Nigeria

- ❖ Nigeria can be considered a representative case study of the WA, having all the range of climatic and vegetation types of this area (Adejuwon 2004): from the wettest Agro-Ecological Zone (AEZ), the Humid Forest, to the semi-arid zone of Sahel Savanna

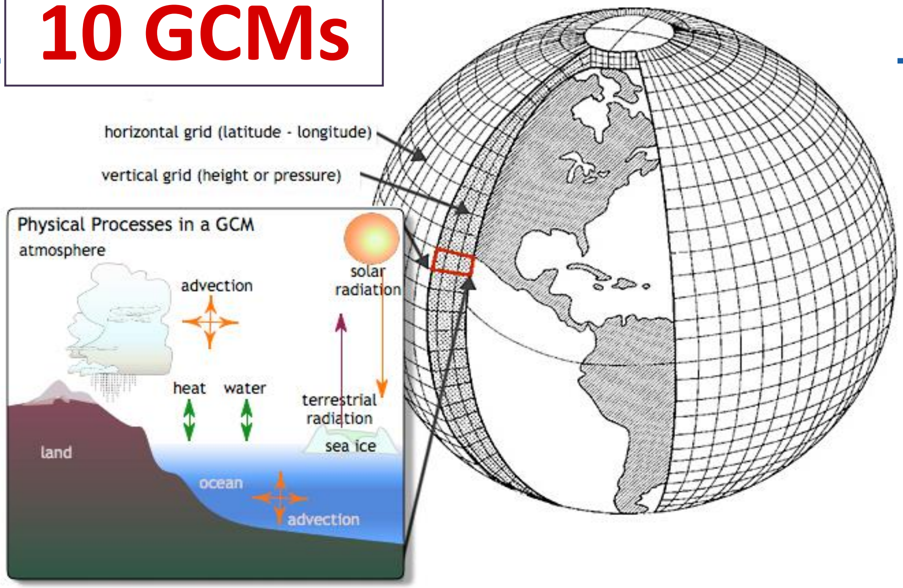


❑ **Agriculture accounts for about 40% of GDP and 70% of employment in Nigeria.**

❑ **Crop production is largely (> 90%) driven by the rainfall level across the Country**

❑ **Stagnant yields in the face of growing population cause increasing dependency on food imports, particularly rice.**

10 GCMs



Model	Res. (°lat x °lon)	Institution	Emission scenario
HadCM3	2.5°x 3.75°	UKMO	A1B
CGCM_2.3.2	2.8°x 2.8°	MRI	A1B
CNRM_CM3	2.8°x 2.8°	CNRM	A1B
CSIRO-Mk3.5	1.9°x 1.9°	CSIRO	A1B
CCSM3	1.4°x 1.4°	NCAR	A1B
MIROC3.2	1.125°x 1.125°	CCSR	A1B
GFDL_cm2.1	2.5°x 2°	GFDC	A1B
ECHAM5	1.875°x 1.875°	MPI	A1B
FGOALS	2.8125°x 2.8125°	IAP	A1B
CMCC-MED	0.75°x 0.75°	CMCC	A1B

COSMO-CLM (RCM)

Future projections (2001-2065)

Crop simulation models

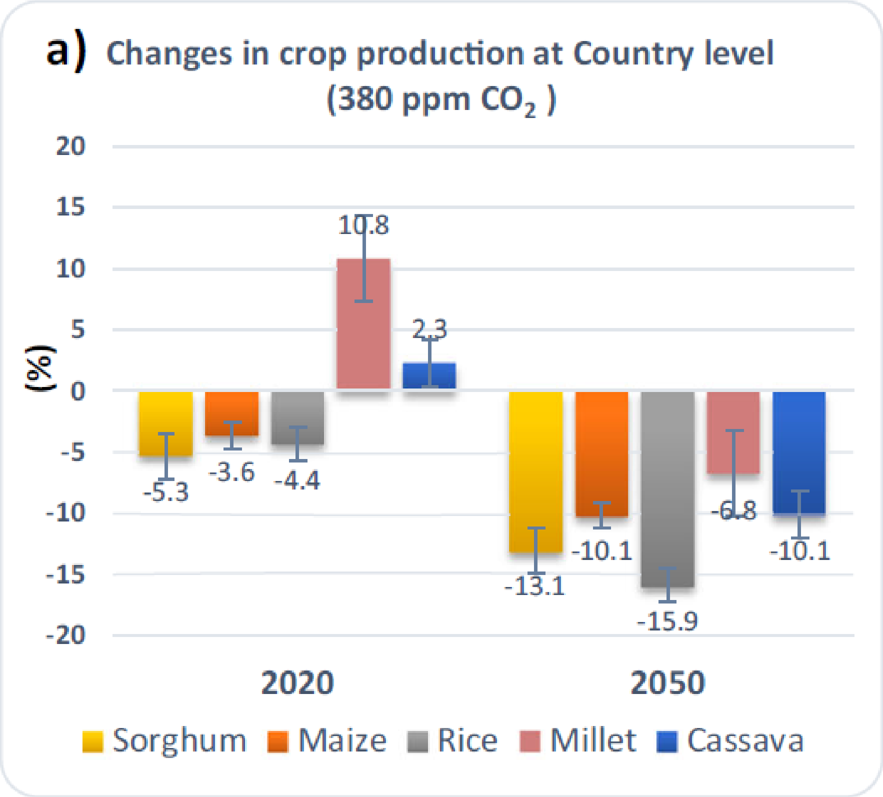
ECONOMIC MODEL

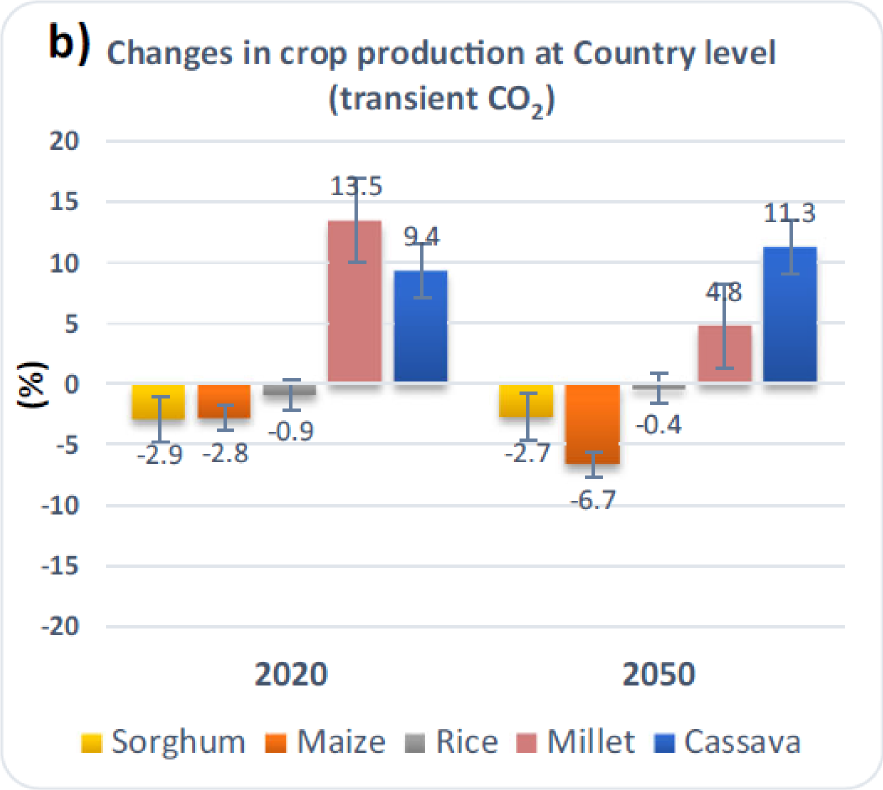
Sorghum, Maize, Millet, Rice, Cassava

⇩

80% of total Nigerian agricultural production

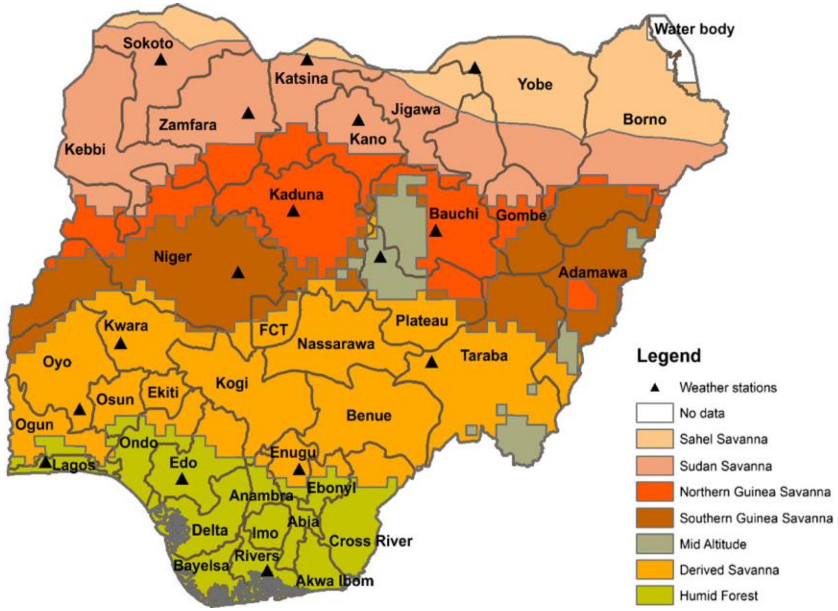
Impacts at Country level

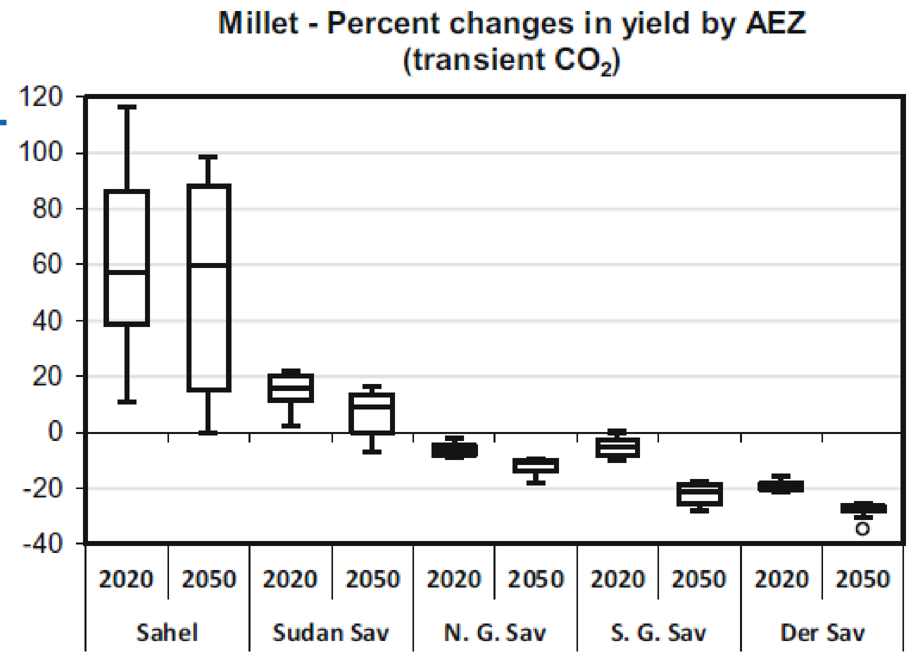


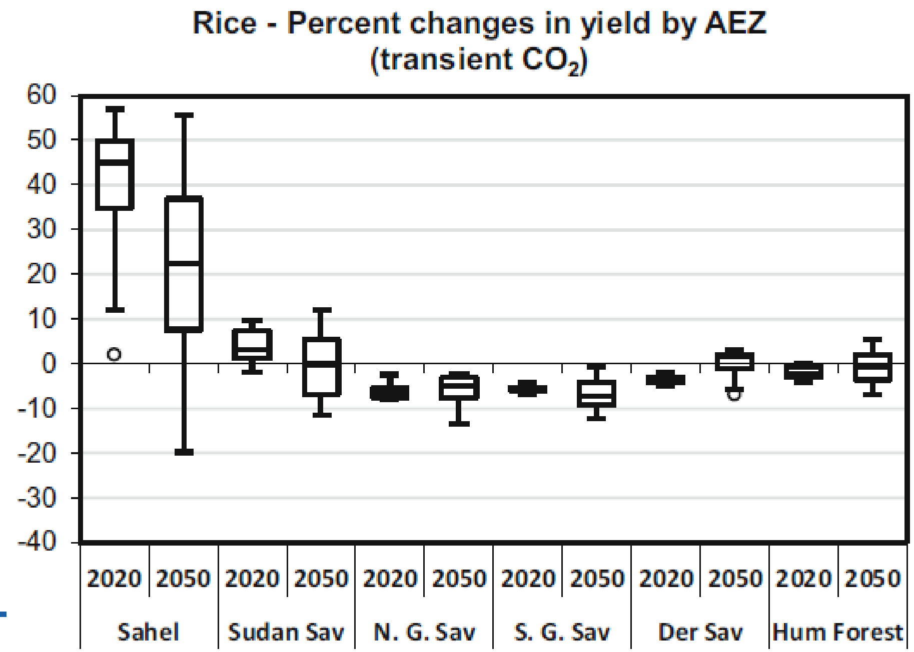


(Mereu et al., 2015)

Impacts at AEZ level







(Mereu et al., 2015)

Risk assessment

- The specific **yield risk** for each crop in any of the AEZs (**Rs**c) was calculated by **defining a threshold yield value (Yt)** calculated for each crop considering the 30-year baseline period (1976–2005).

- **The risk occurs when the crop yield is equal or inferior to one standard deviation below the 30-year mean yield**, which is the threshold value (Yt). The Rsc was calculated considering the relation

$$Rs_c = \frac{n}{N} * 100$$

where **n is the number of times when simulated yield is below the specific Yt** and **N is the total number of simulations**.

- Moreover, an integrated risk index (IR) was calculated for each AEZ, by combining the risk for each crop (Rsc), weighted by the specific harvested area (Hac) in each AEZ:

$$IR = \frac{\sum_1^c Rs_c * Ha_c}{\sum_1^c Ha_c}$$

Risk assessment

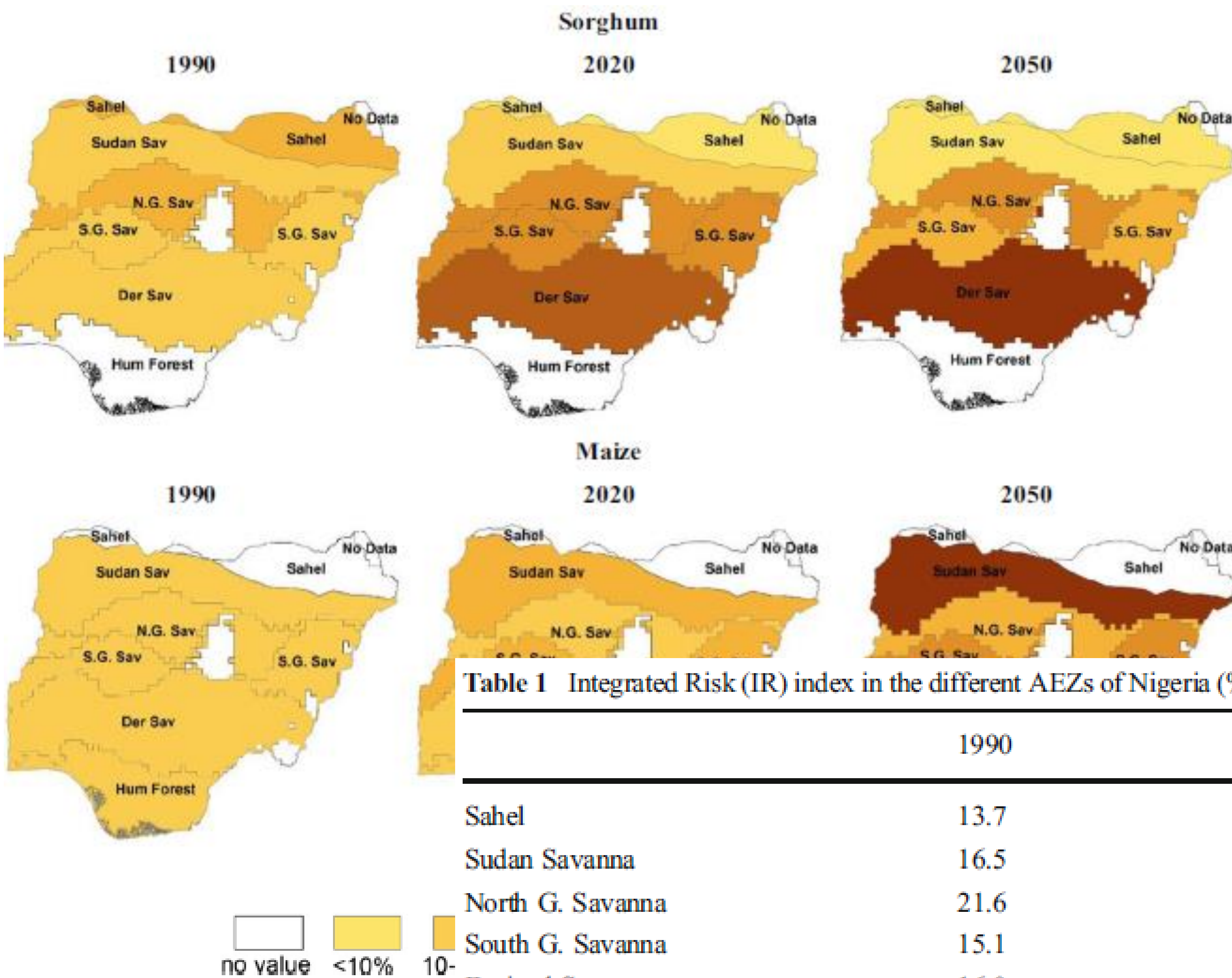
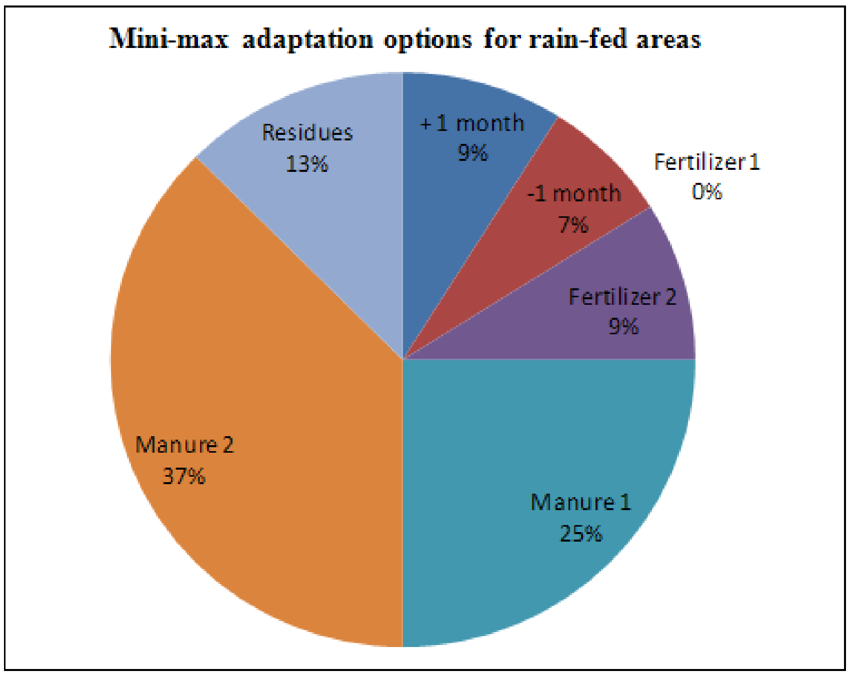


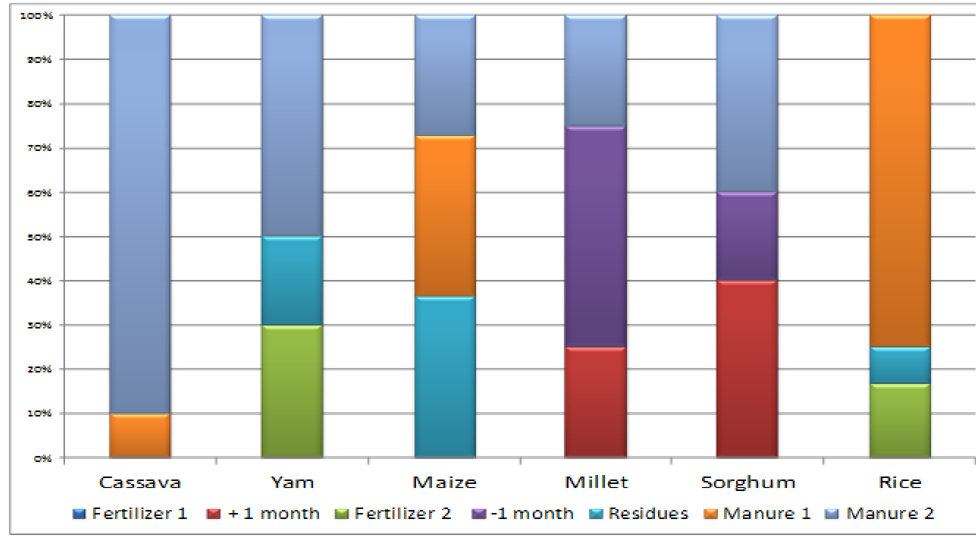
Table 1 Integrated Risk (IR) index in the different AEZs of Nigeria (%) considering transient CO_2 concentration

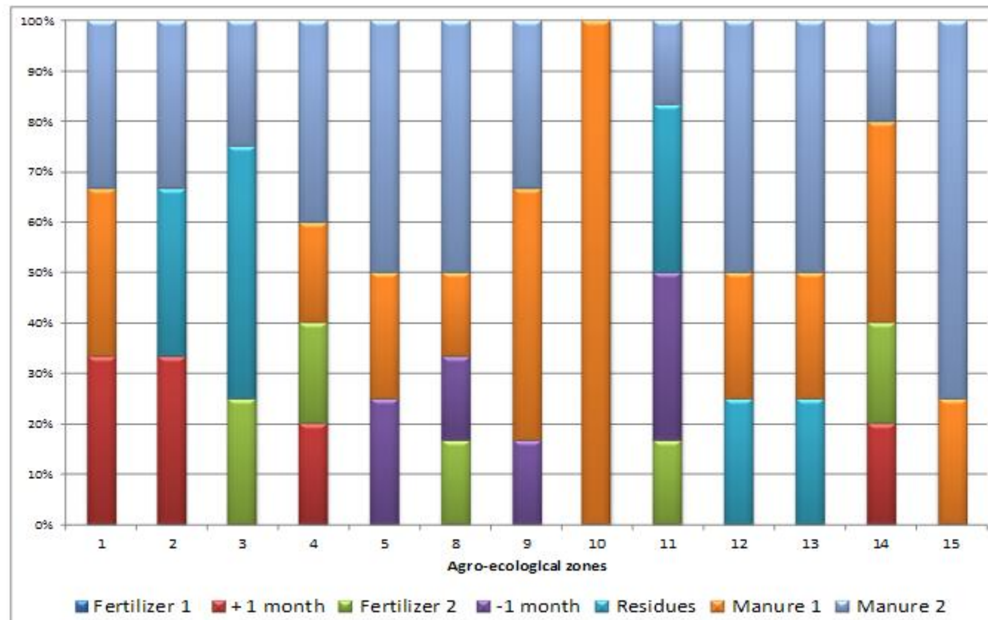
	1990	2020	2050
Sahel	13.7	2.2	2.8
Sudan Savanna	16.5	11.9	11.8
North G. Savanna	21.6	25.2	25.6
South G. Savanna	15.1	23.1	22.7
Derived Savanna	16.0	20.0	22.6
Humid Forest	11.8	11.4	13.1

Regret analysis for adaptation options in rain-fed areas

Mini-max adaptation option, which minimizes the maximum regret across climate models.

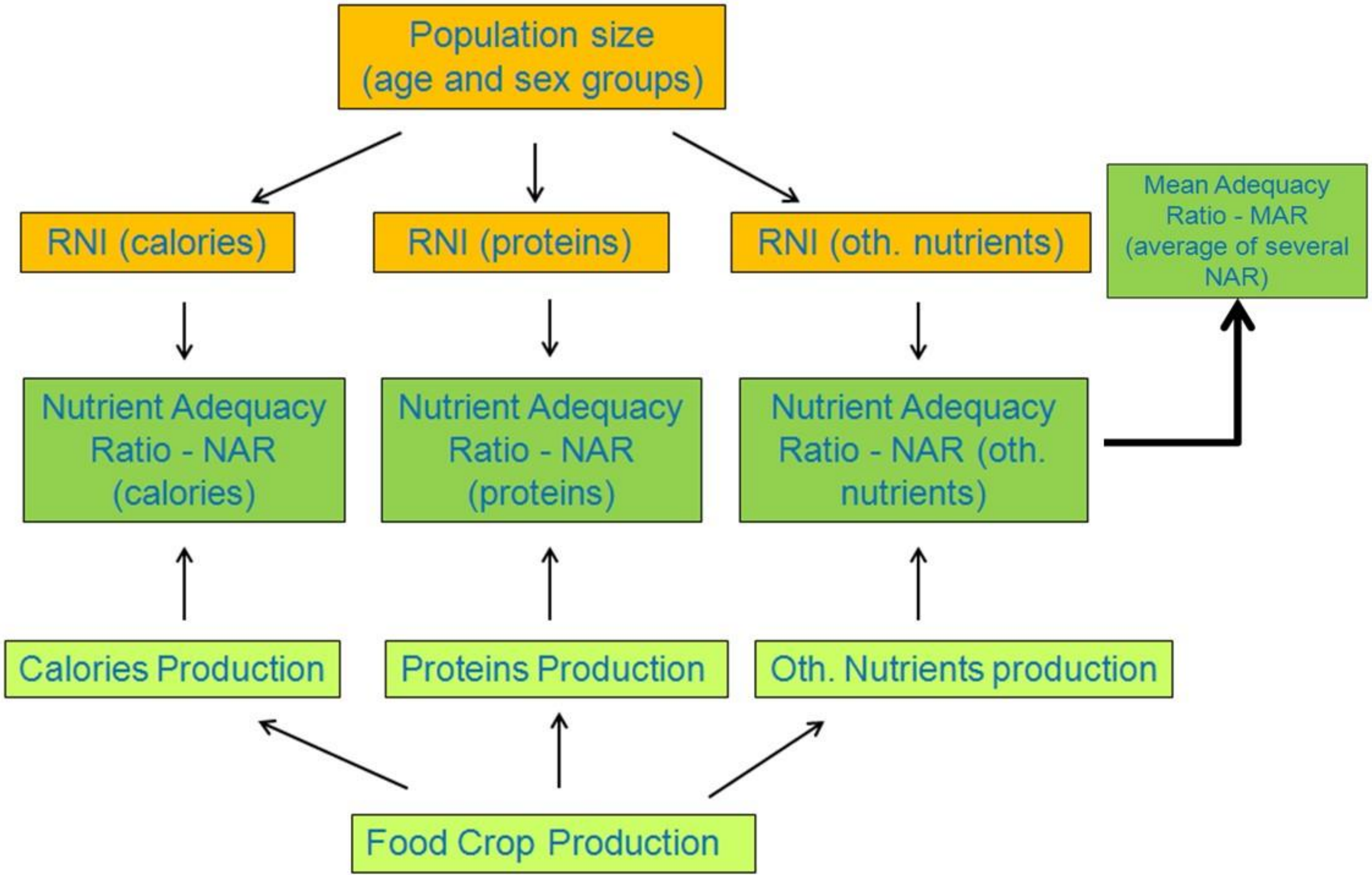






Food Security

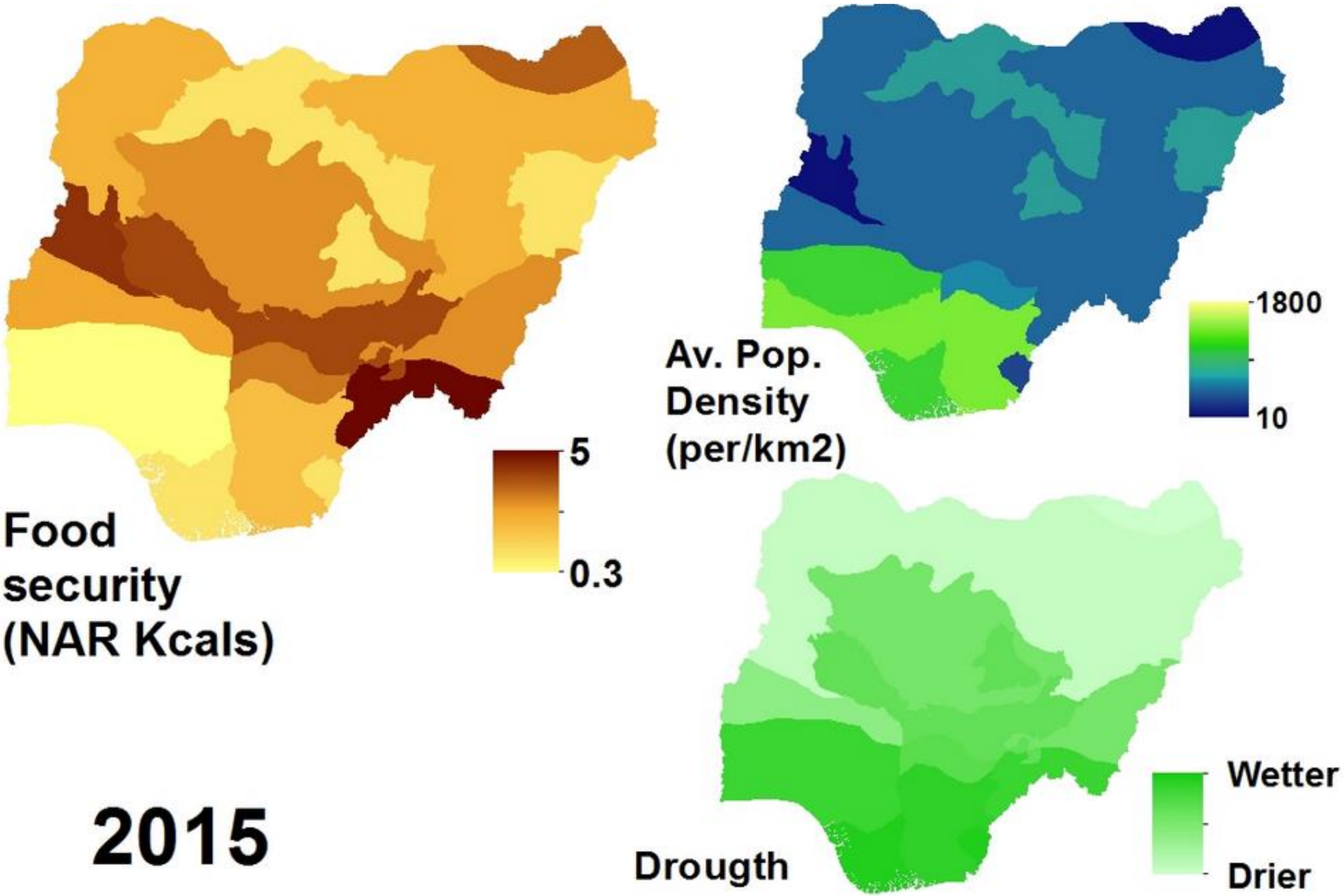
Food security defined as existing:
"when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (1996 WHO summit)



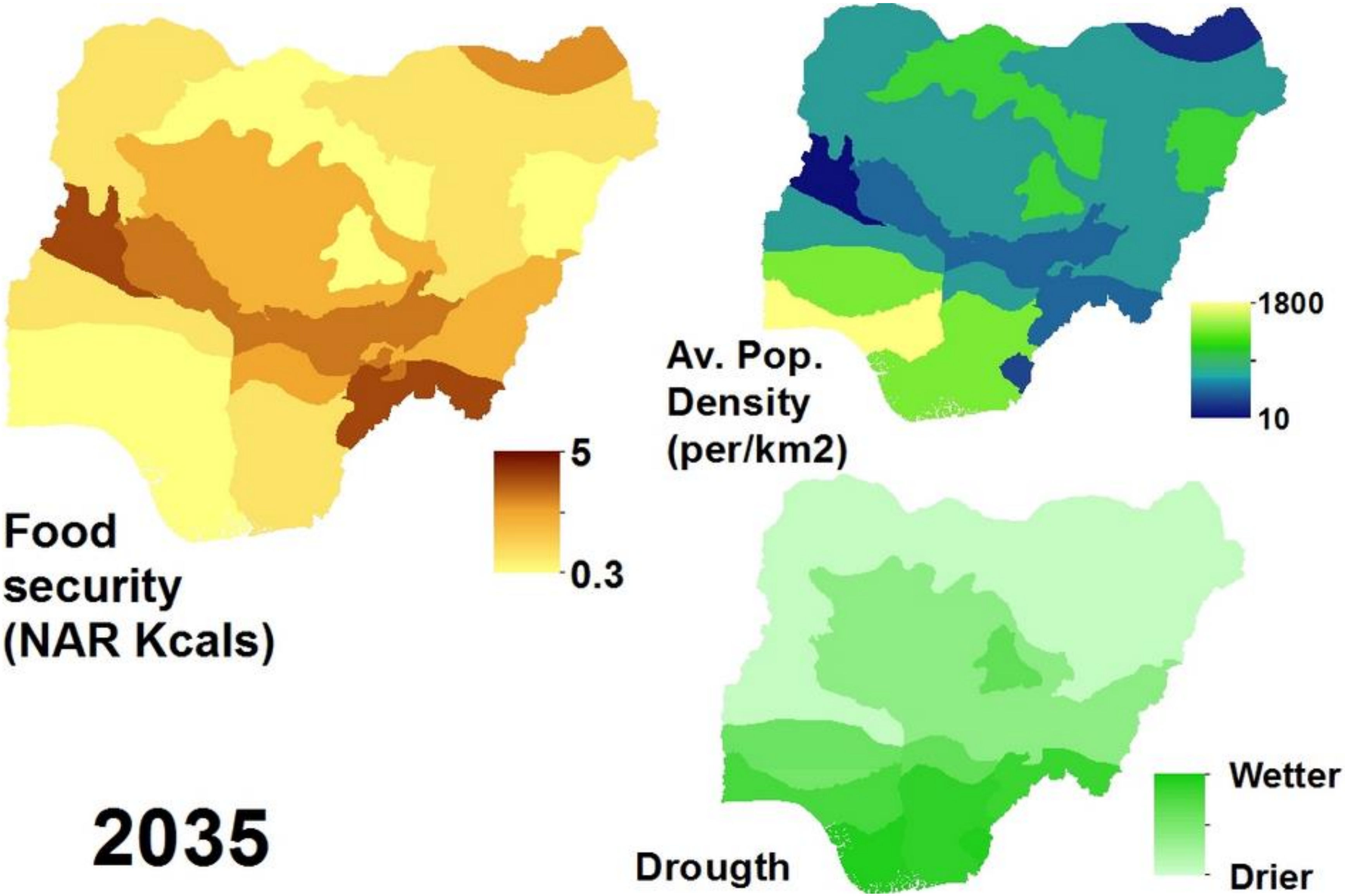
Food security it is reached when the nutritional requirements per capita or over a population are fulfilled

Recommended Nutrient Intake (RNI)

Impact of Climate variability on Food Security: Nigeria



Impact of Climate variability on Food Security: Nigeria



CONCLUSIONS

Vulnerability

Potential Impact

Adaptive capacity

Climate data

- Uncertainties
- Climate models
- Scenarios
- Downscaling techniques
- Resolution
- ....

Agricultural models

- Indicators
- Land evaluation tecniques
- Statistical models
- Process based models
- ....

Economic evaluations

- Socio-economic factors
- Technology
- ....

Thanks

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