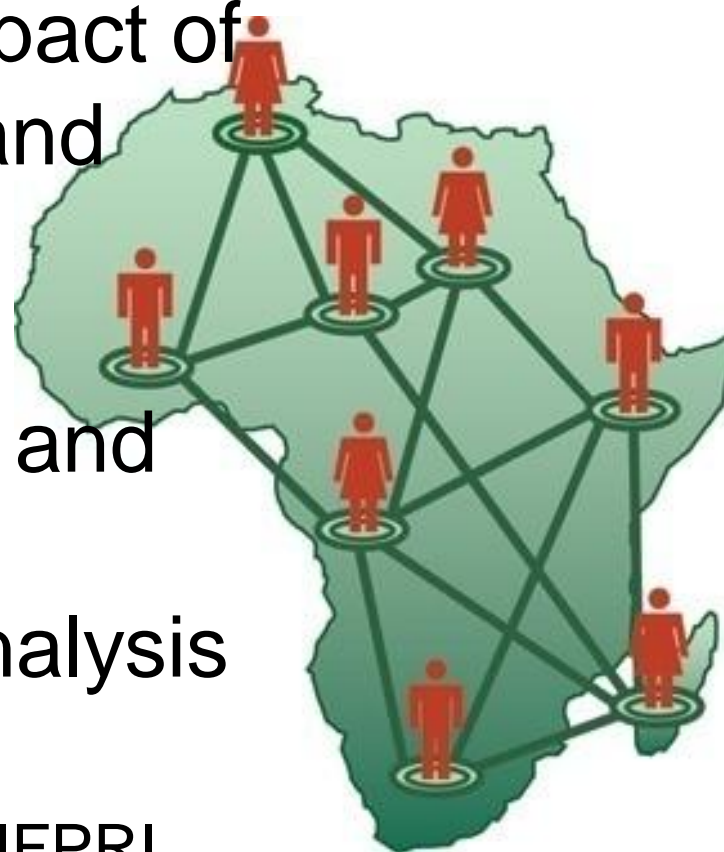


# Simulating the Impact of Climate Change and Adaptation Strategies on Farm Productivity and Income: A Bioeconomic Analysis



Presented by:  
Ismael Fofana, IFPRI

AGRODEP Workshop on Analytical Tools for Climate  
Change Analysis

June 6-7, 2011 • Dakar, Senegal

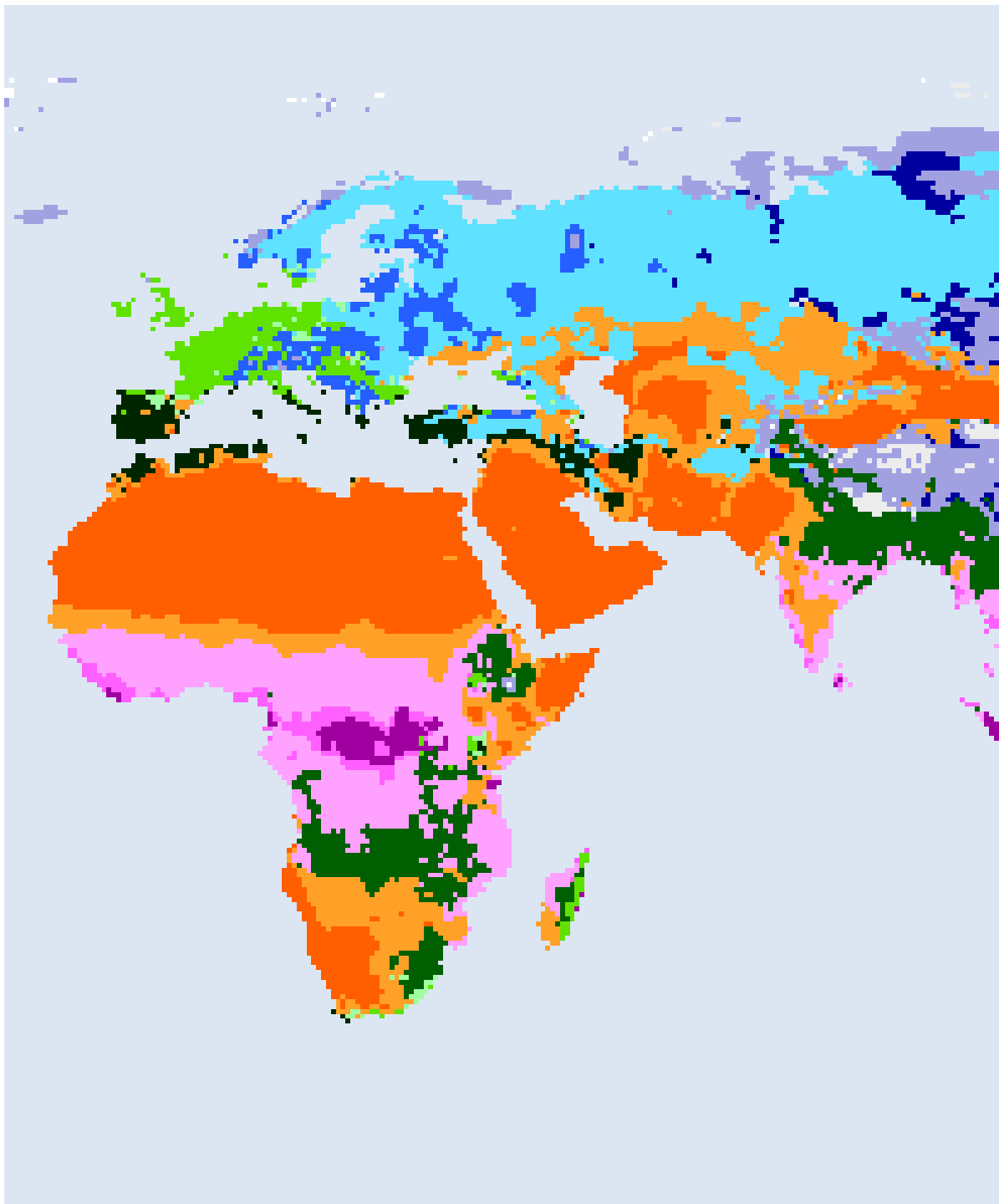
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# Simulating the Impact of Climate Change and Adaptation Strategies on Farm Productivity and Income: A Bioeconomic Analysis

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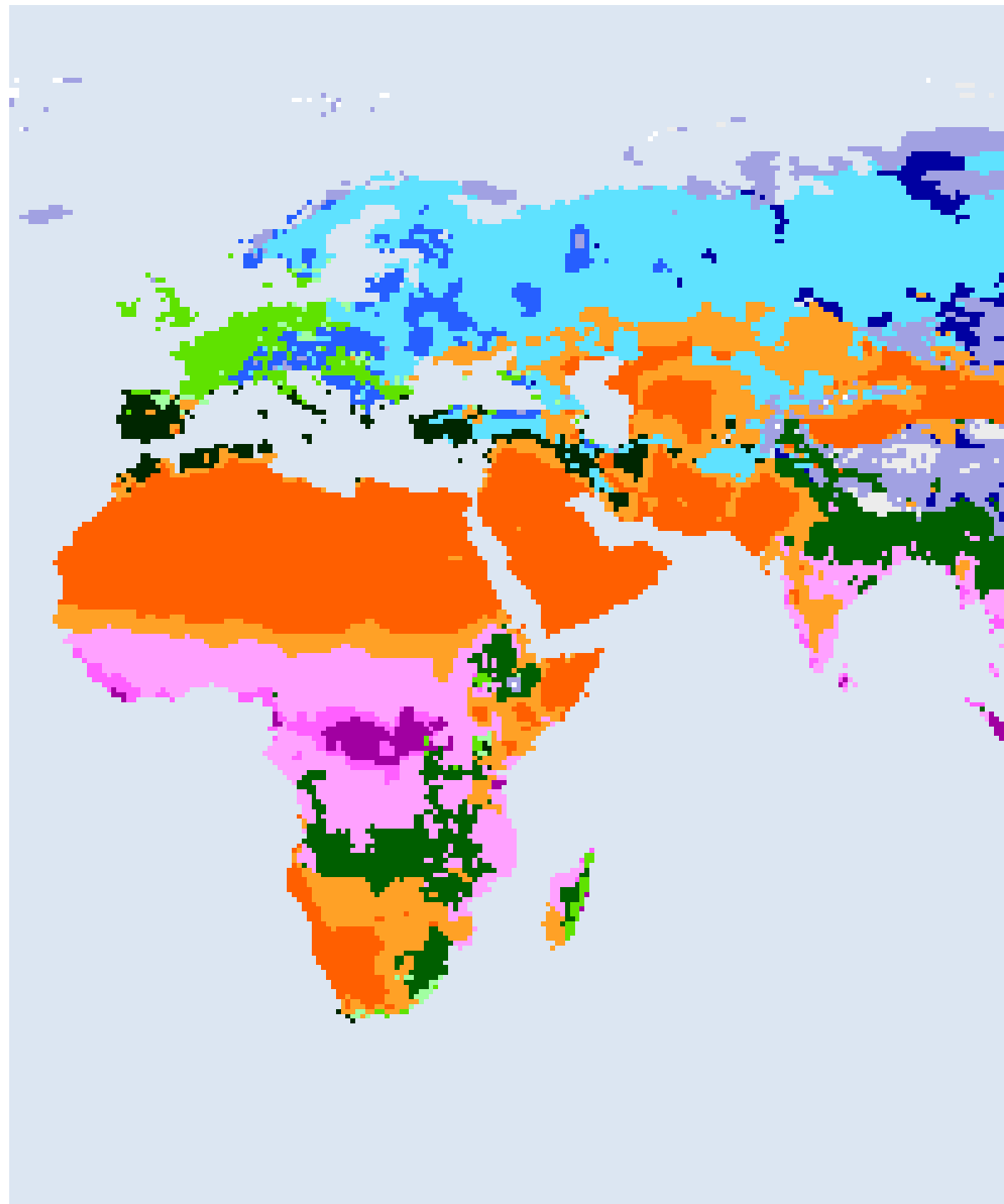
Dakar, Senegal



**1. Issue**

**2. Methodology**

**3. Results**



# 1. Issue

- Our climate is changing; strong evidences on rising temperature, sea-levels, frequency and severity of droughts and floods, ...
- More confidence on IPCC's near-term projections

## IPCC projected global average warming until 2100 under various scenarios

	Economic growth	Environmental sustainability
Homogeneous world	<b>A1 {A1FI; A1T; A1B}</b> : Rapid technological change and economic growth [1.4 - 6.4 °C]	<b>B1</b> : Economic structures toward a service and information economy [1.1 - 2.9 °C]
Heterogeneous world	<b>A2</b> : Slow technological change and economic development [2.0 - 5.4 °C]	<b>B2</b> : Local solutions to economic, social, and environmental sustainability [1.4 - 3.8 °C]

# 1. Issue (cont.)

- Agricultural sector is highly climate sensitive
- Climate defines production areas for crops
- Climate's effect on yield is important

**Objective**: Contribute to better understand the impact of climate change on agriculture and food security in Africa

Analysis at the farm level is a crucial step before moving into a large and general analysis

## 2. Methodology

- Building of climate scenarios upon changes in temperature, precipitation, and carbon dioxide concentration in the atmosphere
- Performing climate sensitivity tests with the climate scenarios using a farm model
  - **Farm model** combines a crop systems model and an economic model run sequentially (Bioeconomic model)
    - **Crop systems model:** CROPSYST
    - **Economic model:** Linear optimization

# CropSyst or Cropping System

## LOCATION

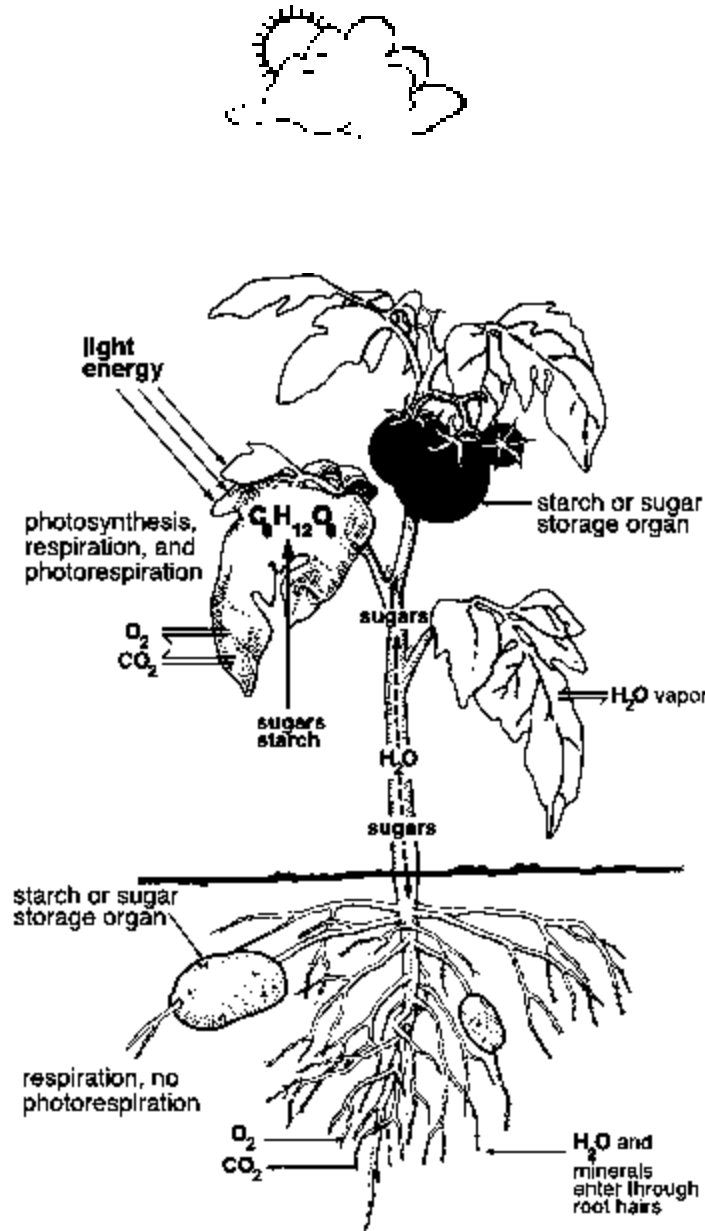
- WEATHER
- Storms
- [Evapotranspiration](#)
- Freezing climates
- Wind

## CROP

- Classification
- Planting
- [Growth](#)
- Morphology
- Phenology
- Vernalization
- Photoperiod
- Harvest
- Residue
- Nitrogen
- Salinity
- CO<sub>2</sub>
- Dormancy

## SOIL

- Leaching
- Runoff
- RUSLE
- Volatilization
- [Texture](#)
- Hydraulics



## MANAGEMENT



- Harvest
- [Irrigation](#)
- Clipping
- Nitrogen
- Conservation
- Tillage

# CropSyst (cont.)

## Crop growth

springwht.crp

Above ground biomass-transpiration coefficient	4.70	kPa kg/m <sup>2</sup>	Classification
Light to above ground biomass conversion	3.00	g/MJ	Planting
At/Pt ratio limit to leaf area growth	0.95	0-1	<b>Growth</b>
At/Pt ratio limit to root growth	0.50	0-1	Morphology
Temperature below which growth rate is reduced	10.00	°C	Phenology
Thermal time to cease temperature limitation	1500	°C-day	Vernalization
Maximum water uptake	13.00	mm/day	Photo-period
Critical leaf water potential	-1500.0	J/kg	Harvest
Wilting leaf water potential	-2200.0	J/kg	Residue
			Nitrogen
			Salinity
			CO <sub>2</sub>
			Dormancy

 OK  Help





# CropSyst (cont.)

## Soil texture

logan82.sil

Last layer	Thickness m	sand %	clay %	silt %	Layer bypass 0-1	
<input type="radio"/> 1	0.100	60.00	25.00	15.00	0.500	<- Texture triangle
<input type="radio"/> 2	0.100	45.00	30.00	25.00	0.500	<- Texture triangle
<input type="radio"/> 3	0.250	45.00	35.00	20.00	0.500	<- Texture triangle
<input type="radio"/> 4	0.300	50.00	20.00	30.00	0.500	<- Texture triangle
<input type="radio"/> 5	0.300	52.00	23.00	25.00	0.500	<- Texture triangle
<input checked="" type="radio"/> 6	0.400	60.00	20.00	20.00	0.500	<- Texture triangle
<input type="radio"/> 7	0.000	60.00	20.00	20.00	0.000	<- Texture triangle
<input type="radio"/> 8	0.000	60.00	20.00	20.00	0.000	<- Texture triangle
<input type="radio"/> 9	0.000	60.00	20.00	20.00	0.000	<- Texture triangle
<input type="radio"/> 10	0.000	60.00	20.00	20.00	0.000	<- Texture triangle
<input type="radio"/> 11	0.000	60.00	20.00	20.00	0.000	<- Texture triangle
<input type="radio"/> 12	1.000	60.00	20.00	20.00	0.000	<- Texture triangle

Default  
Estimated from texture  
Computed from user specified values  
User specified

OK  Help

Description Texture Hydraulic properties



# CropSyst (cont.)

## Evapotranspiration model

logan82.LOC

Description  
Logan, 1982

Evapotranspiration model

Priestley-Taylor  
 Penman-Monteith

Priestley-Taylor Constant  1-2

Aridity factor for VPD  .04-.07

Location / Precipitation / Winter / **Evapotranspiration model** / Wind



# CropSyst (cont.)

## Irrigation

Management file: C:\CropSyst\sample\logan\5.MGT

Automatic irrigation

Maximum allowable depletion  0-1

Depletion observation depth  m

Net irrigation multiplier  0-2

Maximum irrigation application  mm

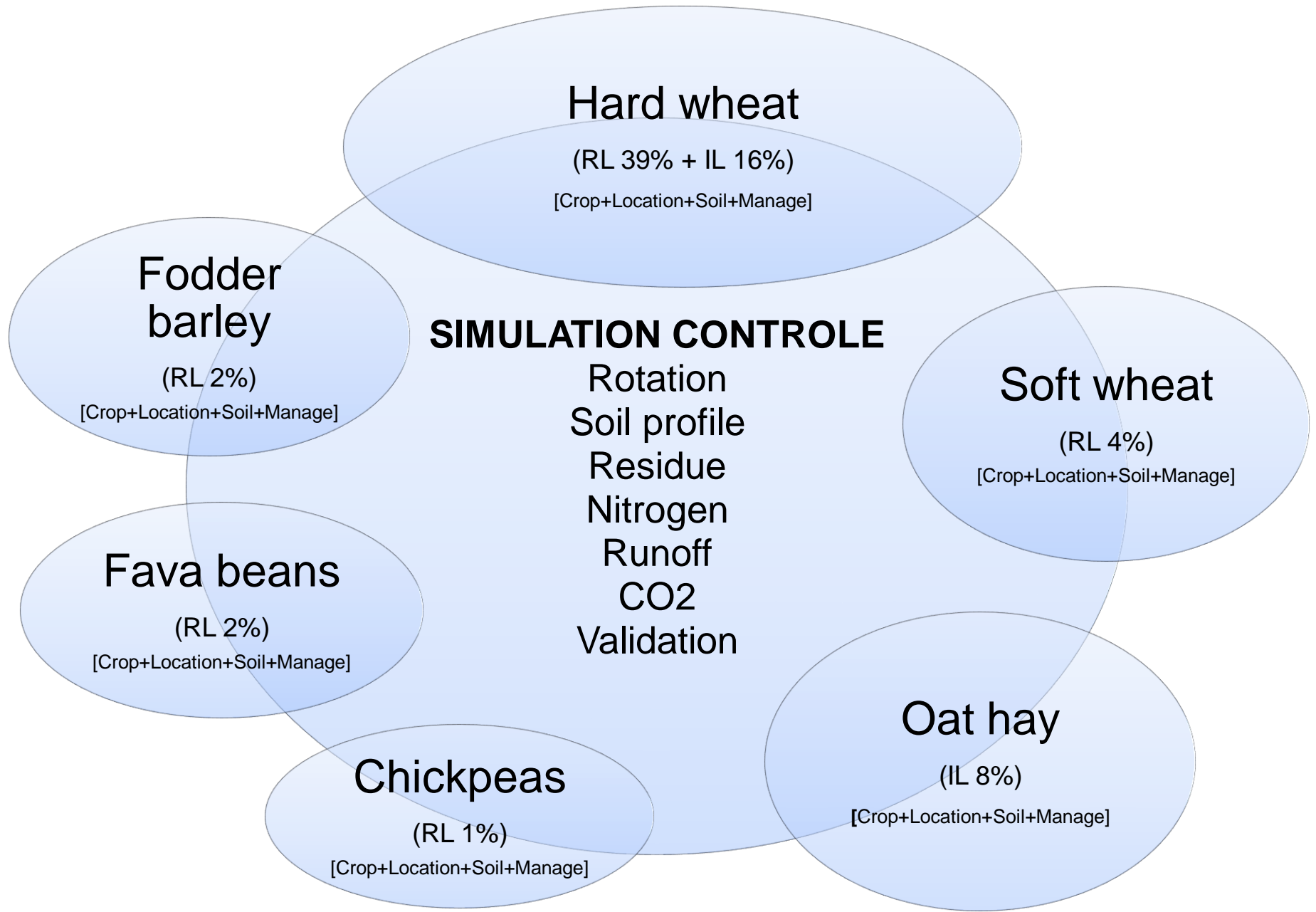
Period Starting date

Ending date

0000/6/3	Irrigation	30.100 mm	0.000 kg	NONE /m3	water	-
0000/6/9	Irrigation	26.100 mm	0.000 kg	NONE /m3	water	
0000/6/17	Irrigation	28.500 mm	0.000 kg	NONE /m3	water	
0000/6/23	Irrigation	30.400 mm	0.000 kg	NONE /m3	water	
0000/6/30	Irrigation	30.400 mm	0.000 kg	NONE /m3	water	
0000/7/7	Irrigation	34.400 mm	0.000 kg	NONE /m3	water	
0000/6/13	Irrigation	37.900 mm	0.000 kg	NONE /m3	water	
0000/7/21	Irrigation	38.700 mm	0.000 kg	NONE /m3	water	

Harvest **Irrigation** Nitrogen Mow, crop, clip, or prune Conservation Tillage operation

# CropSyst (cont.)



# CropSyst (cont.)

## Simulation controle

**Simulation file:** C:\CropSyst\sample\logan\l1\log82.SIM

Description  
Logan, 1982, Mgmt 1 wheat

Starting date 1982/Apr/01

Ending date 1982/Aug/25

Soil file LOGAN82.SIL Edit

Location file LOGAN82.LOC Edit

Report format test.fmt <-None Edit

Infiltration model

- Cascade
- Finite difference

Runoff model

- No runoff
- SCS Curve number
- Numerical solution

Runtime graph

Salinity

Rainfall intensity generation

Validation Simulation

OK Cancel Help

Simulation Soil profile Rotation Residue Nitrogen CO2

# The Economic Model

## Objective

$$\max_L \Omega = \sum_{c,m} (\pi_{c,m} \times T_{c,m}) \quad \text{with} \quad \pi_{c,m} = \left( \sum_j y_{c,m,j} \times \overline{p_{c,j}} \right) - \left( \sum_i q_{c,m,i} \times \overline{p_{c,i}} \right)$$

## Constraints

Soil occupation:  $\sum_c \sum_m T_{c,m} \leq \overline{T^S}$

Rotation:  $S_{cc,mi} \leq S_{cf,mi}$  and  $\overline{S}_c^{\min 5 \text{ years}} \leq S_c \leq \overline{S}_c^{\max 5 \text{ years}}$

Water:  $\sum_c W_{c,t} \leq \overline{W}_t^S$

Animal food: Surface allocated to barley fodder compensated for the change in supplies of animal food (stubbles)

# Hypotheses

- Rational decision making with gross margins the only variable influencing surface allocation
- Fixed products and factor prices (price taker)
- No constraint on the farm's access to other productive factors, e.g. labor and capital

# Hypotheses (cont.)

- Climate change is not associated directly with the appearance of weeds, diseases, and pests
- Climate change does not affect soil's physical and chemical characteristics
- Climate change does not affect Plant's basic physiological, morphological, and agronomic characteristics
- Tree crops are not seriously affected by climate change



## Hypotheses (cont.)

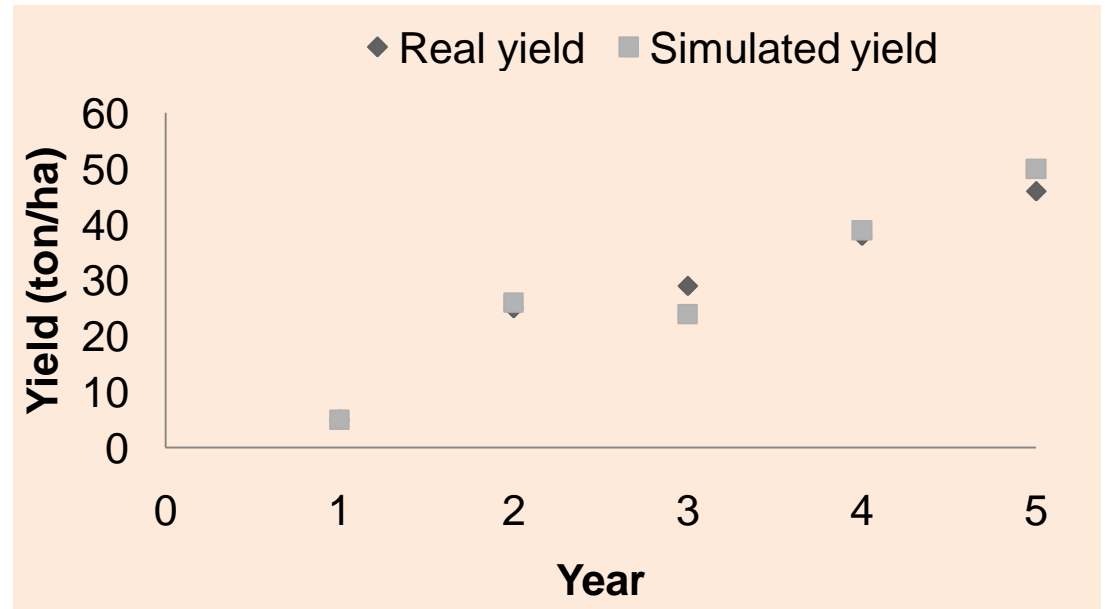
- The contribution of pastureland used to feed animals remained unchanged
- The capacity to ingest of animals and the quality of food are not modified with climate change
- Water requirements for animals do not significantly affect the availability for crops
- Water supply mostly comes from surface water and its availability is proportionally affected by the change in rainfall

# Validation



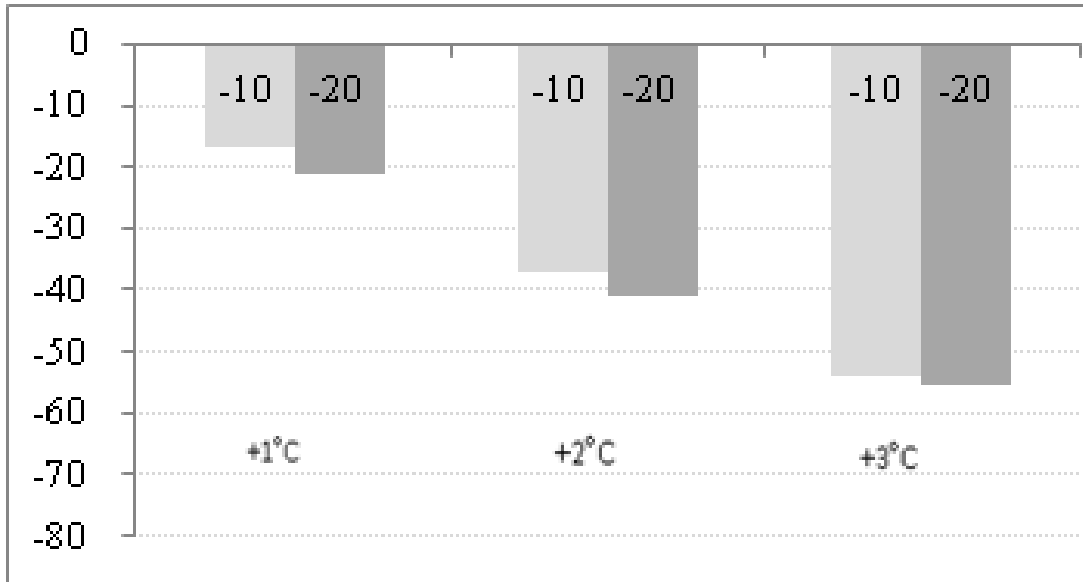
← Calibration results for irrigated hard wheat

Calibration results for rainfed hard wheat



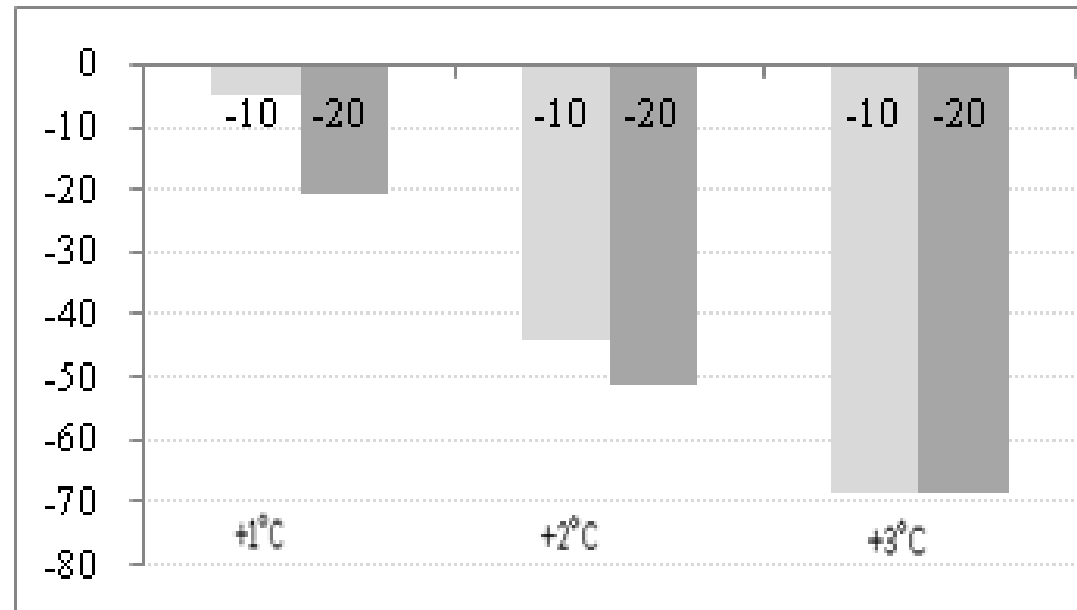
# 3. Results

## Productivity effects



Productivity loss: 15 to 20% in the near-term; 35 to 55% in the long run

## Income effects

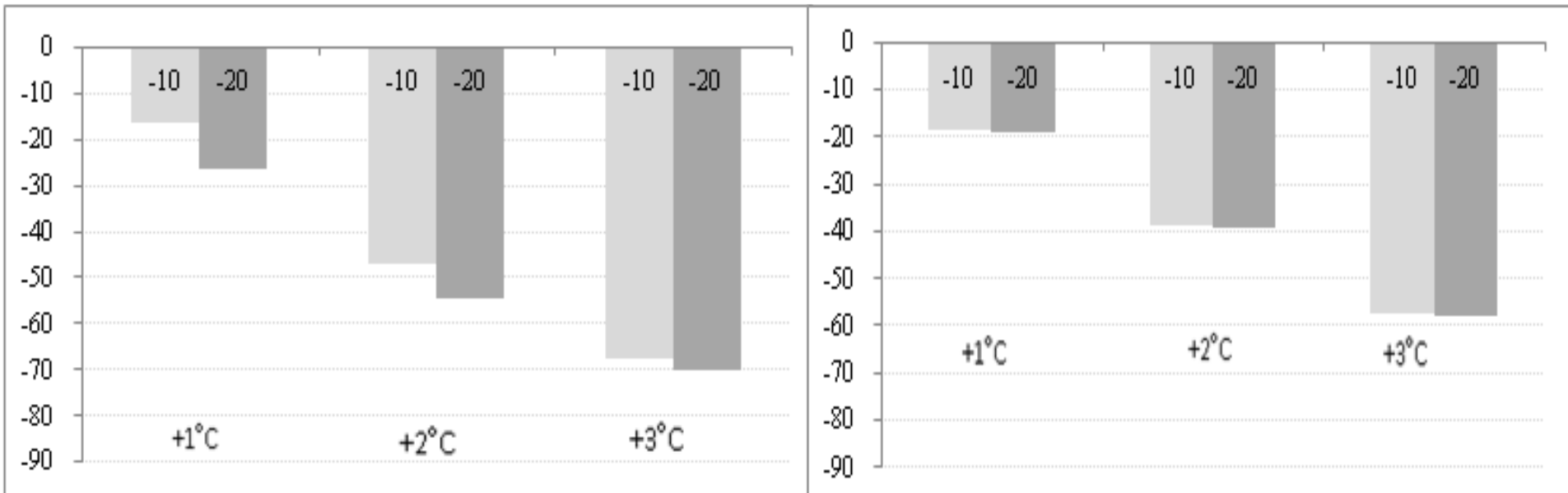


Income loss: 5 to 20% in the near-term; 45 to 70% in the long run

### 3. Results (cont.)

**Yield of rainfed hard wheat**

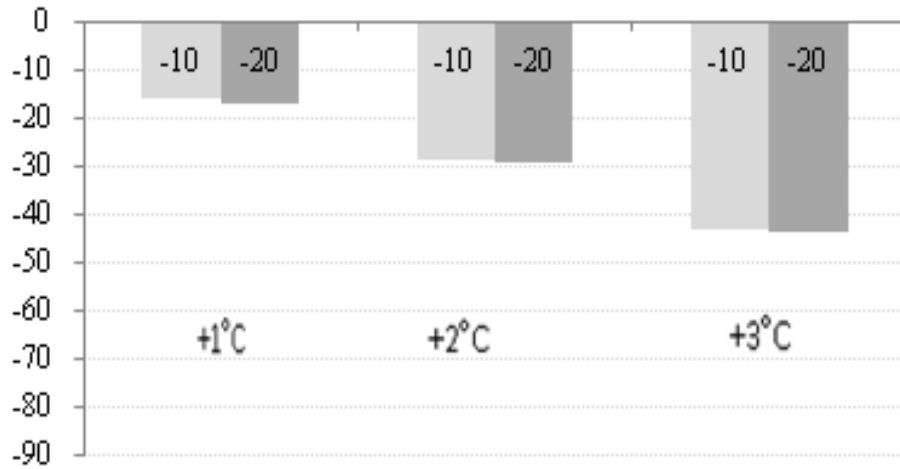
**Yield of irrigated hard wheat**



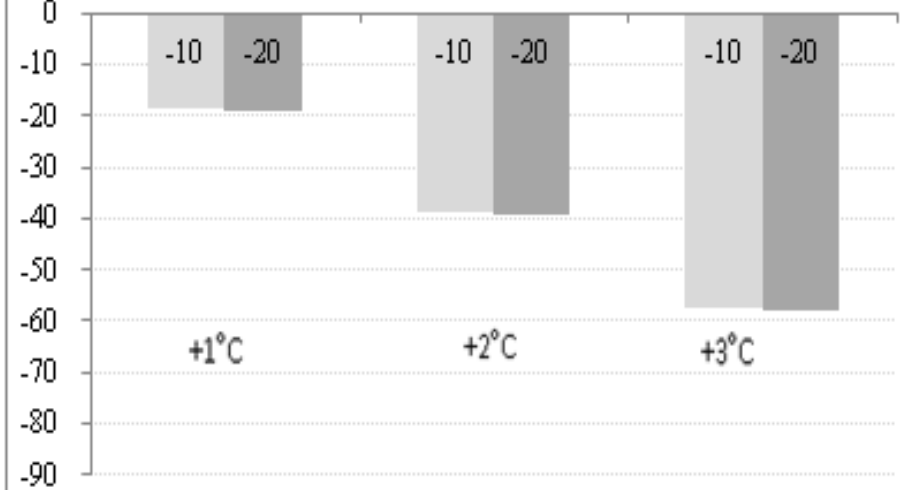
- Irrigated crops less affected than rainfed crops (with 10 percentage points of productivity gap)
- Precipitation-induced productivity gap lessens as the climate warms up

# 3. Results (cont.)

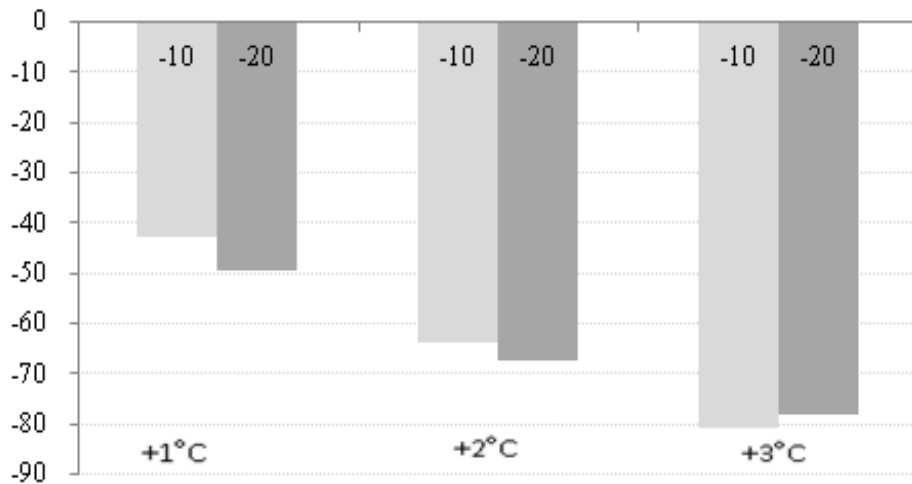
## Yield of irrigated oat hay



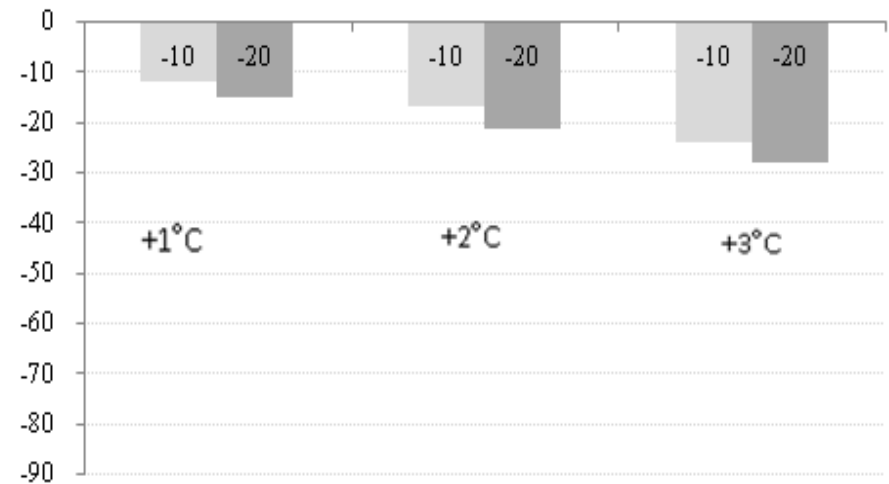
## Yield of irrigated hard wheat



## Yield of rainfed fava beans

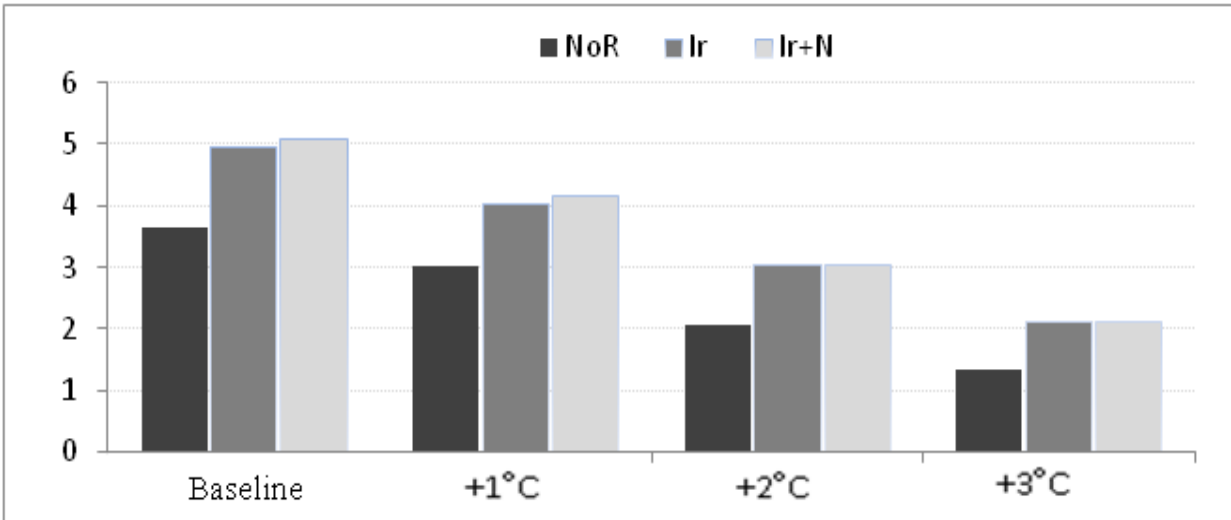


## Yield of rainfed fodder barley

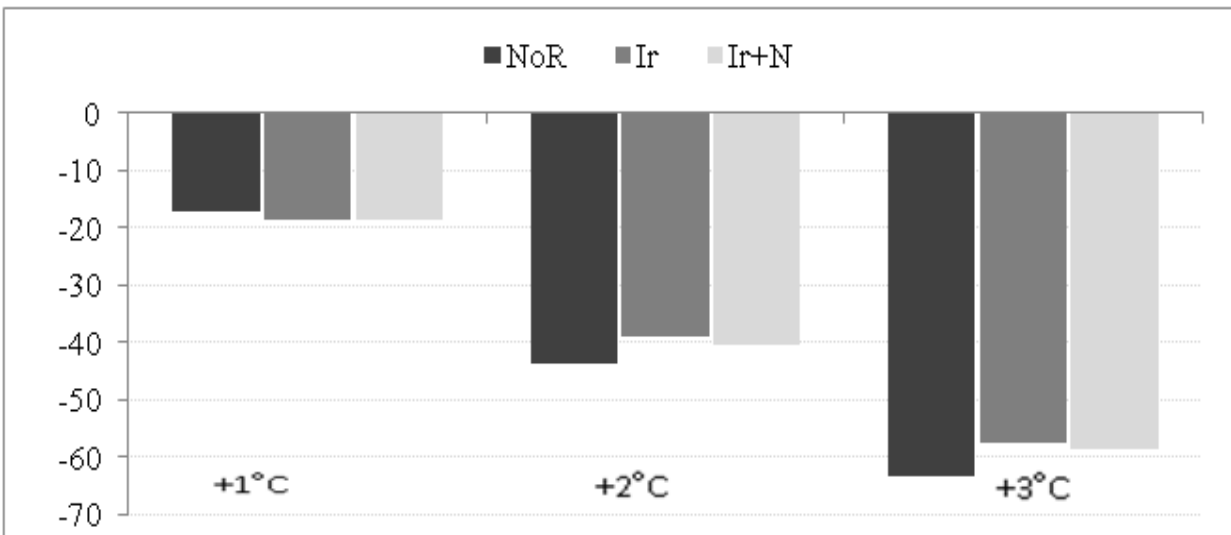


# 3. Results (cont.)

## Hard wheat yield (tons/ha)



## Percentage variation of hard wheat yield



Compensation for the negative effects of climate change through irrigation is worthwhile only for a 1°C increase in temperature

# Summary

1. Yield loss:  $1^{\circ}\text{C} \Rightarrow 15\text{-}20\%$  ;  $2^{\circ}\text{C}$  to  $3^{\circ}\text{C} \Rightarrow 35\text{-}55\%$
2. Rev. loss:  $1^{\circ}\text{C} \Rightarrow 5\text{-}20\%$  ;  $2^{\circ}\text{C}$  to  $3^{\circ}\text{C} \Rightarrow 45\text{-}70\%$
3. Irrigated crops less affected than rainfed crops
4. Precipitation-induced productivity gap lessen as the climate warms up
5. Some crops less affected than others
6. Irrigation, as an adaptation strategy, is worthwhile only for a  $1^{\circ}\text{C}$  increase in temperature

**Thank you for your attention**

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