Agricultural systems and their vulnerability to climate change
Summary of the presentation of Marco Bindi (DISAT-University of Florence, Italy) at the AVEC summer school 2005
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Global warming is projected to lead to substantial temperature increases in Northern Europe during winter and in Southern Europe during summer, affecting natural and socio-economic systems, including agriculture, and warranting further study. We begin with some definitions.

"Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." It is a "function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity" (see Fig. 1, IPCC, 2001, p. 995). Exposure plus sensitivity estimate potential impact, which combined with adaptive capacity is used to estimate vulnerability (Figure 1).

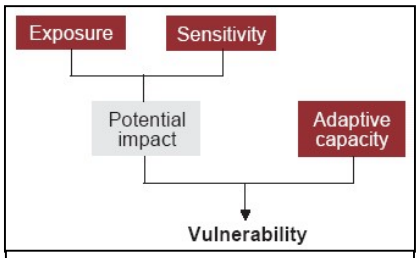

Fig. 0: Vulnerabilty as function of Exposure, sensitivity and adaptive capacitay

1. **Exposure (How is climate changing?)**
   Agricultural systems are highly exposed through:
   - Increases in atmospheric CO_2 concentration
   - Changes in mean climate (temperature, precipitation)
   - Increases in extreme climate events

2. **Sensitivity (What is the sensitivity of agricultural systems to climate change ?)**
   The sensitivity of agricultural systems to climate change is very high because all the components of the systems are strongly affected (see Box 1, where factors affecting each component are in parentheses.)

3. **Potential Impact (How will climate change affect agricultural systems?)**
   Climate change may strongly affect agricultural systems through potential impacts on:
   - Ecophisiological processes regulating crop growth (1. Photosynthesis: General Increase, with larger responses for C3 species (+31%); 2. Evapotranspiration: Reduction up to-20% (wheat), more evident under nutrient shortage; 3. Biomass Accumulation: Above ground: increases up to 30% (cotton and vine); below ground: increases up to +70% (cotton); The predicted increases in temperature will determine a reduction of the length of the growing period
   - Suitable area for crop cultivation (Arable crops currently grown in the southern Europe will become suitable for the cultivation in northern European countries or in higher altitude areas in the south (e.g., summer crops such as maize, sunflower and soybeans)
   - Yield quantity and quality (Negative impact of climate change on crop yields in the Med. region without CO_2 effect under HadCM3 - 2031-2060 (2° C global temperature rise); Prevalent negative impact of climate change on cereal yields without CO_2 effect under HadCM3 scenario)

The combination of the impacts shows that, at regional level, increasing CO_2 concentrations ameliorate crop yield losses and improves gains in same cases (see Table 1). In the same way the increasing of the CO_2 concentration allows an increase of crop yield in globally important agricultural areas (e.g., North America, China, and Australia). Overall, the net effect of climate change may strongly affect agricultural systems through the potential impacts on ecophysiological processes regulating crop growth (e.g., photosynthesis, transpiration, etc.), suitable area for cultivation, and both the mean and variability of crop yield and quality.

Box 1: The components of the agricultural system and their sensitivity to climate changes

Crops
- *Crop phenology, i.e., length of growing season (temperature)*
- *Gas and water exchange fluxes, i.e. photosynthesis, transpiration, etc. (CO_2, temperature, precipitation)*
- *Crop yield (CO_2, temperature, precipitation)*
- *Yield quality (CO_2)*

Livestock
- *Animal growth and reproduction (temperature)*
- *Animal health (temperature, air humidity)*
- *Forage quality, i.e. nutrient content C/N (CO_2)*

Pests and Diseases
- *Proliferation of insect and pests due to longer growing seasons, higher possibility to survive during winter time (temperature, air humidity)*
- *Consumption rate of insect herbivores, quality of the biomass of host crop, e.g. leaf N% (CO_2)*
- *Spread of both wind-borne pests and bacteria and fungi (wind)*

Weeds
- *Alteration of the weed-crop competitive interactions (C3 and C4 species) (CO_2)*
- *Effectiveness of herbicides (temperature)*

Available water
- *Soil water content (precip. and temperature)*
- *Level of water tables (precip. and temperature)*
- *Risk of water salinisation (sea level rise)*

Soil fertility and erosion
- *Decomposition of soil organic matter (precip. and temperature)*
- *Cycling of the main nutrient elements in the soil-plant-atmosphere system (i.e. enhancement of CO_2 and N_2O greenhouse gas emissions) (temperature)*
- *Plant nitrogen fixation (temperature)*
- *Wind erosion (wind, precip.)*
- *Water erosion (i.e. run-off) (precip.)*

4. Adaptive capacity (How can agricultural systems adapt to a changing climate?)

Agronomic and crop adaptation strategies may be used to reduce losses or to increase gains due potential impacts of climate change (Giannakopoulos et al., 2005). In most cases in the temperate zone, agronomic adaptation is projected to ameliorate crop yield losses and improve gains, but in tropical areas with low adaptive capacity, crop yields tend to remain below baseline levels.

Agricultural adaptation strategies for climate change may be applied on different temporal and spatial scales. In the short term, crop systems can be managed to reduce yield variability by changing crop varieties, agronomic practices, and fertilizer and pesticide use, and also by conserving soil moisture through conservation tillage practices and using new tools such as seasonal forecasts. In the long-term, adaptation involves larger structural system changes to optimize production, including changing land allocation, developing new „designer“ cultivars, substituting more heat tolerant crops, using microclimate modifications to improve water use efficiency, and changing nutrient management. Spatially, adaptation may occur at the farm, regional, or national level.

5. What is the vulnerability of agricultural systems under future climate change?

Vulnerable components which need further study include:
- Mean yields of C_4 crop yield and summer crops (summer drought and heat waves)
- Inter-annual variability of crop yields (increase in climate extreme events)
- Yield quality (drought stresses)
- Interaction with pest/diseases (higher winter temperature)
- Competition with weeds (higher CO_2 concentration)

Vulnerable regions: Northern and southern current marginal areas of Europe seem to be particularly vulnerable to climate changes
- Northern areas: increase in plant protection, increase in risk of nutrient leaching, acceleration of soil organic matter breakdown.
- Southern areas: lower yield, higher yield variability, reduction of suitable areas for traditional crops

Tab. 1: Combination of impacts of climate change and their influences to yield changes in Europe

		(% difference A2-present)			
		N-W	N-E	S-E	S-W
Climate only	C4 summer	5.8	-2.54	-9.26	-8.94
	Legumes	-13.42	-8.11	-36.43	-25.81
	C3 summer	-10.44	-6.92	-8.19	-11.81
	Tubers	-4.24	-6.8	-15.77	-12.1
	Cereals	-3.49	3.71	-17.17	-11.29
+ CO_2	C4 summer	8.78	0.21	-6.7	-6.37
	Legumes	-4.86	0.97	-30.15	-18.48
	C3 summer	-2.85	0.96	-0.41	-4.34
	Tubers	7.53	4.39	-5.66	-1.55
	Cereals	4.68	12.49	-10.15	-3.77

Table 2. Regional change (%) in crop production and GDP under UKMO-GCM scenario

Regions	Crop prod.	GDP	
			Adaptation Level 1:
Developed countries			♠ Planting shifts < 1 month
Climate only	-18.6	-28.9	♠ + H20 for irrigated crops
+CO_2	-2.1	-9.8	♠ change in crop varieties
+ adaptation 1	+5.0	-3.6	**Adaptation Level 2:**
+ adaptation 2	+6.4	+0.8	♠ Planting shifts >1 month
Developing countries			♠ ▪ fertilizer application
Climate only	-27.1	-35.1	♠ installation of irrigation
+ CO_2	-4.5	-13.0	♠ new crop varieties
+ adaptation 1	-3.9	-12.3	
+ adaptation 2	-0.8	-5.6	