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TOOLS AND TECHNIQUES FOR ADAPTATION AND MITIGATION RESEARCH

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ABSTRACT

Agricultural systems are inherently sensitive to variability in weather and climate, whether naturally-forced or due to human activities. Robust predictions of possible changes in crop productivity and crop distribution due to climate in the future are vital for our understanding and management of cropping systems over the coming years to decades.

The Intergovernmental Panel on Climate Change defines adaptation as ‘the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities’ (Parry et al. 2007). Mitigation is the actions taken to reduce greenhouse gas emissions or enhance their sinks (Verbruggen, 2007). Most crop adaptation studies in practice study both the impacts and adaptation of climate change. For example, an assessment of sowing a different crop genotype (as an adaptation option) may be examined in response to the impacts of artificially imposed changes in climate and atmospheric conditions, such as elevated CO_2 or warmer temperature. Tools and techniques for adaptation and mitigation research on crops comprise those that involve plant experiments and those that employ simulation modelling.

Different plant experiment techniques range from those that use plant growth chambers to impose tightly controlled differences in climate to those in near-field conditions that more closely match some aspects of projected climate changes. The latter include Free-Air CO_2 Enrichment rings (for the study of responses to CO_2 and drought), temperature gradient tunnels (CO_2 and temperature) and open-topped chambers (CO_2 or ozone). None of these experiment systems entirely simulate all components of a changed climate, but meta-analyses of many of these studies can provide a broad consensus of impacts of climate change (for example, Ainsworth et al. 2005) that potentially can inform adaptation options. Plant experiments to study possible mitigation options from agricultural systems may include the measurement of methane emissions from paddy rice soils with treatments such as altered water management, different soil organic matter content or rice cultivars that may result in lower methane emissions. Also, results from such crop plant experiments are used extensively to develop, evaluate and parameterise crop simulation models.

Many assessments of adaptation options for agriculture in future climates use simulation models. Such assessments of the impacts of and adaptation to climate change involve two quite different models; a climate model and a crop or agricultural system model. Understanding the nature of each type of model is crucial to interpretation of simulation results for adaptation. In particular, numerical climate models and crop simulation models are on different spatial and temporal scales. Climate change projections are made using general circulation models (GCM) run at the global scale. Adaptation options in agriculture are commonly at a much smaller scale, often at the level of a farm where many decisions are made. GCM output can be used directly for assessments over large areas, such as countries and regions (eg Challinor et al., 2004). However, more often downscaling of climate information is done prior to the crop simulation using either dynamical methods (regional climate models run with GCM boundary conditions) or statistical techniques (for example, weather generators). There are even techniques that combine the use of some GCM output directly with statistical techniques, for example to reconstruct patterns of rainfall (for example, Hansen et al 2006).

There are important sources of uncertainty within climate – crop projections that need to be recognised in order to quantify the boundaries of confidence of assessments of adaptation options. Uncertainty arises from internal (natural) variability within climate models, greenhouse gas emission scenarios, as well as from the representation of processes in climate models and crop simulation models. Recent studies have started to account for these sources of uncertainty in an explicit manner (eg Hawkins and Sutton, 2008; Challinor et al., 2008).

Mitigation research in agriculture using simulations requires a representation of land-surface processes that contribute to greenhouse gas emissions and their interaction with agricultural practices. Land surface processes are included in earth systems models, or the land surface schemes of GCMs; for example, the Joint UK Land Environment Simulator (http://www.jchmr.org/jules/). However, there is currently only a basic representation of agriculture and cropland in these models. Nevertheless, these models have the potential to capture the feedbacks between changes to agricultural practices and land use and greenhouse emissions to the atmosphere in a consistent manner. Hence, this is an active research field.

In conclusions, a range of research tools are available to study adaptation and mitigation of agriculture to climate variability and change, from well-established plant experiment techniques, to the mature discipline of crop simulation modelling and the potential of the next generation of earth systems models.

KEYWORDS
Climate change, earth system modelling, plant experiments, crop simulation models

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Tools and techniques for adaptation and mitigation research

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Context and definition

Adaptation and mitigation research

- plant experiments
- simulations

Conclusions

Adaptation to climate change

"Adaptation will be necessary to address impacts resulting from the warming which is already unavoidable due to past emissions"

Where adaptation is …

"the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities"

From Parry et al, 2007

Intergovernmental Panel on Climate Change
4th Assessment Report, WGII, Technical Summary

Adaptation by crop producers

Crop management practices
- add or improve irrigation and drainage systems
- change crop sowing times and growing periods
- alter crops grown and crop protection strategies

Crop genotype
- more tolerant to environmental stress & new pests
- better suited to new environments

Post harvest storage practices

Plant experiments

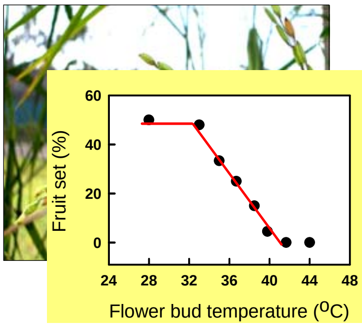
Plant experiments

Free Air CO_2 Enrichment, FACE

Courtesy of Steve Long, University of Illinois

Variability in climate

Crop productivity is highly vulnerable to variations in climate



Hot temperature

After a single hot day, only the brown grains contain rice seed that will be harvested

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Adaptation to high temperatures in rice genotypes

		30°C	35°C	38°C
Azucena	S	53	29	6
Bala	T	73	66	39
CG 14		72	58	24
Co 39	T	68	67	39
IR 64		76	56	26
Moroberekan	S	67	39	14
N22	T	81	75	54
WAB 56-104	S	78	63	23

Spikelet fertility of rice genotypes to high temperature at anthesis.
S is susceptible, T is tolerant to high temperatures.

from Jagadish et al, 2008

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Mitigation research

Mitigation …

"actions take to reduce greenhouse gas emissions or enhance their sinks"

Verbruggen, 2007

Agriculture accounted for 10-12% of total global GHG emissions in 2005

includes ~60% of global $N_2$0 and 50% of CH_4 emissions

Smith et al., 2007

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Mitigation research

Mitigation …

"actions take to reduce greenhouse gas emissions or enhance their sinks"

Verbruggen, 2007

Experiments include the measurement of CH_4 and N_2O efflux using field chambers + sampling system or eddy covariance techniques within a crop field

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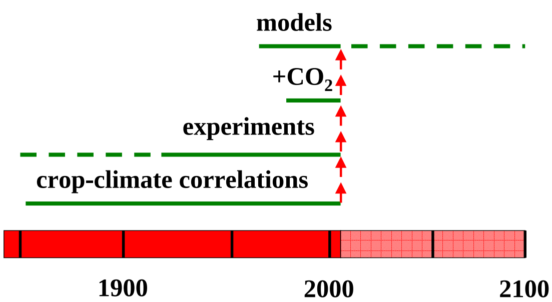
Knowledge base on crops and climate



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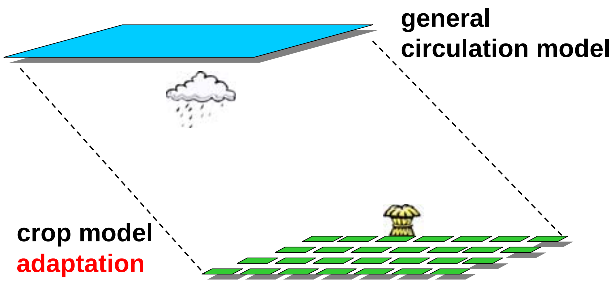
Adaptation and mitigation research …

using simulations

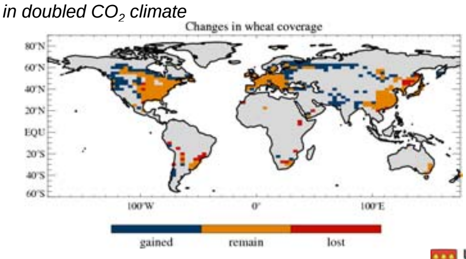
Using climate information for adaptation research



Use GCM output directly

1. Use a large area crop model
2. Run simulations on a GCM grid in current and future climate runs

Wheat in doubled CO_2 climate

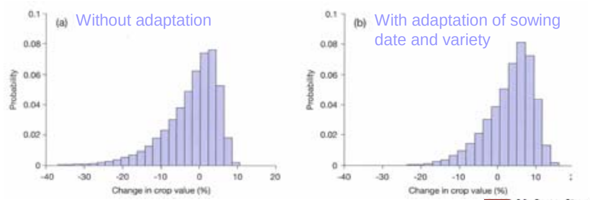


Example from Osborne et al, 2008

Use meta-models at different sites

1. Derive response surface   yield change = $aCO_2 + bT + cP$
2. Impose a specified change or GCM change
3. Sample response surface (and aggregate)

Wheat in Australia in 2070

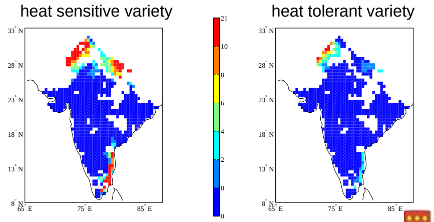


Example from Howden and Jones, 2004

Use regional climate models

- Regional climate model forced by boundary conditions from a GCM
- Finer spatial resolution (25 - 50km)
- Potential for resolving more detailed climate patterns

Groundnut seed-set in India for 2080



Example from Challinor et al, 2005

Impose a change on climatology

1. Obtain climatology for sites or regions
2. Impose a GCM change
3. Run crop simulation model (and aggregate)

Rice yield across Asia under 2 x CO_2 climate

Without adaptation

		Climate model		
		GFDL	GISS	UKMO
Crop model	ORYZA	+6.5	-4.4	-5.6
	SIMRIW	+4.2	-10.4	-12.8

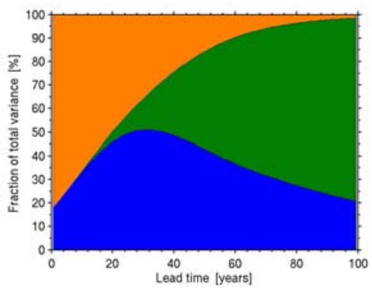
With adaptation using heat-tolerant genotype

		Climate model		
		GFDL	GISS	UKMO
Crop model	ORYZA	+14.9	+15.6	+12.9
	SIMRIW	+18.7	+24.9	+25.3

Example from Matthews et al, 1997

Climate model uncertainty

Relative importance of different sources of uncertainty in climate projections of surface air temperature



Orange is internal variability

(natural variability, ENSO, NAO,...)

Green is scenario uncertainty

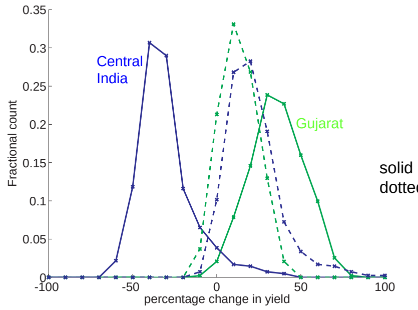
Blue is model uncertainty

(with same forcing)

from Hawkins and Sutton, 2008

Sampling model crop model uncertainty

Groundnut yields in India



solid = current 'fixed' variety
dotted = 'adapted' variety

from Challinor and Wheeler, 2008

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mitigation

Mitigation simulations - offline

Matthews and Wassmann (2003) added the dynamics of O_2 and CH_4 in the soil to the CERES-rice crop model

CH_4 emissions (Tg per year)	baseline climate	+ 3 t ha^{-1} DM	+ field drainage	+ both
Total [1]	7.8	17.4	6.5	13.9

[1] China + India + Indonesia + Philippines + Thailand

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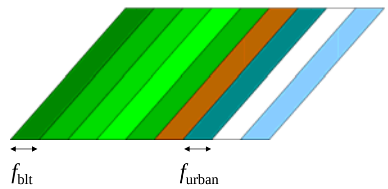
Mitigation simulations - online

how is land surface/vegetation represented in a GCM?

Example, the Met Office Surface Exchange Scheme (MOSES)

5 plant functional types, bare soil, urban, ice , inland water

Broad leaf trees
Needle leaf trees
C3 grasses
C4 grasses
shrubs



Fluxes determined over each tile. Aggregated according to fractional coverage

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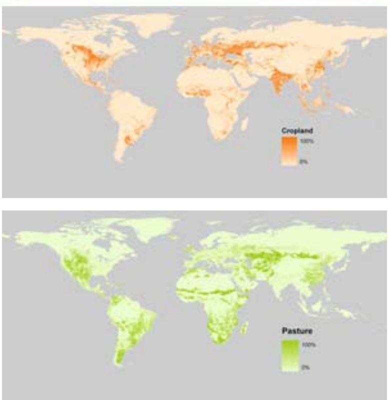
Significant global coverage



About 40% of the land surface is managed for crops and pasture

(Foley et al. 2005)

Source: SAGE
www.sage.wisc.edu/

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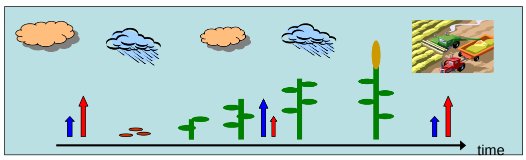
Putting crops in land-surface schemes



Wheat and maize in Europe
ORCHIDEE-STICS by Gervios *et al.* 2004

Crops in US
Agro-IBIS by Kucharik & Brye 2003

Many crops globally
LPJ-mL model by Bondeau et al. 2007

Annual crops globally
GLAM-MOSES by Osborne et al. 2007

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Conclusions

- Changes in CO_2, and in the mean and variability of climate, presents new challenges to agro-ecosystems
- A range of experiment- and model-based techniques exist for research on possible adaptation and mitigation strategies
- Many adaptation options / decisions are at farm level. Be aware of the assumptions and uncertainties associated with using climate model output for crop / farm simulations
- Fully coupled crop-climate simulations can offer a consistent approach for mitigation research, and also for impacts and adaptation
- Better information gained through projections will be important for managing risk to agro-ecosystems from climate variability and change

Thank you

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