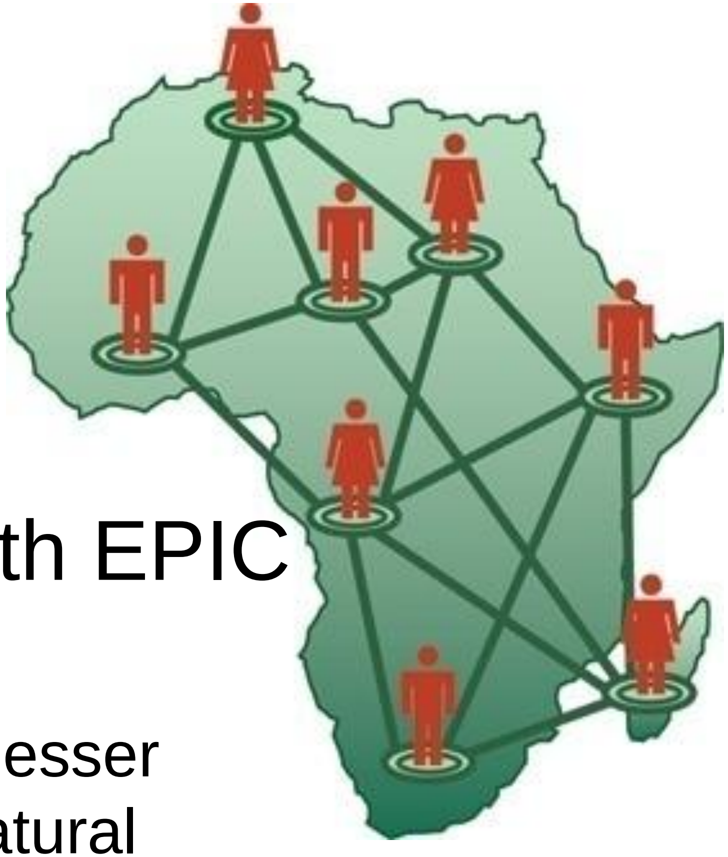
Bio-physical impact analysis of climate change with EPIC



Presented by:

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AGRODEP Workshop on Analytical Tools for Climate Change Analysis

June 6-7, 2011 • Dakar, Senegal

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Bio-physical impact analysis of climate change with EPIC

Ch. Heumesser, E. Schmid, F., Strauss, J. Balkovic, et al.

AGRODEP members' meeting and workshop-
June 6-8 2011- Dakar, Sénégal

1. INTRODUCTION – Challenges for Agriculture in Europe

Introduction – Challenges for Agriculture

- Challenges in meeting increasing food demand on global scale in the next decades:
  - Population growth, increase in average per capita income and water-intense lifestyle.
  - To meet food demands:
    - Future land expansion might be limited due to conflicting demands and physical limits.
    - An increase in agricultural productivity by intensification, e.g. **irrigated agriculture** is expected in the future.
  - Environmental regulations may constrain particular management practices.
  - Potential for water scarcity on local and regional scale.
  - Growth in domestic and industrial water consumption will decrease the available water resources for agriculture.
  - **Climate change** is likely to change the productivity of agricultural systems.

Introduction – Irrigated Agriculture

- On a global scale, agriculture accounts for 70% of anthropogenic water withdrawals.
- ~ 20% of total arable cropland is under irrigation, producing about 40% of global harvest (Bruinsma, 2003).
- Salinization induced by irrigation affects 10% of the world irrigated land (Schoups et al. 2005)
- About 25% of the world irrigated agricultural systems have been withdrawing above the regeneration rate
- Poor property right specification on water resources and inefficient irrigation practices which result in land degradation and loss of productivity (FAO, 2008b)

Introduction- Irrigated Agriculture in Europe

- In parts of **Southern Europe:** Agriculture accounts for up to **80 %** of total water us (mostly crop irrigation) (EEA 2009).

- In **Northern Europe**, agriculture's contribution to total water use varies from almost **zero to over 30 %** (mostly livestock farming) (EEA 2009).

- Proportion of area equipped for irrigation in selected countries.

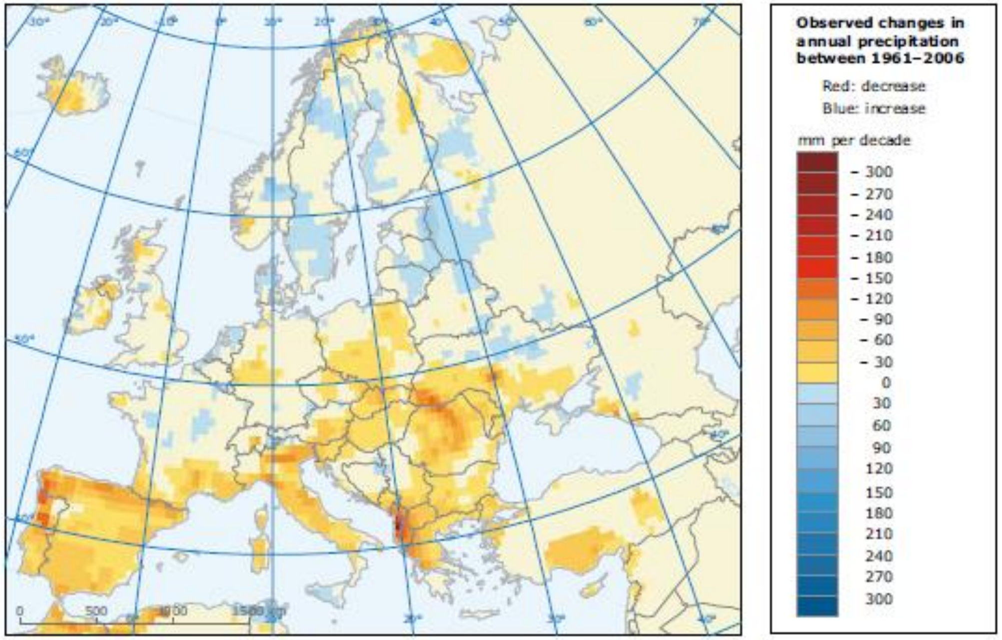
Country	Country area (1000 ha)	Agricultural area (1000 ha)	Arable land area (1000 ha)	Area equipped for irrigation: total (1000 ha)	Proportion of area actually irrigated from area equipped for irrigation	Agricultural water withdrawal as proportion of total renewable water resources
Austria	8387	3240	1382	119	0·335	0·00025
Czech Republic	7887	4249	3032	47	0·368	0·00456
Hungary	9303	5807	4592	153	0·492	0·0236
Slovakia	4903	1930	1377	180	0·249	ND
Slovenia	2027	500	177	4	0·506	ND

Source: Trnka et al. 2010;

- Assumed fraction of irrigation methods in Europe: Basin and Furrow: ~34%, Drip irrigation systems ~18%,Sprinkler ~48% (Sauer et al. 2010).

Introduction- Climate Change in Europe

- There is a **warming trend** (+0.90°C for 1901-2005) throughout Europe which has been accelerating in the last 30 years (Alcamo et al. 2007)



Observed changes in annual precipitation 1961–2006

Source: The data come from two projects: ENSEMBLES (http://www.ensembles-eu.org) and ECA&D (http://eca.knmi.nl) EEA, 2009

- Regional climate models project a larger warming in winter than in summer in Northern Europe and the reverse in central and Southern Europe. (cp. Christensen and Christensen 2007)

Introduction- Climate Change in Europe

- Trends in **precipitation** and changes in seasonal precipitation are more variable spatially and temporally (IPCC 2007)
- For all scenarios **mean annual precipitation** increases in northern Europe and decreases further south (IPCC 2007).

- Mediterranean regions, Central Europe and Eastern Europe :
  - Precipitation trends are projected to be negative.
  - Precipitation sums will decline in the early growing season (April-June) (Trnka et al. 2010)
  - Major and unprecedented drought events are more likely to occur in the near future than at any time in the past 130 years (Brazdil et al. 2009a,b; Trnka et al. 2010)
  - A reduced groundwater recharge rate is predicted for Central and Eastern Europe (Eitzinger et al. 2003; in IPCC 2007)
  - For Central and Southern Europe, areas under water stress can increase from 19% in 2007 to 35% in 2070 (IPCC, 2007).

2. EPIC - *Environmental Policy Integrated Climate*

EPIC - *Environmental Policy Integrated Climate*

- Developed in the 1980s as "The Erosion Productivity Impact Calculator" to asses the status of U.S. soil and water resources (Williams et al., 1984; Williams, 1990; Jones et al., 1991).

- EPIC compounds various components from CREAMS (Knisel, 1980), SWRRB (Williams et al., 1985), GLEAMS (Leonard et al., 1987), and has been continuously expanded and refined to allow simulation of many processes important in agricultural land management (Sharpley and Williams, 1990; Williams, 1995, 2000) => ***Environmental Policy Integrated Climate*** (Williams, 1995).

- A major carbon cycling routine was performed by Izaurralde et al. (2006) based on the approach used in CENTURY (Parton et al., 1994). Current research efforts are focusing on model algorithm that address green house gases emissions (e.g. N_2O, CH_4).

EPIC is part of a model family

Watershed Scale

APEX

Agricultural Policy Environmental eXtender

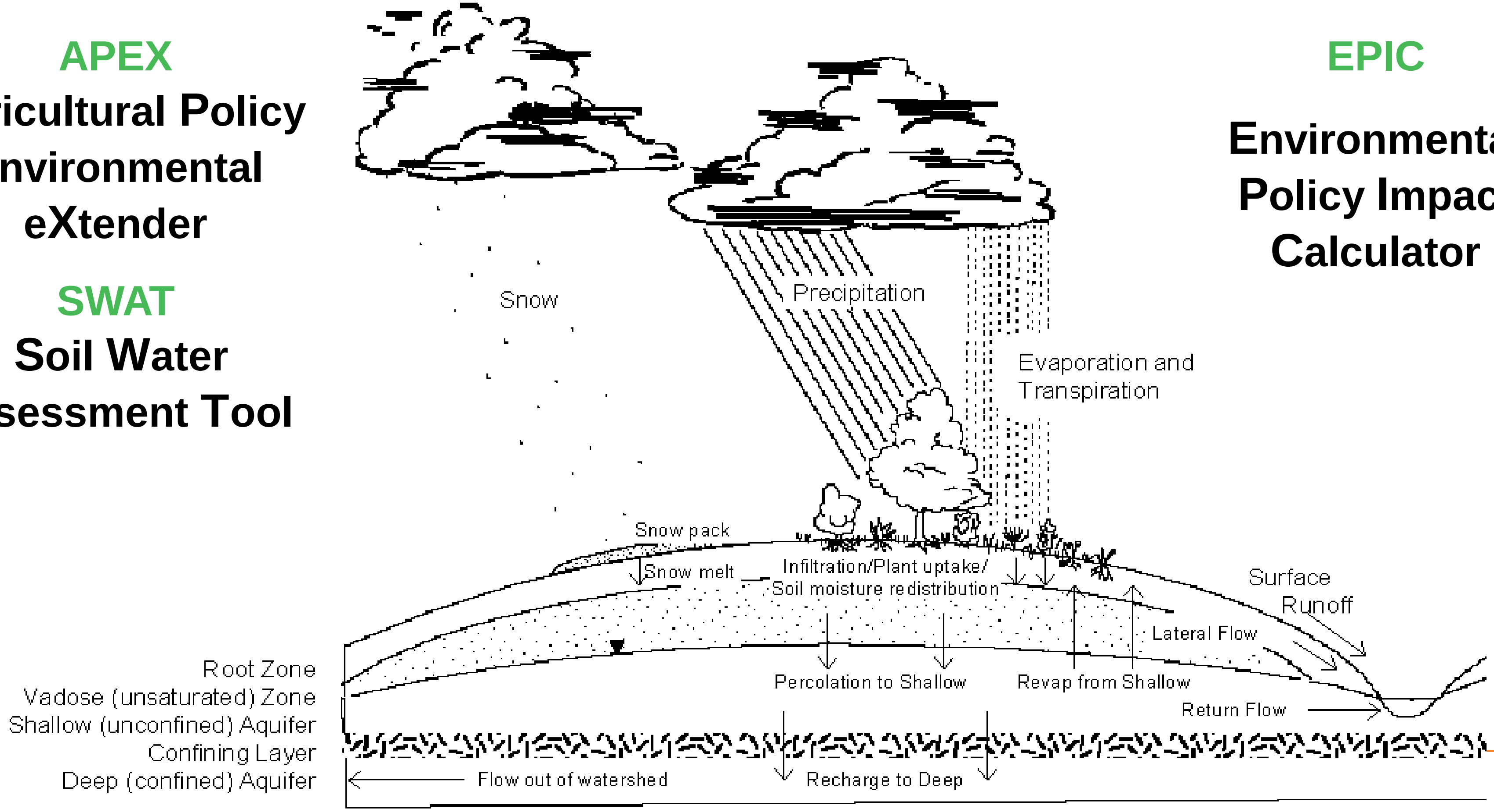
SWAT

Soil Water Assessment Tool

Field Scale:

EPIC

Environmental Policy Impact Calculator



Major EPIC components

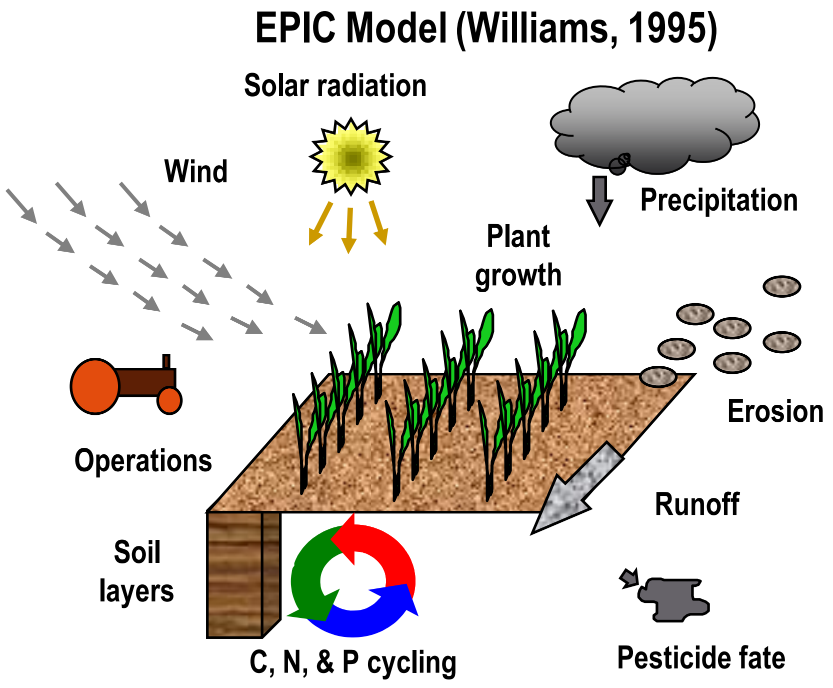
- weather simulation & actual daily weather
- hydrology (runoff, evapotranspiration, percolation)
- erosion-sedimentation (wind and water)
- nutrients (N, P, K) and carbon cycling (C)
- salinity
- plant growth and competition
- soil temperature and moisture
- tillage & management & grazing
- cost accounting

EPIC operates on a daily time step, and is capable of simulating hundreds of years if necessary.

EPIC - *Environmental Policy Integrated Climate*

4 major input:

1. Weather
2. Soil
3. Topography
4. Land use Management



EPIC - *Environmental Policy Integrated Climate*

Major simulation outputs:

Dry matter crop yield [t/ha]
Dry matter straw yield [t/ha]

Carbon
Carbon in Crop Yield (YLC) [kg/ha],
Carbon Respiration (RSPC) [kg/ha],
Carbon in Sediment (YOC) [kg/ha],
Carbon in Percolation (CLCH) [kg/ha],
Carbon in Runoff (CQV) [kg/ha],
Topsoil Organic Carbon (OCPD) [t/ha]

Water Balance:
Rainfall (PRCP) [mm],
Irrigation (IRGA) [mm],
Potential EvapoTranspiration (PET) [mm],
Actual EvapoTranspiration (ET) [mm],
Runoff (Q) [mm],
Subsurface flow (SSF) [mm],
Percolation (PRK) [mm]

Nitrogen Balance:
Fertilization (FTN) [kg/ha],
Deposition (NPCP) [kg/ha],
Fixation (NFIX) [kg/ha]
Nitrogen in Crop Yield (YLN) [kg/ha],
Air Volatilization (AVOL) [kg/ha],
Denitrification (DN) [kg/ha],
Organic Nitrogen in Sediment (YON) [kg/ha],
Soluble Nitrogen in Runoff (QNO3) [kg/ha],
Soluble Nitrogen in Subsurface Flow (SSFN) [kg/ha],
Soluble Nitrogen in Percolation (PRKN) [kg/ha],
Nitrogen losses through Burnning (BURN) [kg/ha]

Others
Sediment losses (MUST, USLE, RUSL) [t/ha]
Gross Nitrogen Mineralization (GMN) [kg/ha]
Net Nitrogen Mineralization (NMN) [kg/ha]
Nitrification (NITR) [kg/ha]

…

Integrative Climate Change Impact Modelling

Thematical Databases	Bio-physical process modelling	Scale	Economic Land Use Models	Economic-, Energy & Ecosystems models
Climate		Field, Farm, Environment	**FAMOS[space]** (BOKU)	**CGE** (Wegener Zentrum)
Soil and Topography		Region & Austria	**PASMA** (BOKU/WIFO)	**PROMETEUS** (WIFO)
Land use & management	**EPIC** **APEX** (TAES/JGCRI/BOKU)	Pixel & Countries	**BeWhere** (IIASA/BOKU)	**MultiREG** (Joanneum)
		EU-Regions & ROW	**EUFASOM** (Uni. Hamburg, IIASA, BOKU, u.a.)	**ERSEM** (Uni. Hamburg)
Economics & Administration & Statistics		Global	**GLOBIOM** (IIASA, Uni. Hamburg, BOKU, u.a.)	**POLES** (JRC-IPTS)

Integration →

Scale ↓

EPIC & GLObal BIomass Optimization Model

economic scale

- resource endowments for world regions
- economic data (e.g. prices, costs, trade, production, consumption)

GLOBIOM

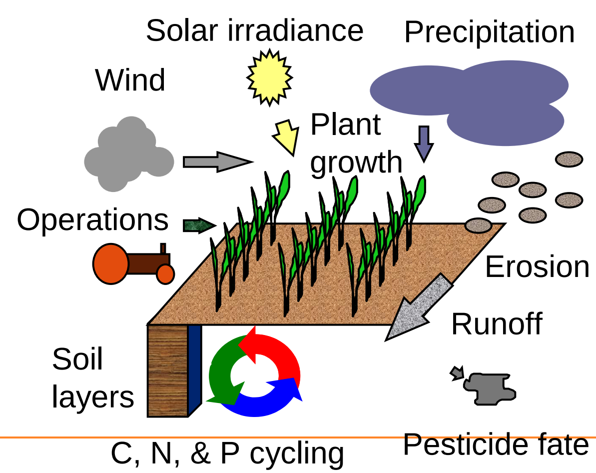
- benefits, costs
- economic surpluses
- performance indicators & impacts

bio-physical impacts

EPIC Model

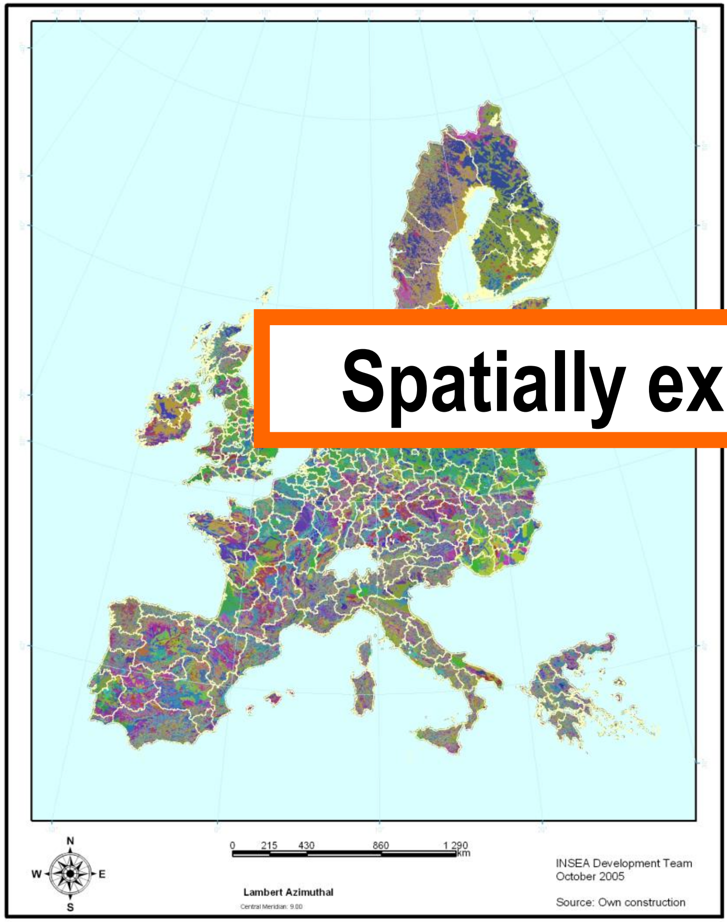
geo-spatial scale

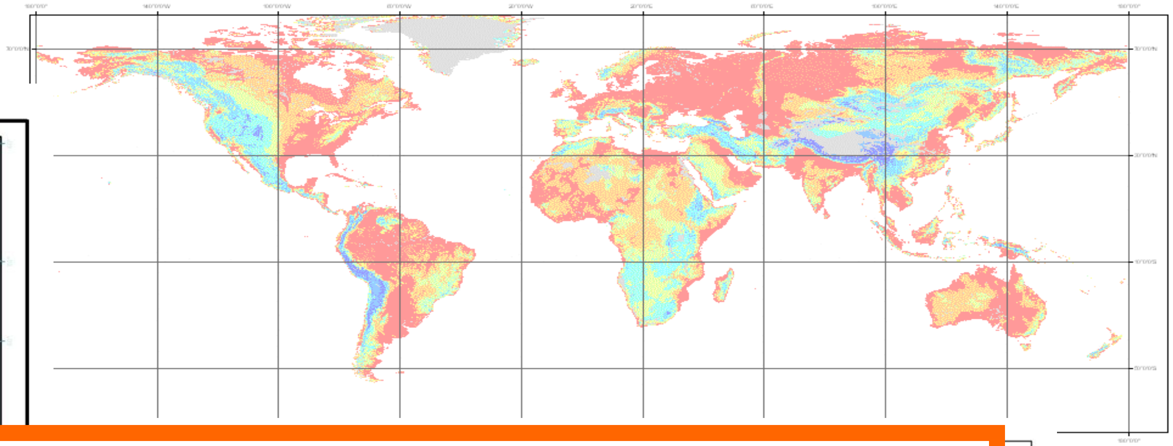
- weather/climate data
- soil data
- topographical data
- land use and crop management data



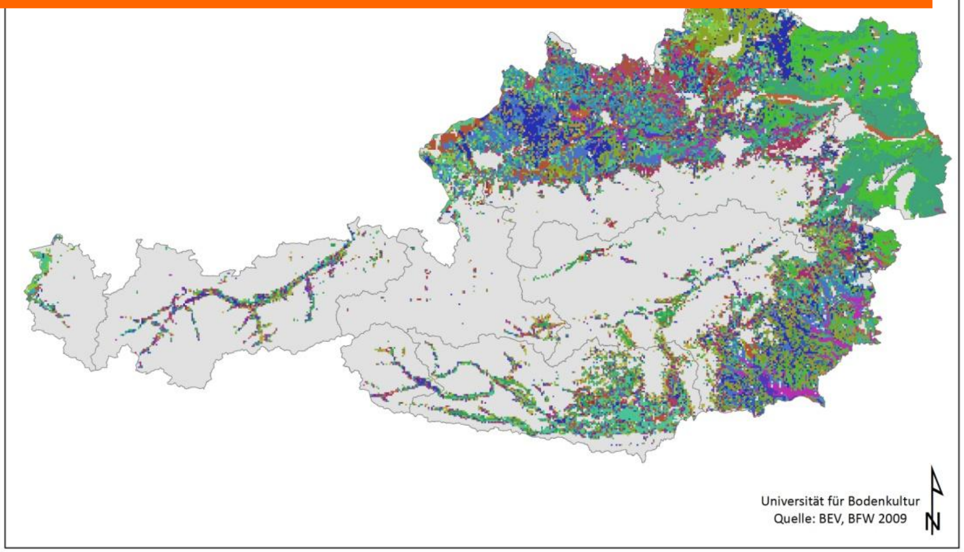
Representative EPIC modules

EPIC - Homogenuous Response Units (HRU)





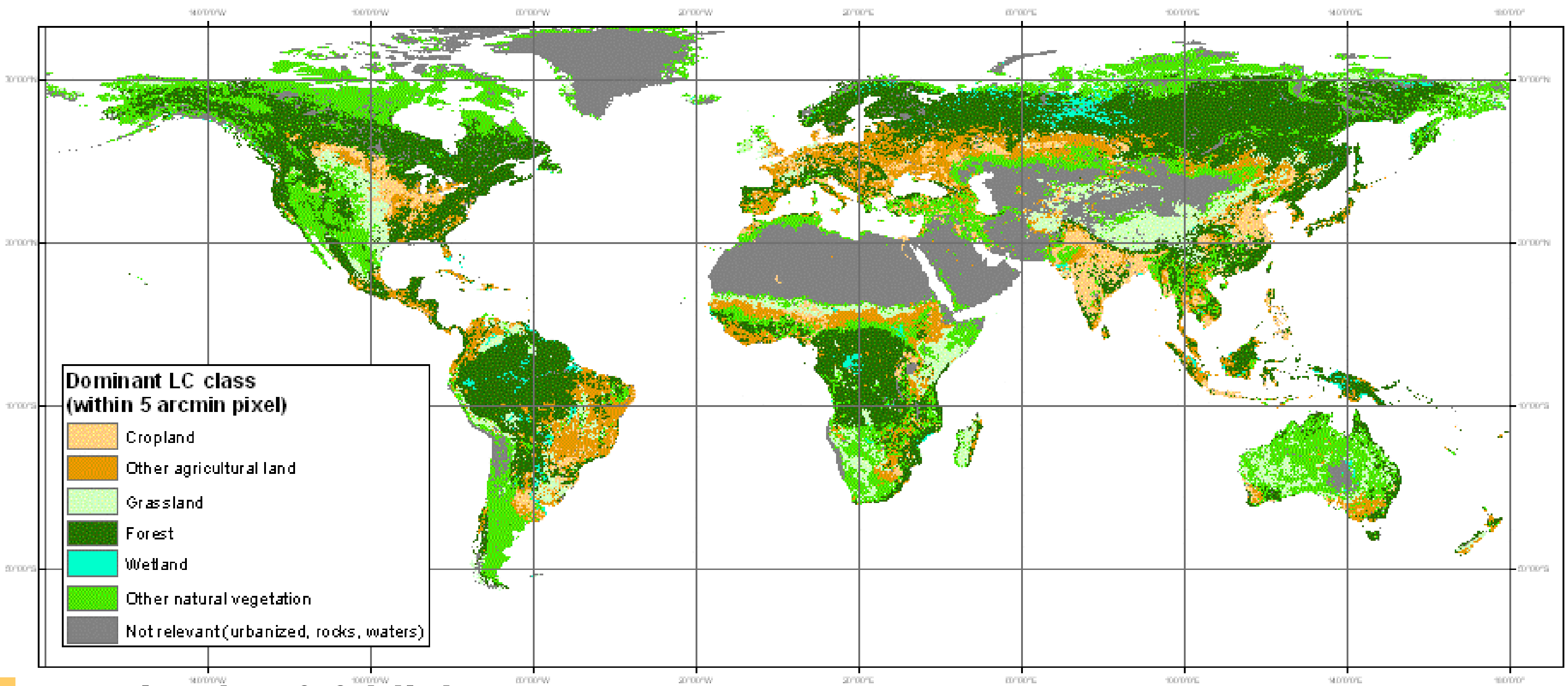
Spatially explicit site-specific qualities



2.1. Global EPIC database

Global EPIC – Land Cover

Global Land Cover (GLC2000; IFPRI, 2007)



crop lands: 0.9 bil. ha

other agri. lands: 1.5 bil. ha

grass lands: 1.1 bil. ha

forest lands: 4.0 bil. ha

wet lands: 0.2 bil. ha

nat. veg. lands: 2.5 bil. ha

Global EPIC – CROPS

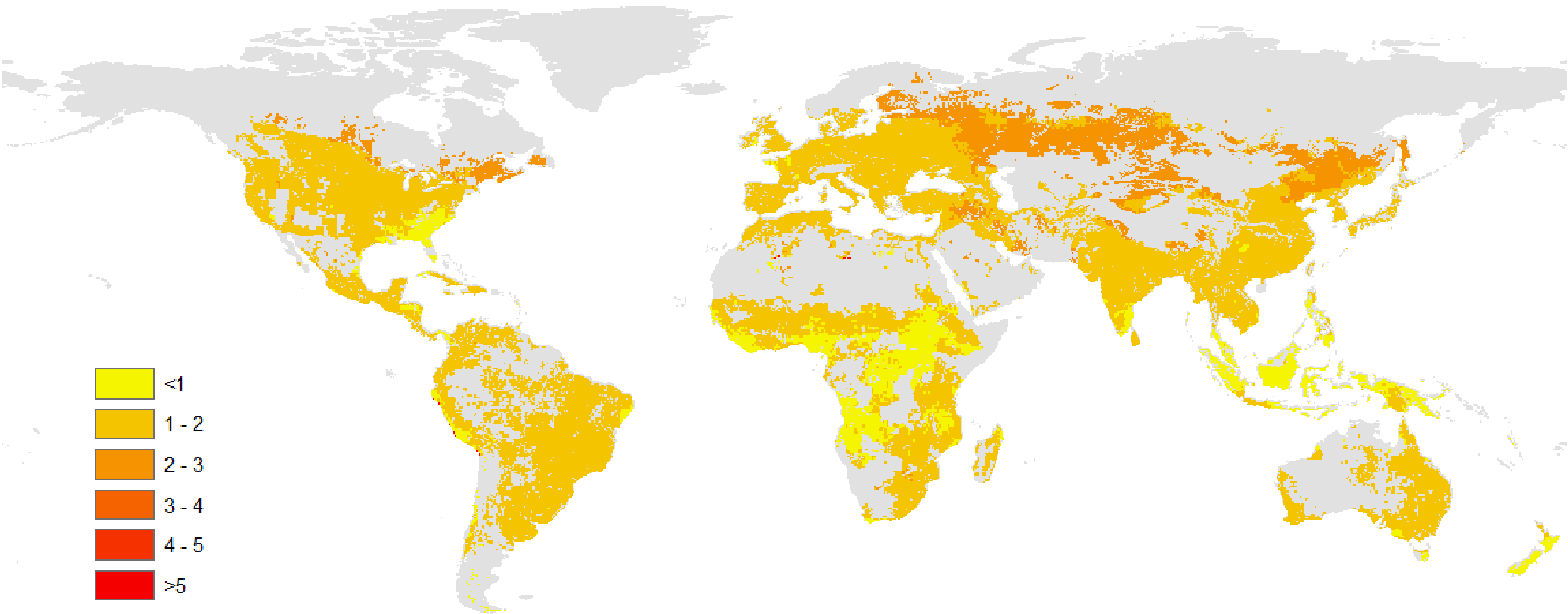
20 crops simulated on all GLC

- BARL barley
- CASS cassava
- CHKP chick peas
- CORN corn
- COTS cotton
- COWP cow peas
- DRYB dry beans
- GRSG grain sorghum
- OATS oats
- PMIL millet
- PNUT peanuts/groundnuts
- POTA potatoes
- RAPE rape seeds
- RICE rice
- RYE rye
- SOYB soybeans
- SPOT sweet potatoes
- SUGC sugar cane
- SUNF sunflower
- WWHT wheat

Global EPIC – crop management

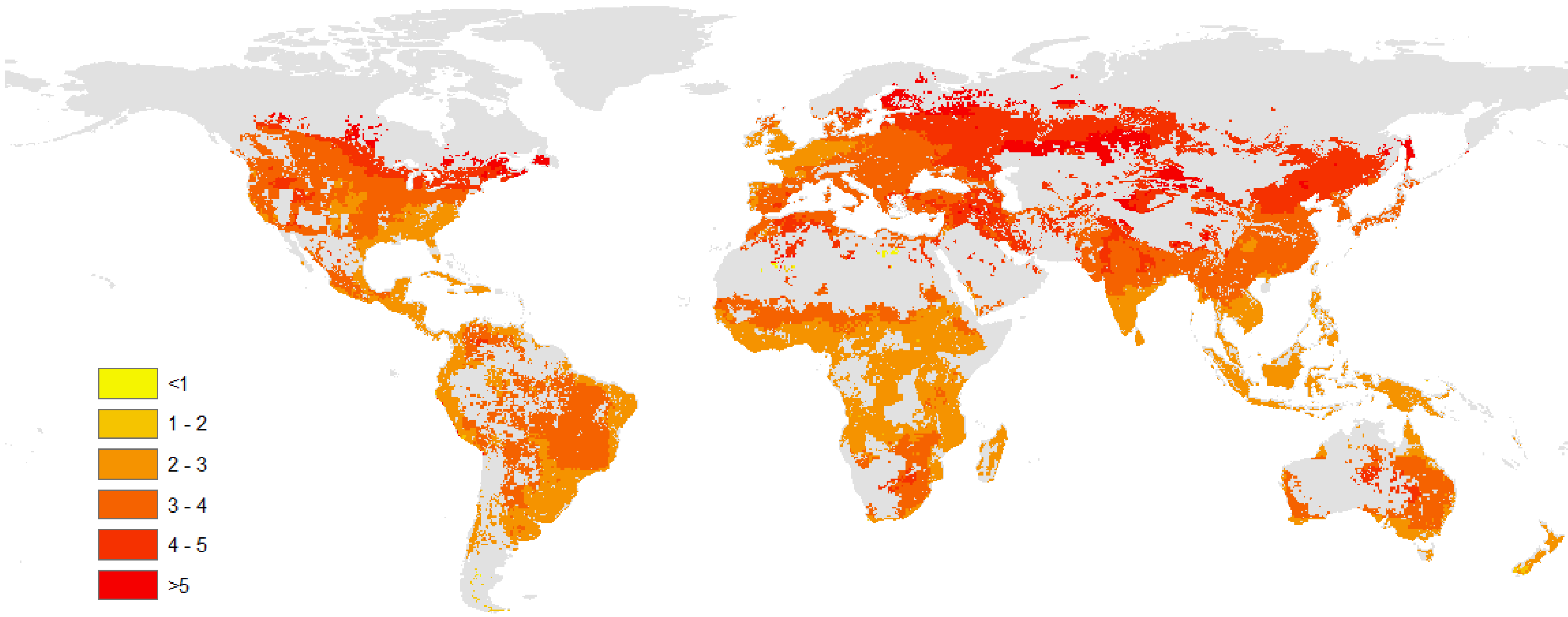
- **3 Crop Input Systems simulated on all GLC:**
  - AN: automatic nitrogen fertilization – N-fertilization rates based on N-stress levels (N-stress free days in 90% of the vegetation period). The upper limit of N application is 200 kg/ha/a.
  - AI: automatic nitrogen fertilization and irrigation – N and irrigation rates are based on stress levels (N and water stress free days in 90% of the vegetation period. N and irrigation upper limits of 200 kg/ha/a and 300 mm/a.
  - SS: subsistence farming – no N fertilizations and irrigation.
- **Climate Data**
  - using Tyndall Climate Change Data, A1fi Scenario

Mean Temperature change on cropland in 2050 in °C (Base 2000)



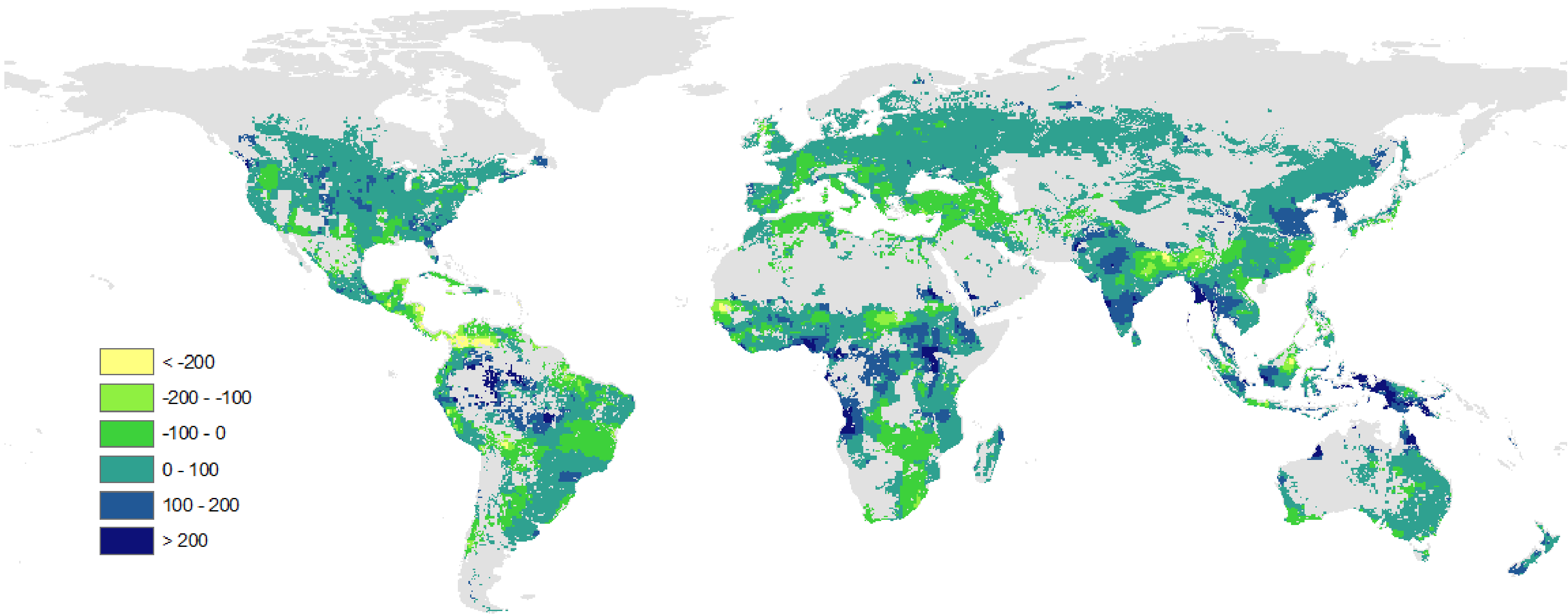
Tyndall Climate Change Data, A1fi Scenario

Mean Temperature change on cropland in 2100 in °C (Base 2000)



Tyndall Climate Change Data, A1fi Scenario

Annual Precipitation Change on cropland in 2050 in mm (Base 2000)



Tyndall Climate Change Data, A1fi Scenario

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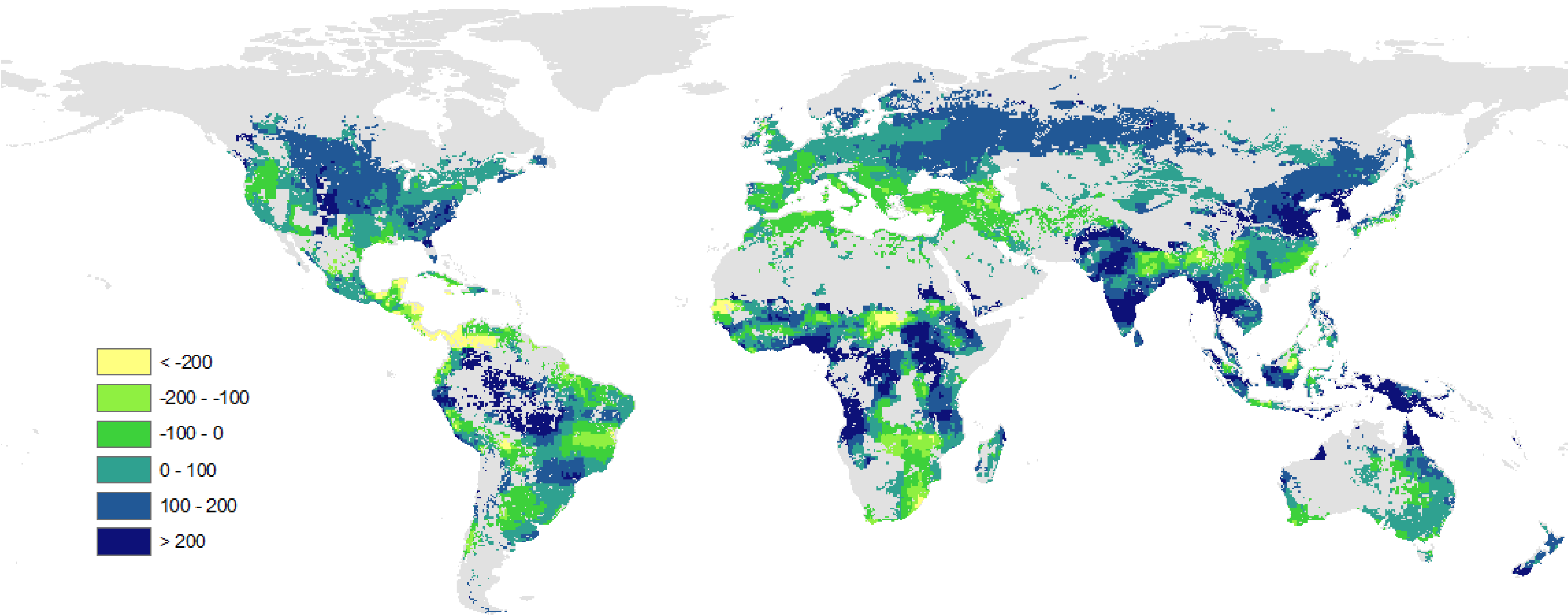
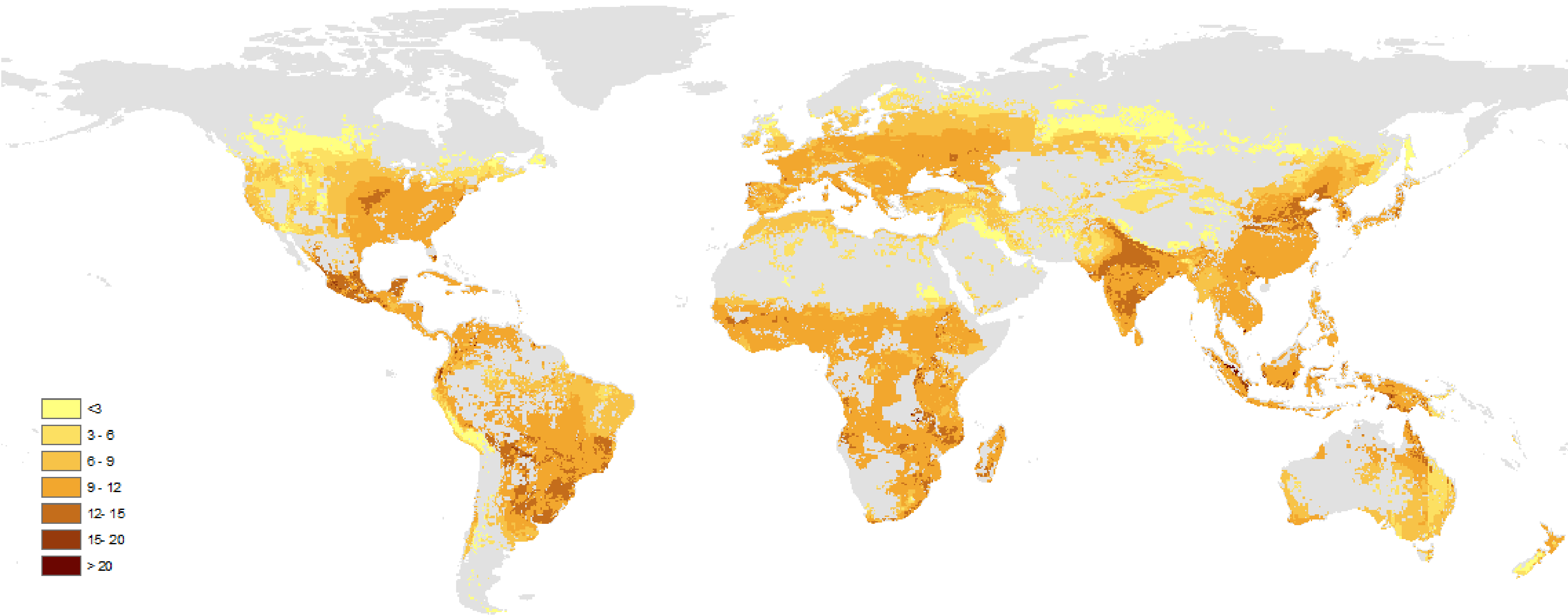
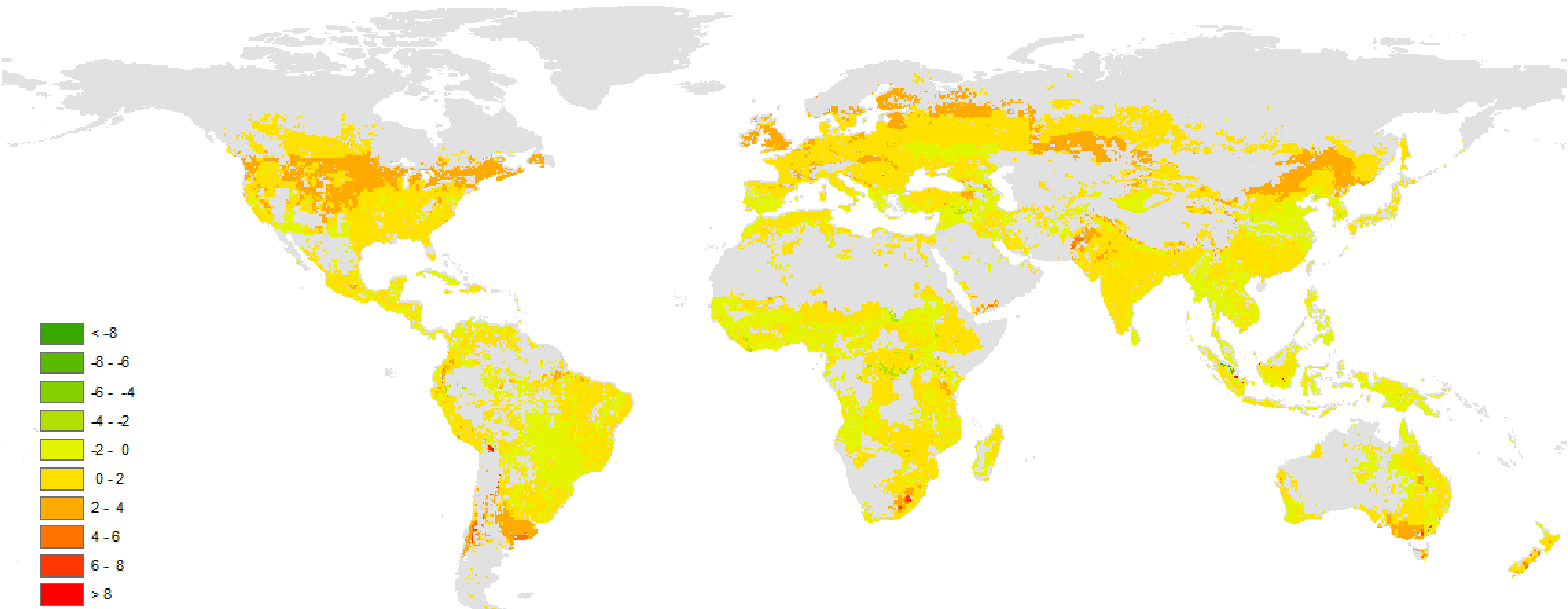


Tyndall Climate Change Data, A1fi Scenario

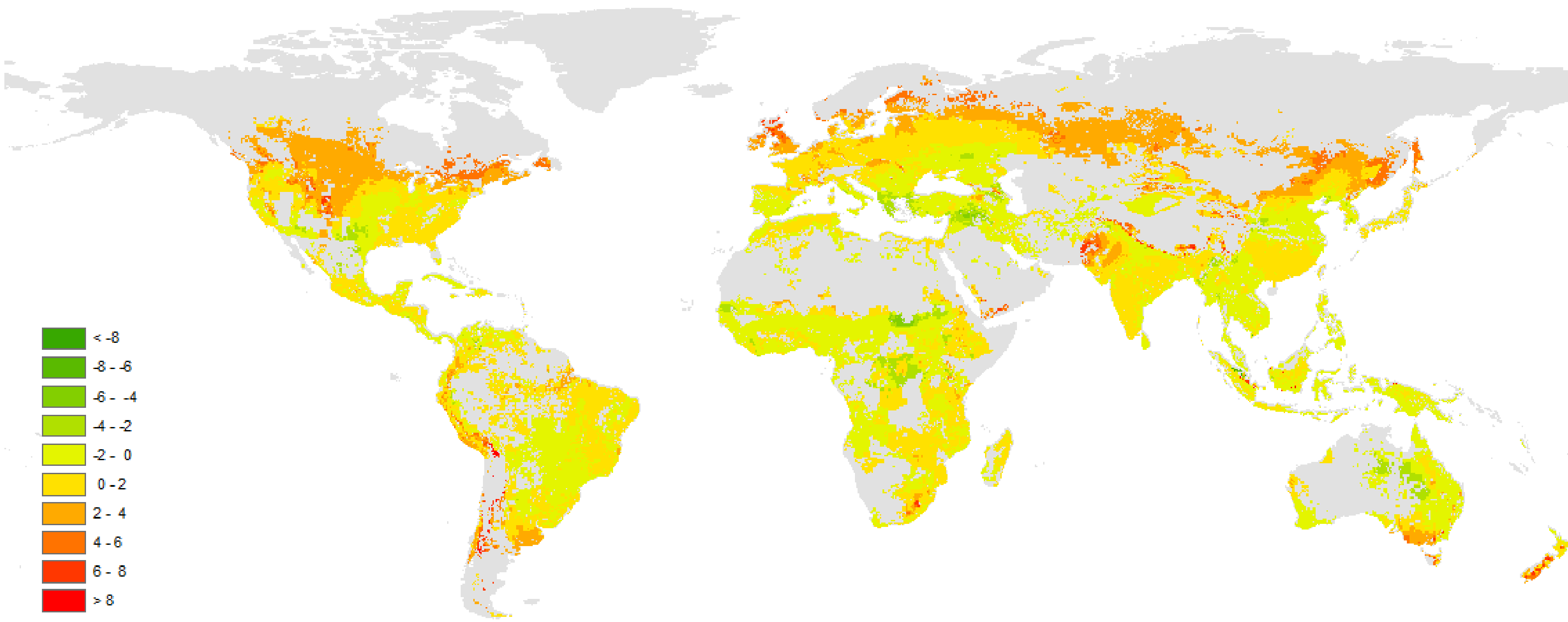
Corn Yields in t/ha (DM) on cropland, automatic fertilization and irrigation (AI management), (Base 2000)



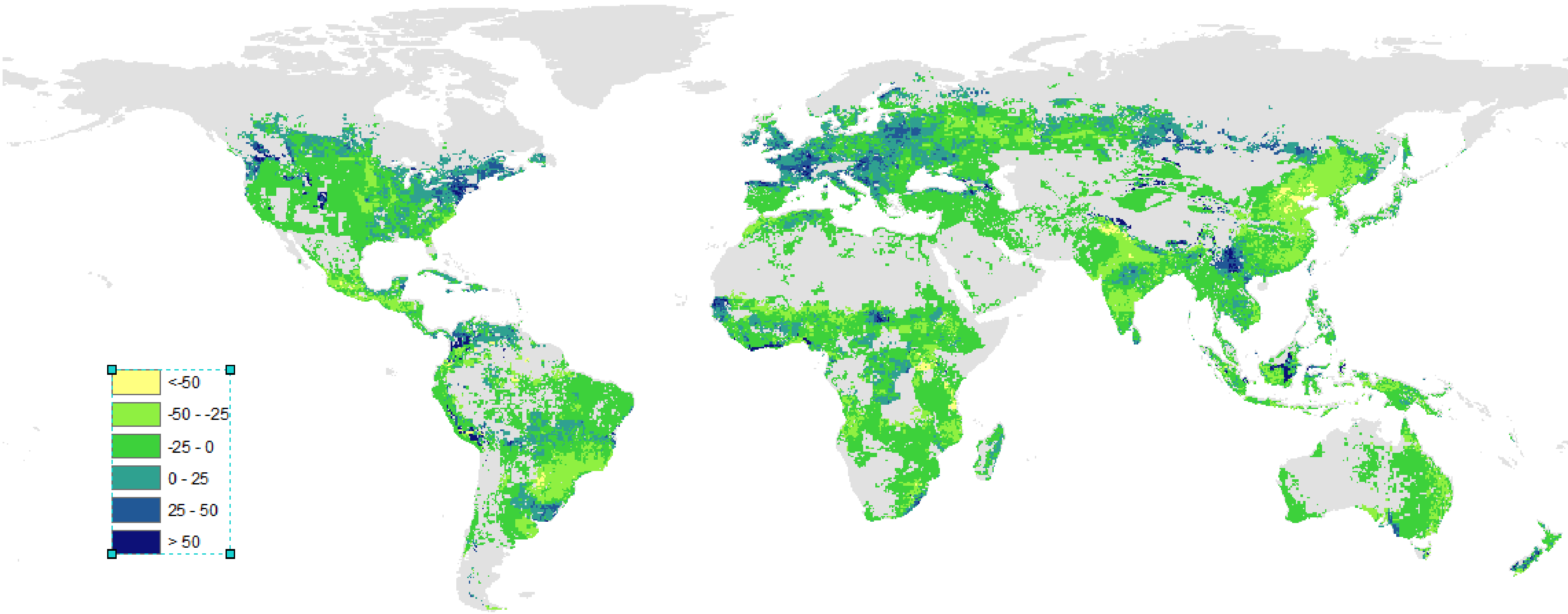
Changes in Corn Yields on cropland in 2050 in t/ha (DM), AI management system (Base 2000)



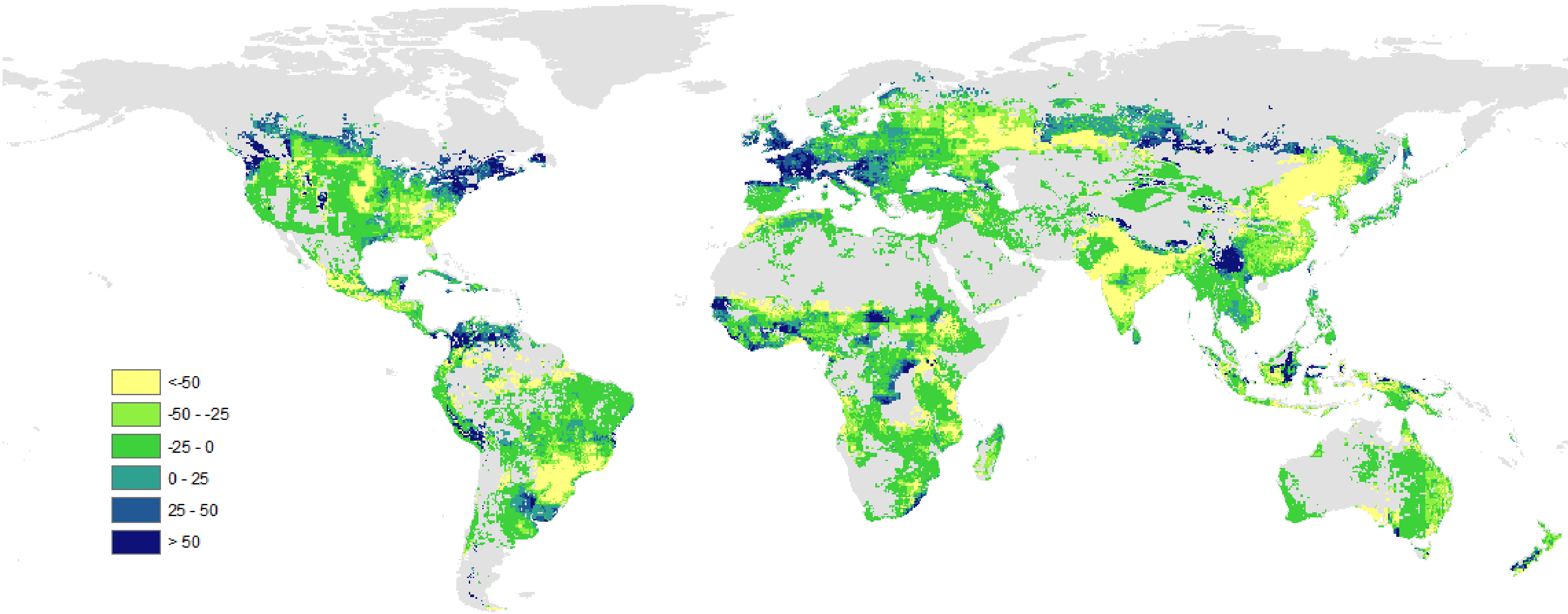
Changes in Corn Yields on cropland in 2100 in t/ha (DM), AI management system (Base 2000)



Changes in irrigation water on cropland in 2050 in mm, AI management system (Base 2000)



Changes in irrigation water on cropland in 2100 in mm, AI management system (Base 2000)



3. CASE STUDY –Adaptation options in the Austrian Marchfeld

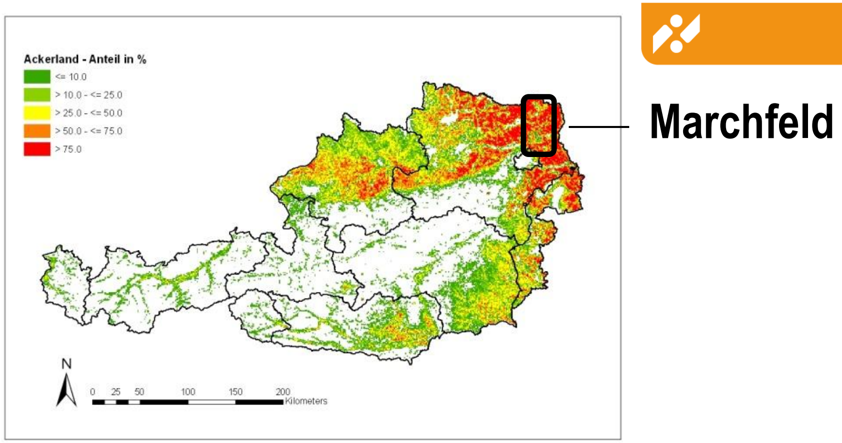
3.1. The region Marchfeld

3.2. Statistical climate data for Austria (EPIC input)

3.3. Investment in Irrigation Systems

3.4. Optimal Crop Management Portfolio

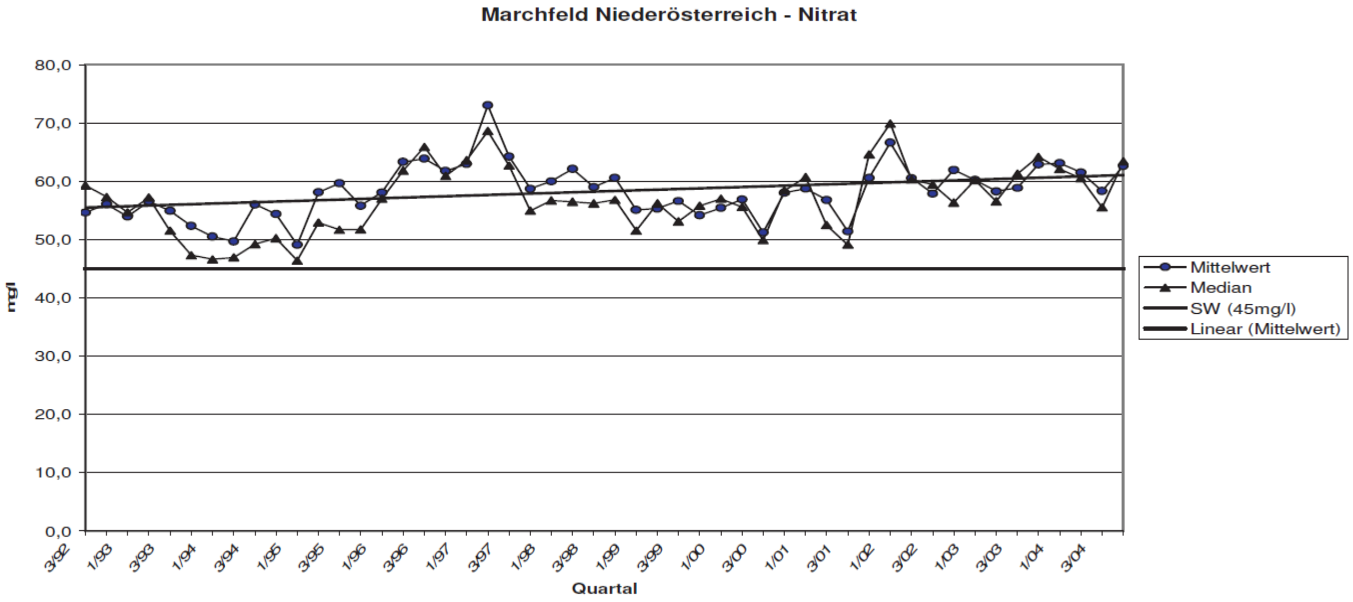
3.1. Case Study – the region Marchfeld



- Marchfeld is part of the Vienna Basin and influenced by a semi-arid climate
- Arable area: 65,000 ha.
- Area supporting irrigation: 60,000 ha
  of which 30% are regularly irrigated (sprinkler irrigation).
- Cereals, root crops and vegetables comprise the main agricultural products of the region.
- 312 soil types can be differentiated in Marchfeld (Anonymous 1972).
- 1975-2007: the average annual precipitation sum was 531 mm
- Vegetation period from April – September the average monthly precipitation sum was only 331 mm

3.1. Case Study – Marchfeld

- **Nitrate pollution of groundwater** is also a serious concern in Marchfeld. The legal threshold levels of 45 mg/l for groundwater and 50 mg/l for drinking water are exceeded at most gauge stations.



3.2. Statistical Climate Model

- Statistical climate model for Austria based on in situ weather observations from 1975-2007 (Central Institute for Meteorology and Geodynamics)

- Stochastic weather scenarios for the period 2008-2040 by bootstrapping of temperature residuals, observed data for solar radiation, precipitation, relative humidity, wind: drawn from observations of historical period:

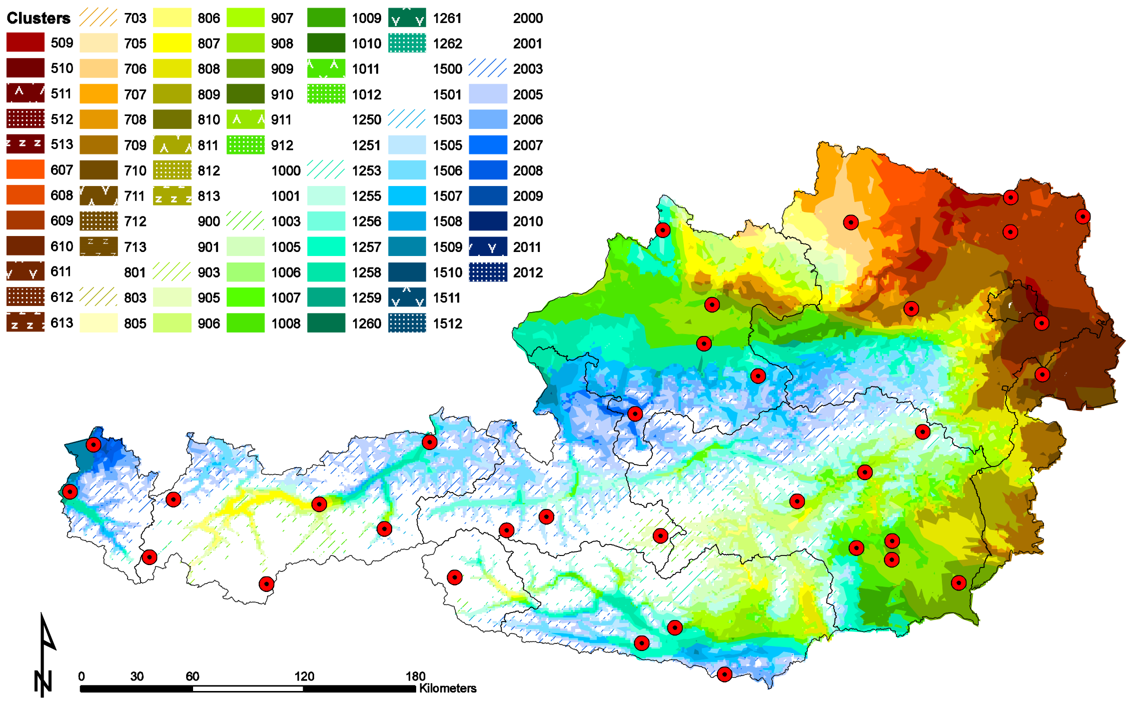
- Assumption:
  - Increase in annual average temperature until year 2040.
  - No trend in precipitation. Assumption: distribution similar to past 30 years.

- Various precipitation scenarios for sensitivity analysis
  - increasing/decreasing annual precipitation sums;
  - unchanged annual precipitation sums with seasonal redistribution

3.2. Statistical Climate Model Databse for Austria (average over 1961-1990)

Niederschlag [mm]	Klasse
100 bis <500	500
>500 bis <600	600
>600 bis <700	700
>700 bis <800	800
>800 bis <900	900
>900 bis <1000	1000
>1000 bis <1250	1250
>1250 bis <1500	1500
>1500	2000

Temperatur [°C]	
< 0	0
>0 bis <2.5	1
>2.5 bis <4.5	3
>4.5 bis <5.5	5
>5.5 bis <6.5	6
>6.5 bis <7.5	7
>7.5 bis <8.5	8
>8.5 bis <9.5	9
>9.5 bis <10.5	10



Datengrundlage für Clustereinteilung: ÖKLIM (Auer et al., 2000)
Datengrundlage für die Wahl der repräsentativen Wetterstationen (gekennzeichnet durch die roten Punkte): StartClim (Schöner et al., 2003)

3.3. Investment in Irrigation Systems

Leading research questions:

- Aim to model an agriculturalist's decision to invest in a more or less water efficient irrigation system under precipitation uncertainty in semi-arid Central Europe.
- How is the decision to invest affected by:
  - Various soil types?
  - Policy instruments
    - Water prices

      ○ Volumetric prices
      ○ Non-volumetric pricing (e.g. per output/ha/input-basis)
      ○ Market –based mechanisms; Tradable water quotas
      ➢ Problem: information about water usage? What are effects of water prices on adoption of water saving technologies? (Moore et al. 1994)

    - Subsidies

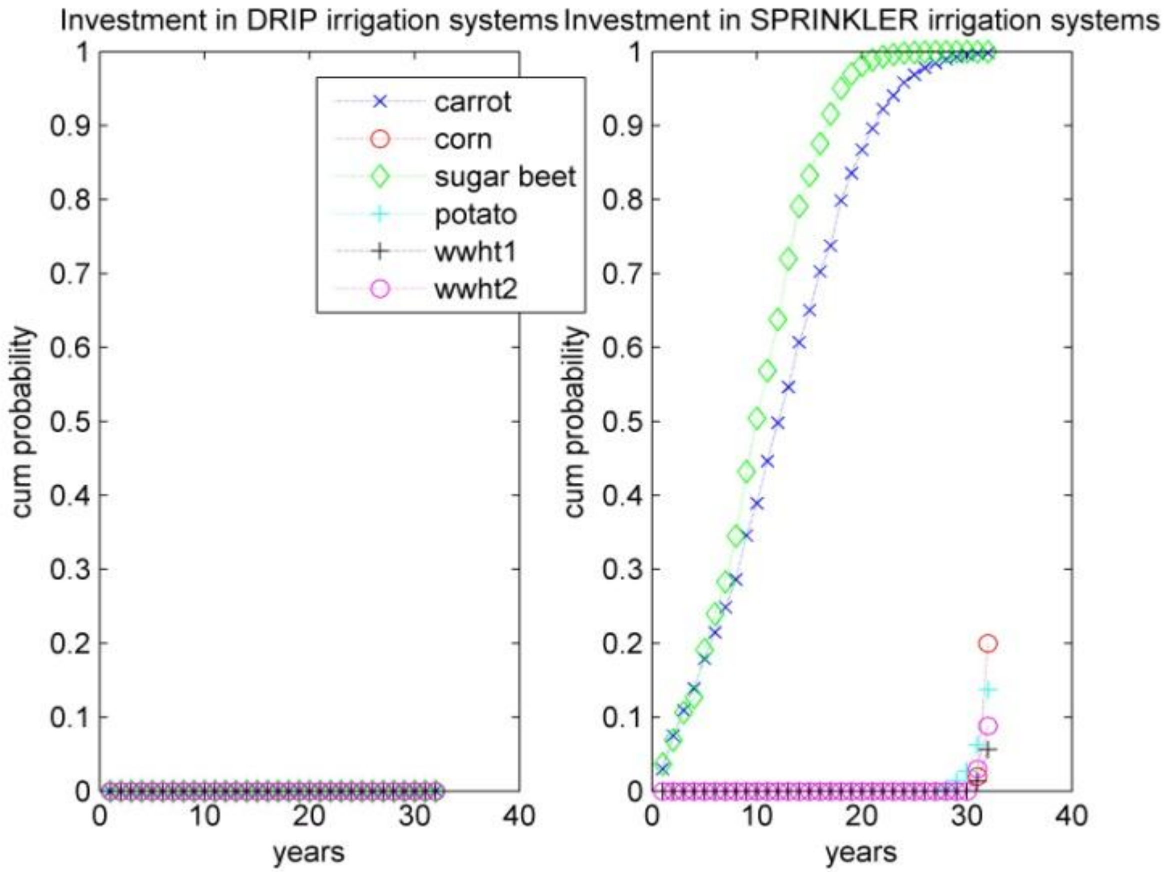
      E.g. Case study Tunisia: subsidies as proportion of capital cost 40-60% to encourage shift from furrow to drip irrigation (Vidal, 2001; Bjornlund et al. 2009)

3.3. Investment in Irrigation Systems – Data and Methods

- **EPIC**
  - Carrots, Sugar Beet, Potato, Corn, Winter Wheat,
  - Conventional tillage
  - Drip and Sprinkler irrigation
  - Automatically determined nitrogen fertilizer and irrigation amount.
  - 2 soil types
- Dynamic programming approach under weather uncertainty.
  - Stochastic optimal control problem on a finite horizon with a discrete stochastic component.
  - The optimal actions are derived recursively by dynamic programming using the Bellman equation
- Characteristics of the model:
  - Weather/climate uncertainty for period 2009-2040 (i.e. 300 precipitation scenarios)
  - Agents choose the optimal investment strategy and time to maximize expected sum of profits.
  - Model is performed for each crop separately!

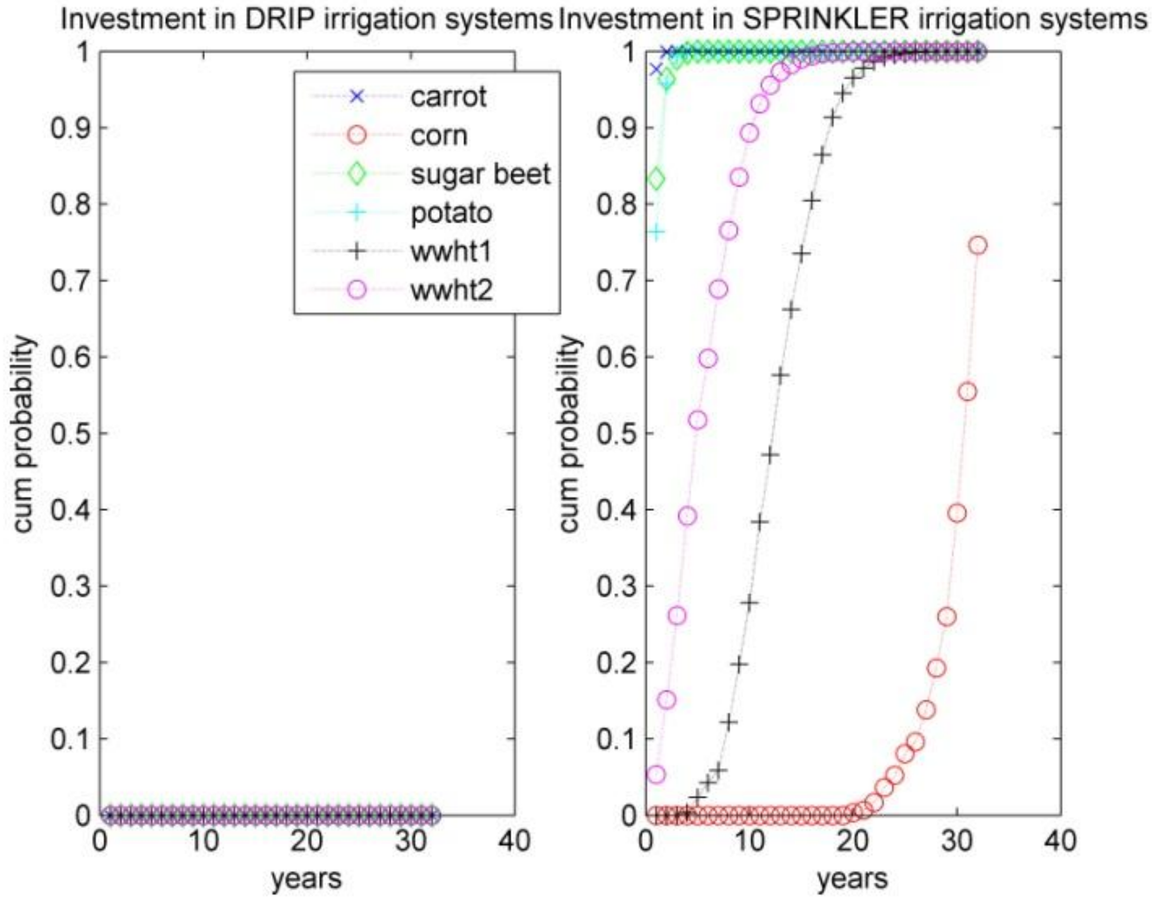
3.3. Investment in Irrigation Systems – Results: Optimal Timing of Investment

Soil 1



3.3. Investment in Irrigation Systems – Results: Optimal Timing of Investment

Soil 2



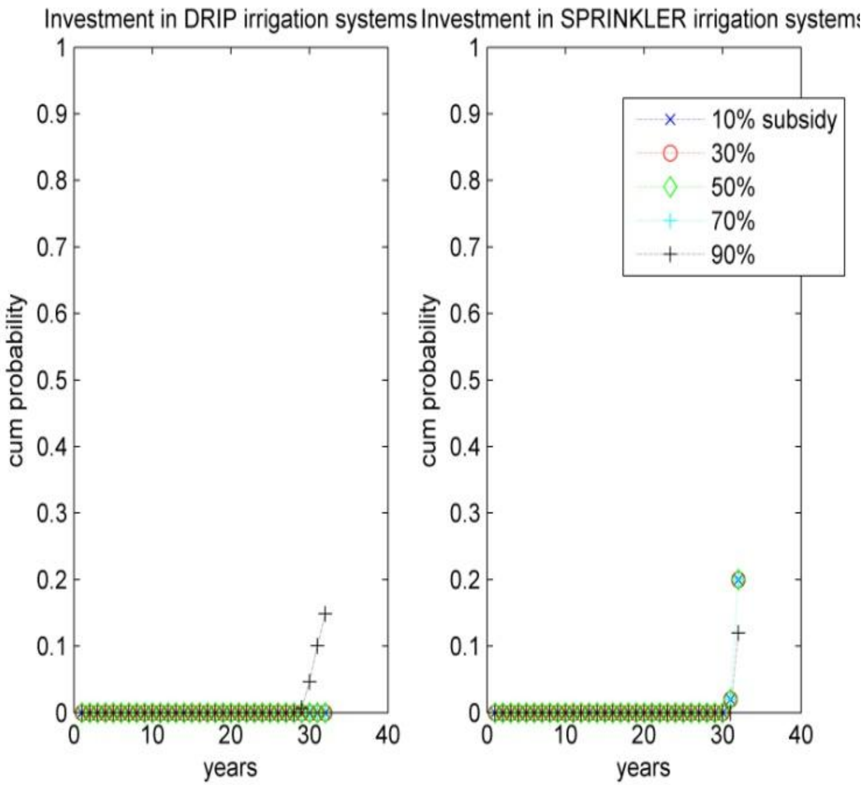
3.3. Investment in Irrigation Systems – Policy Scenario 2 : Subsidies

Crop		NO POLICY		WATERPRICES			
SOIL 2				**20 cent**		**50 cent**	
		Year	**Cum. prob.**	**Year**	**Cum. prob.**	**Year**	**Cum. prob.**
CORN	**Drip**		No adoption		No adoption		No adoption
	Sprinkler	2040	75 %	2040	30%	2040	3%
CARROT	**Drip**		No adoption		No adoption		No adoption
	Sprinkler	2012	100%	2012	100%	2012	100%
S. BEET	**Drip**		No adoption		No adoption		No adoption
	Sprinkler	2015	100%	2018	100%	2030	100%
POTATO	**Drip**		No adoption		No adoption		No adoption
	Sprinkler	2015	100%	2015	100%	2015	100%
W.WHEAT1	**Drip**		No adoption		No adoption		No adoption
	Sprinkler	2035	100%	2036	100%	2040	96%

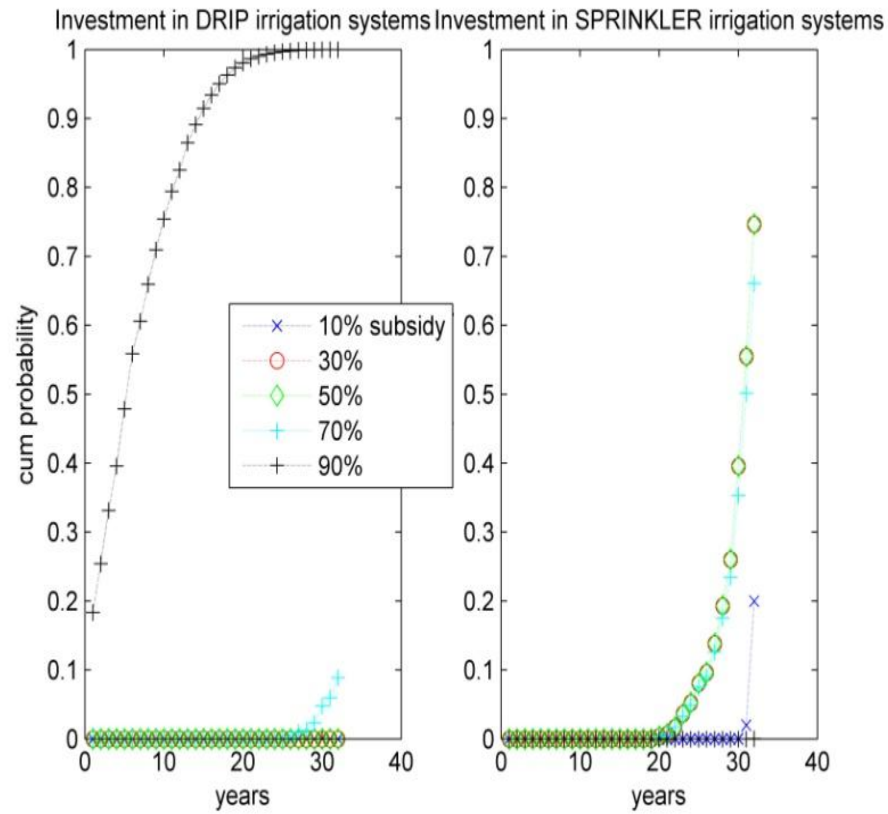
3.3. Investment in Irrigation Systems – Policy Scenario 2 : Subsidies

CORN

Soil 1



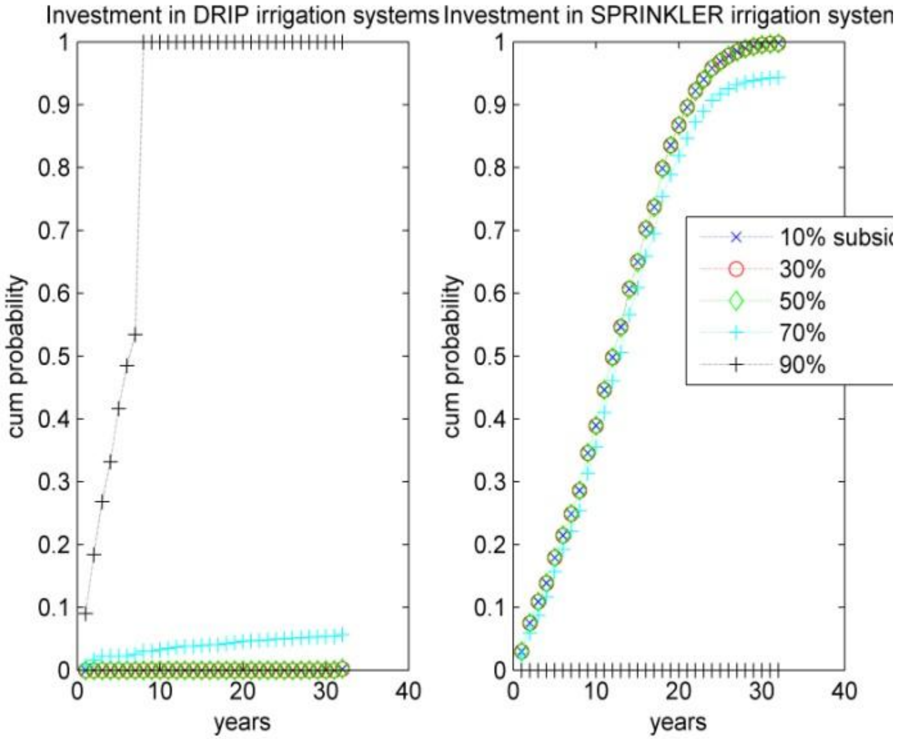
Soil 2



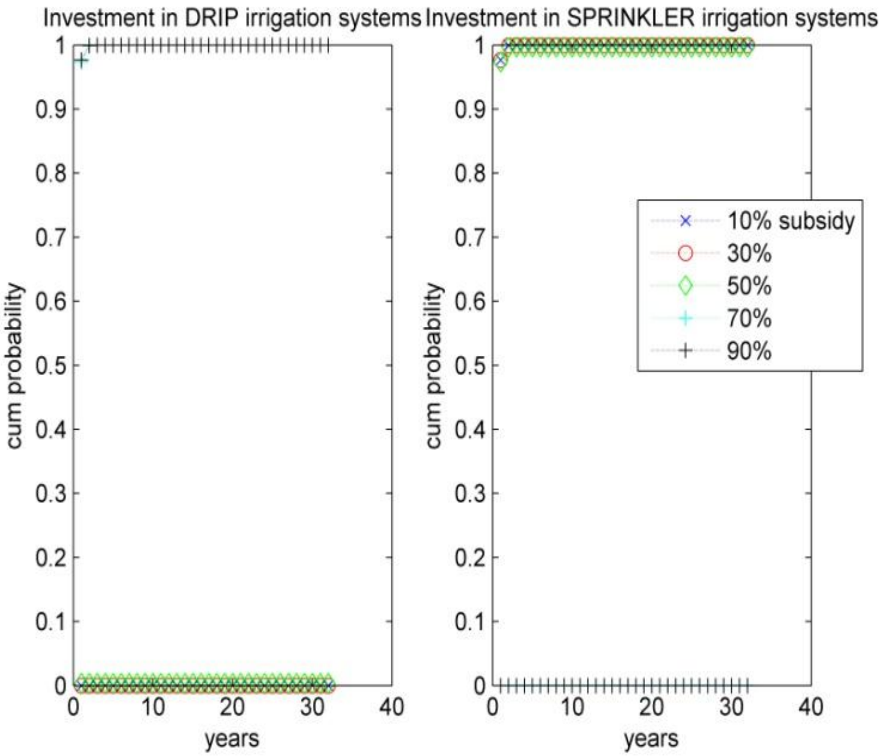
3.3. Investment in Irrigation Systems – Policy Scenario 2 : Subsidies

CARROT

Soil 1



Soil 2



3.3. Investment in Irrigation Systems – Conclusion

- Drip irrigation exhibits higher water productivity than sprinkler irrigation. On soil 1 clearly less irrigation water is needed for both irrigation systems.

- Though more water efficient, drip irrigation seems too expensive for adoption, regardless whether crops are cultivated on soil 1 or 2.

- Water prices do not enforce adoption of drip irrigation but rather drive out all irrigation systems. However, the probability to adopt sprinkler irrigation decreases slower on soil 2 than soil 1.

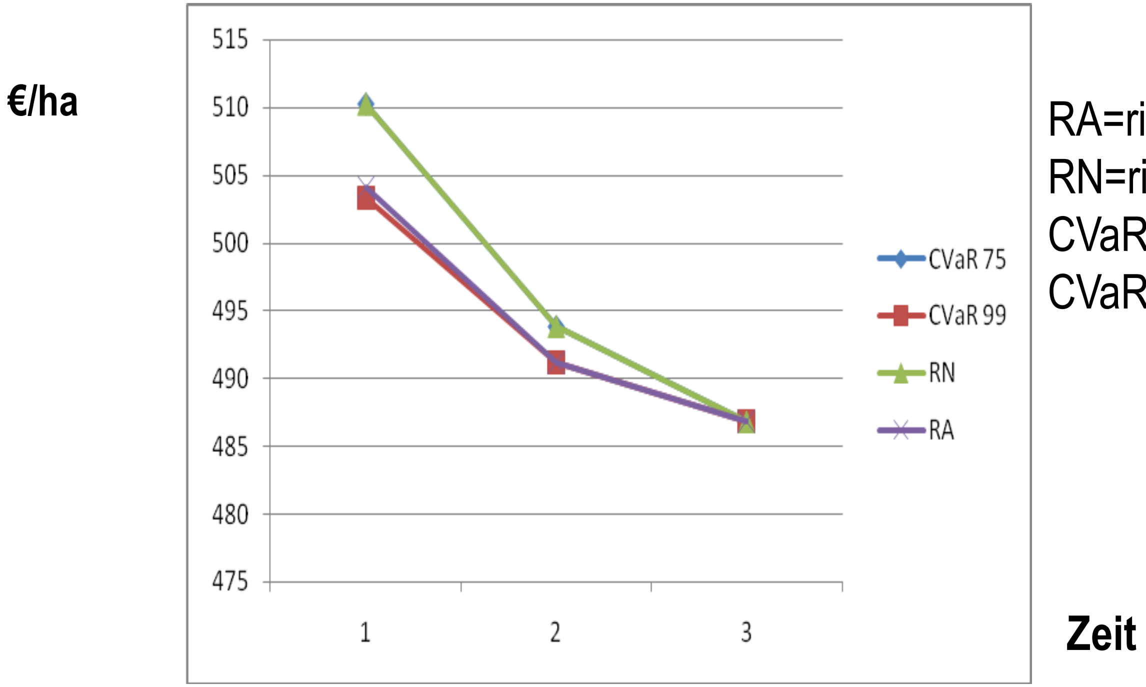
- Subsidies on drip irrigation systems seem effective to support the adoption of drip irrigation. However, to ensure full adoption of drip, subsidies of ~ 90% of capital costs are needed, regardless of soil type.

3.4. Portfolio Optimization Model- Data and Method

- **Strauss et al. 2009**
- **EPIC**
  - Corn, Winter Wheat, Sunflower, Spring Barley
  - Conventional tillage, reduced tillage, minimum tillage
  - Irrigation/ No irrigation
  - Straw removal/no straw removal
  - Recommended fertilizer amounts, + 20%, - 20%
- **Method:**
  - CVaR: Conditional Value at Risk; E-V – Model
  - Risk levels: indifferent to risk; high loss-aversion
  - Environmental constraints: Nitrate leaching is minimized
  - Output: optimal share of crops and management systems in three time periods (2008-2020; 2021-2030; 2031-2040)

3.4. Portfolio Optimization Model- EXPECTED PROFITS

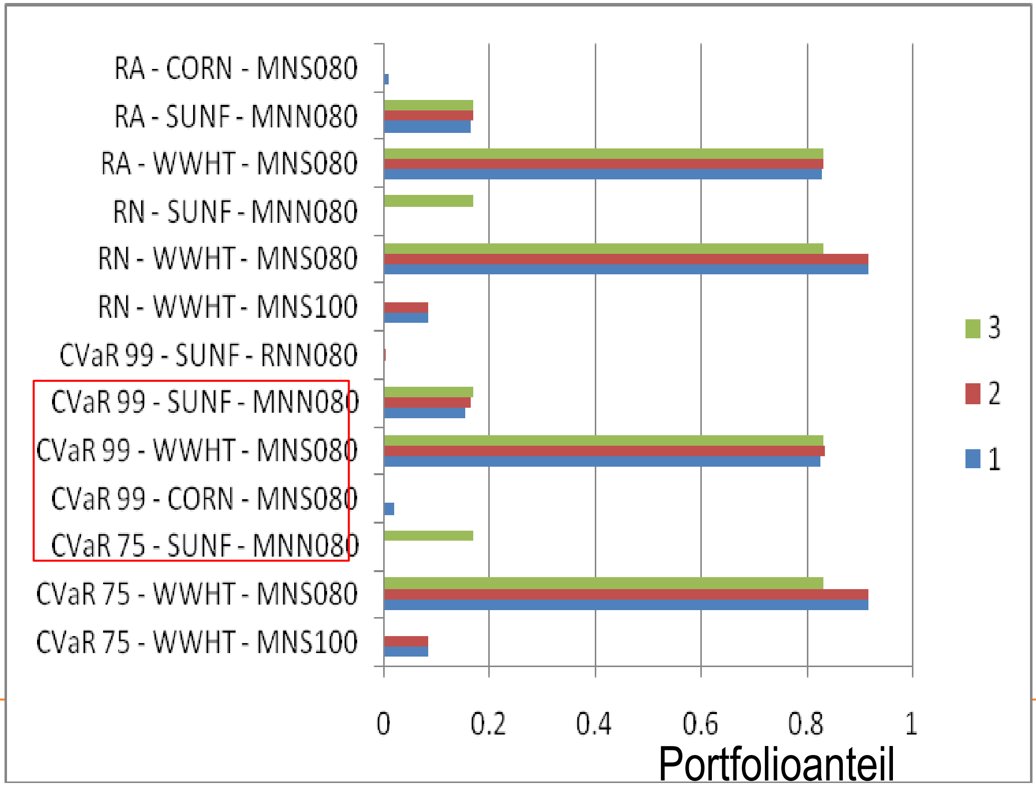
- **Expected profits (€/ha) decrease with increasing temperatures** in 3 time periods (1: 2008-2020, 2: 2021-2030, 3: 2031-2040)
- Thereby, the influence of risk aversion decreases



RA=risikoavers (λ=2.5)
RN=risikoneutral (λ=0)
CVaR 75: β=75%
CVaR 99: β=99%

3.4. Portfolio Optimization Model-RESULTS

- Code:
  - 1. Digit: M (minimum); R (reduziert); C (konventionell) -> Tillage
  - 2. Digit : N/I -> no Irrigation/Irrigation
  - 3. Digit : N/S -> no straw removal/straw removal
  - 4.-6. Digit : 080/100/120 -> 80/100/120% fertilizer



3.4. Portfolio Optimization Model- CONCLUSION

- Crop yield and Profits decrease over time
- Increasing temperatures and risk aversion have different impact on optimal crop management portfolios.
- Minimum tillage, low levels of fertilizer application, winter wheat and sunflower are most often found in optimal crop management portfolios.

CONCLUDING REMARKS

CONCLUDING REMARKS

- Climate change impact analysis require data and models (i.e. biophysical and economic models) with sufficient reliability, detail and resolution.

- Adaptation options need to be locally/regionally as well as empirically assessed/evaluated => stakeholder participation

- Empirical model analysis yield powerful complementary information about adaptation options, impacts and externalities over space and time.

Thank you for your attention!

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