

Topic 1 – Agrometeorology and agrometeorological measurements

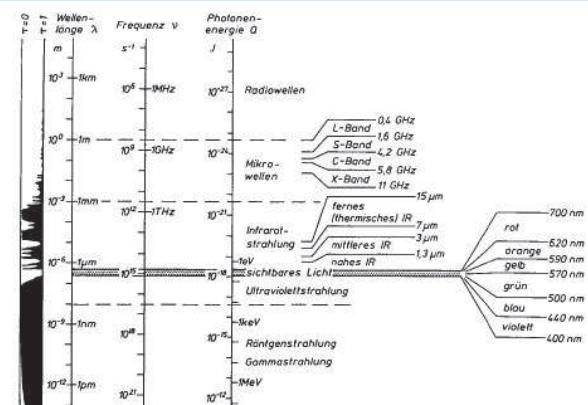
The lectures contain an introduction of basic concepts in our physical environment (radiation, energy and water balance) as well as planning of experiments and measurement theory and training including detailed information on sensors. The topics contained important components in measuring meteorological/agrometeorological conditions and data generation for agrometeorological model inputs: data collection methods, signal transfer, measurement methods of single parameters such as temperature, radiation, air humidity, evapotranspiration, leaf wetness, precipitation, wind and turbulence, soil water content, infrared thermography.

Crop growth factor: Radiation and energy balance

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Electromagnetic spectrum



Short wave radiation

- Global radiation**
(0.3 ... 3.0 μm, Maximum at 0.5 μm)
Unit: W/m²
Radiation source is the sun with 6000 °K surface temperature
- Ultraviolet radiation (UV)**
(UVC: 0,01-0,28 μm, UVB: 0,28-0,31 μm, UVA: 0,31-0,38 μm)
- Visible radiation**
0,38-0,75 μm used for photosynthesis
PAR (Photosynthetic Active Radiation, 30-40% of global radiation)
- Near Infrared radiation**
>3,0 μm

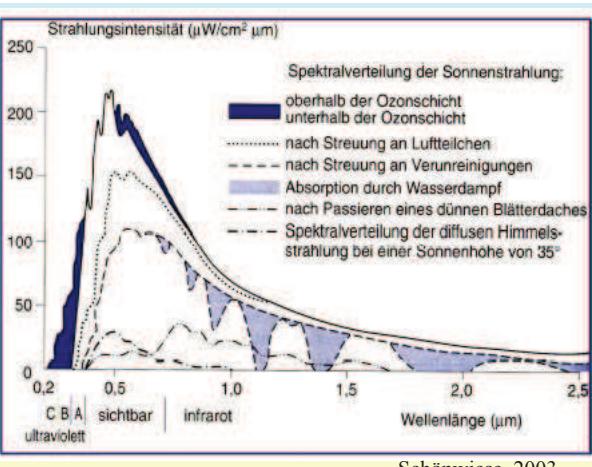
Thermal or long wave radiation

(3.0 ... 100 μm, Maximum at 10 μm);
Main radiation source is the Earth
with app. 287 °K surface temperature
Unit: W/m²
(irradiance)

- Solar constant**

Radiation intensity at the upper atmosphere

1369 W/m²



Wave length, frequence, photon energy

Energy balance and water balance

$$0 = R_n - G - H - L.E (-\Delta S)$$

Rn = Net radiation
 G = Soil heat flux
 H = Sensible heat flux
 L.E = Latent heat flux (evaporation)
 L = latent heat ($2,45 \cdot 10^5$ J/kg)
 E = Amount of water
 AS = energy stored in biomass
 Units : MJ.m⁻² ; W.m⁻²



Energy balance

$$0 = P - L.E - R - \Delta S_w + K - D$$

P = Precipitation
 LE = evapotranspiration
 R = Runoff
 ΔS_w = Soil storage change
 K = Capillary rise, D = Drainage

Water balance

Daily course of radiation energy balance components

$$G = R_s + R_d \text{ (global radiation)}$$

$$R = a (R_s + R_d) \text{ (reflection)}$$

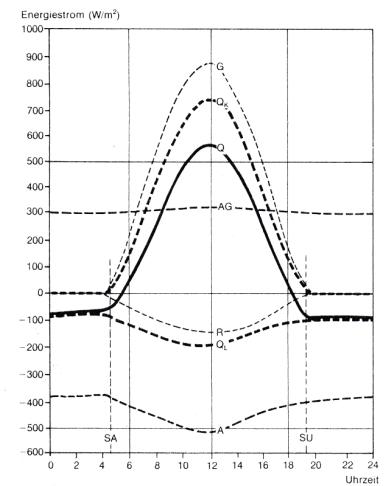
$$Q_k = R_k \text{ (net global radiation)}$$

$$A = R_E \text{ (thermal emission)}$$

$$A_G = R_A \text{ (thermal atmospheric)}$$

$$Q_L = R_L \text{ (thermal balance)}$$

$$Q = R \text{ (total net radiation)}$$



Radiation effects on plants

- Energy source (photosynthesis)
- Plant development (initiation of germination, growth direction, morphological modifications: such as stretching growth, number of branches, leaf thickness)
- Flowering time
- Stress- and damaging factor (Photodestructive impacts, i.e. UV-Radiation)

Spectral ranges and impacts on plants

Spektralbereich	Wellenlänge (nm)	eingestrahlte Sonnenenergie (%)	Wirkung			
			photosynthetisch	photomorphogenetisch	photodestraktiv	thermisch
UV	<280-380	0-4	unbedeutend	gering	wirksam	unbedeutend
photosynthetisch aktiver Bereich (PhAR)	380-710	21-46	virksam	virksam	gering	wirksam
nahe Infrarot	710-4000	50-79	unbedeutend	wirksam	unbedeutend	wirksam
langwellige Strahlung	>3000	0	unbedeutend	unbedeutend	unbedeutend	wirksam

Larcher 2001

Radiation within canopies

Scattering

Change of direction without change of inert radiation energy bzw.

Reflexion (Albedo)

Part of radiation reflected from a surface

Absorption

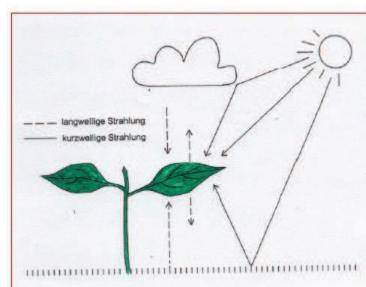
Absorption of energy from photons by leafs.

Chlorophyll is absorbing medium for photosynthesis
Receptors: Chlorophyll a, b + Carotinoide
(located in Chloroplasts)

Transmission

Transmitted part of radiation through canopies and leafes

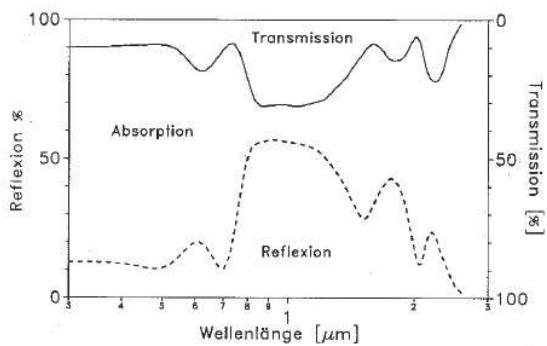
Plant and radiation components



Reflexion: 6-10%

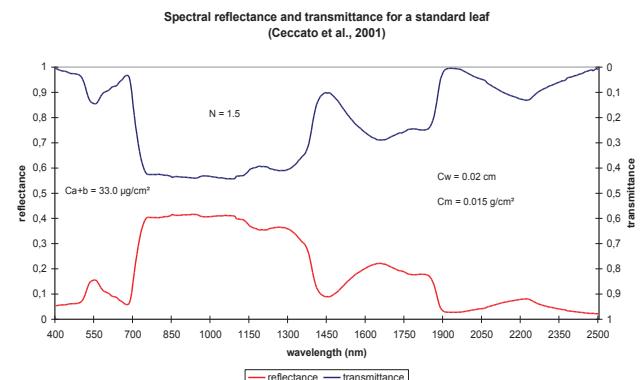
Absorption: 60-80%

Transmission: 10-20 %

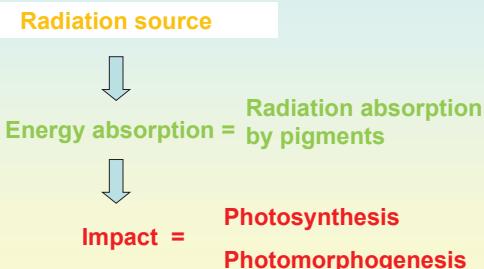


Absorption, Transmission and Reflexion of leafs depending on wavelentghs

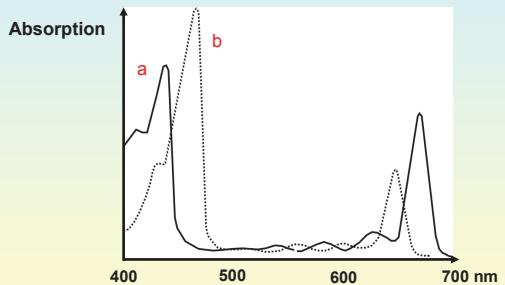
Strahlungsvorgänge im Blatt: Abhängigkeit von Transmission, Reflexion und Absorption von der Wellenlänge



Radiation and photosynthesis

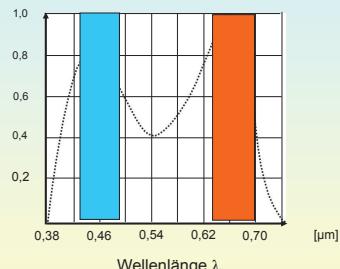


Absorption spectra of Chlorophyll a and b



Verändert nach RICHTER 1982

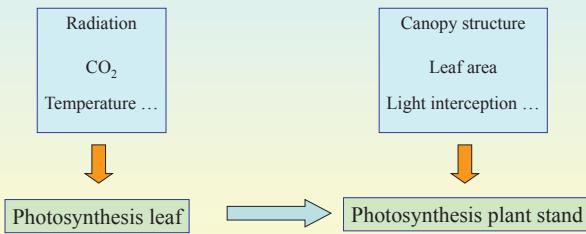
2 absorption spectra in the blue and red range, reflection in the green range



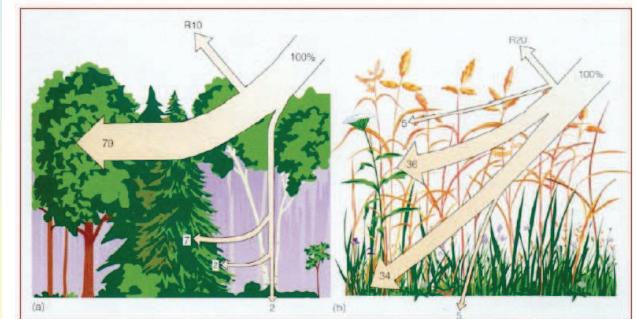
- Maximum of reflexion of leafes in green $0.55 \mu\text{m}$
(therefore leafes we see as „green“)
- Increase of reflexion and transmission in the Infrared $> 50\%$
(information on canopy health)

Photosynthesis of canopies

Photosynthesis :



Light interception in canopies



Nach Larcher, 2001

Radiation interception (attenuation)

...in canopies depends on:

- Distribution of leaves
- Leaf angle
- Leaf density:

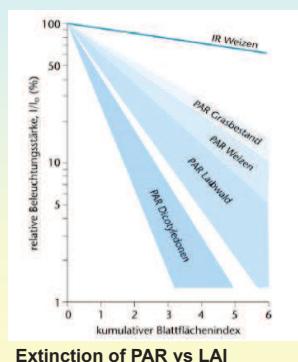
LAI = leaf area index:

$$\text{LAI } [\text{m}^2/\text{m}^2] = \frac{\text{Total leaf area (one side)}}{\text{ground area}}$$

Lambert-Beers law of extinction

$$I = I_0 * e^{-kLAI}$$

I ... Radiation below a canopy
 I_0 ... Radiation at top of canopy
 k ... Attenuation coefficient
 (depends on canopy structure)
 (z.B. Cereals, Meadows: 0,3-0,5;
 Forest: 0,7-1)
 LAI ... Leaf area index (m^2/m^2)



Relative radiation level

... Amount of radiation at shaded locations (i.e. below forest canopy)

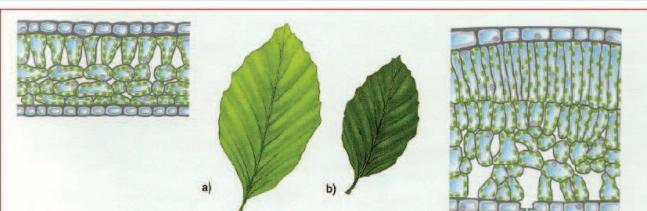
$$I / I_0$$

i.E. deciduous forest, Summer: 3-10%, Winter: 50-70%
 Minimum requirement for plants: 0,5 – 1%

Wind:

Causes sun flecks, increase of radiation levels
 below canopies

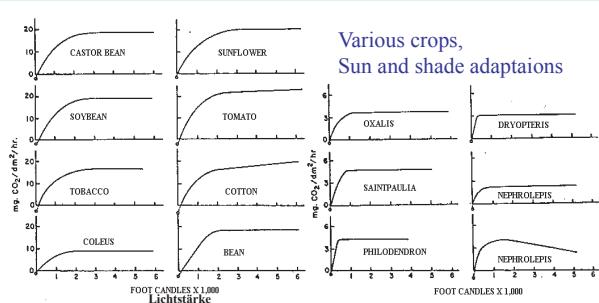
Shade and sun leaves



a.) Shade leaf b.) Sun leaf
 (morphological response of plants to light climate)

Light response of assimilation at leaf level

Further modified by: Temperature and CO₂, water stress, nutrient stress



Pflanzengruppe	Minimum I _x in kLx	Saturation I _s in kLx
A LANDPFLANZEN		
1. Kräutige Blütenpflanzen C ₃ -Pflanzen	1 – 3 1 – 2 1 – 2	über 60 30 – 80 50 – 80
Lachwerkschäfte Nutzpflanzen (C ₃)	0,2 – 0,5	5 – 10
Sommergrüner Schattenkrüter		
2. Holzpflanzen		
o Sommergrüne Laubbäume und Sträucher	1 – 1,5 0,3 – 0,6	25 – 50 10 – 15
o Lichshälder		
o Schattenblätter		
Immergrüne Laub- und Nadelbäume	0,5 – 1,5 0,1 – 0,3	20 – 50 5 – 10
o Lichshälder		
o Schattenblätter		
3. Schattenpflanzen	0,1 – 0,4	2 – 8
4. Moose und Flechten	0,4 – 2	10 – 20
B WASSERPFLANZEN		
Planktonalgen	1 – 2	(7) 15 – 20
Gezeitentang		10 – 20
Tiefenalgen		1 – 2
Phanerofaunen	< 1 – 2	(5) 10 – 30

Light response characteristics of plant types

Daily course of radiation response of assimilation

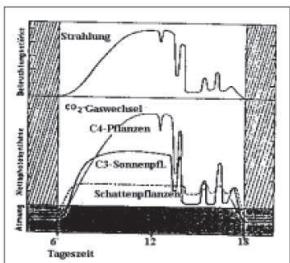
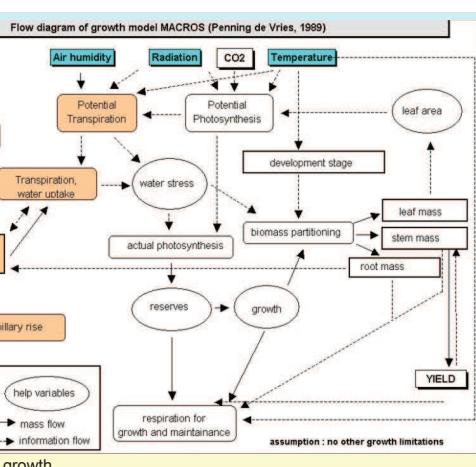
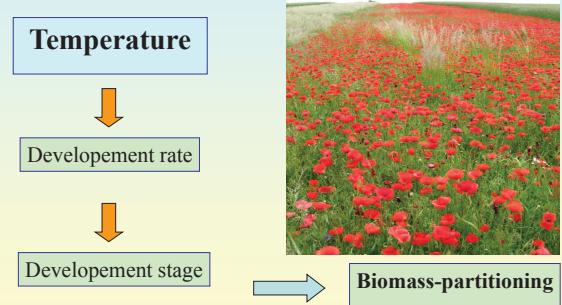


Abb. 15.: Schematischer Tagesverlauf des CO₂-Gaswechsels in Abhängigkeit vom Strahlungsangebot.

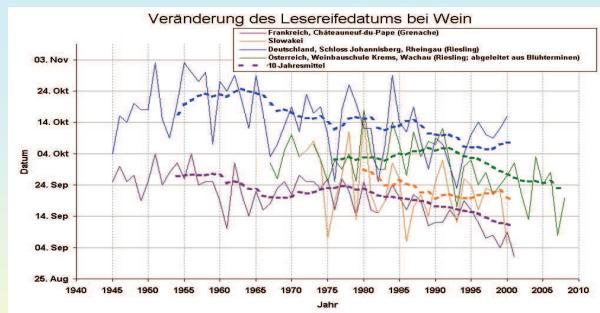
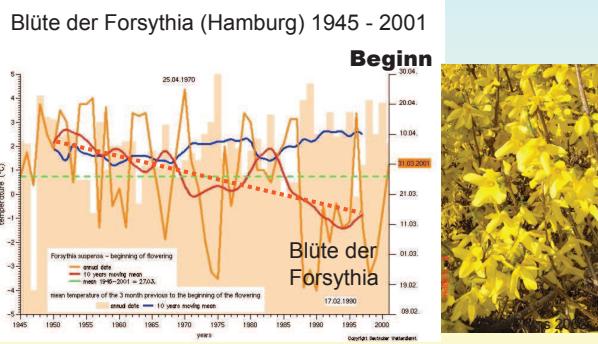
Crop growth factor: Temperature



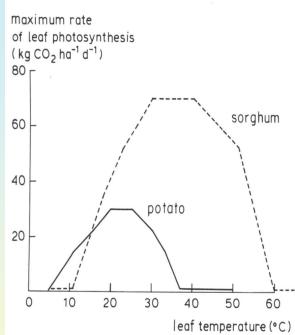
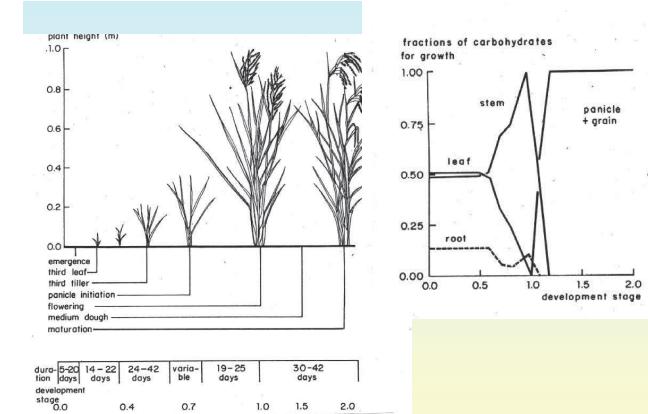
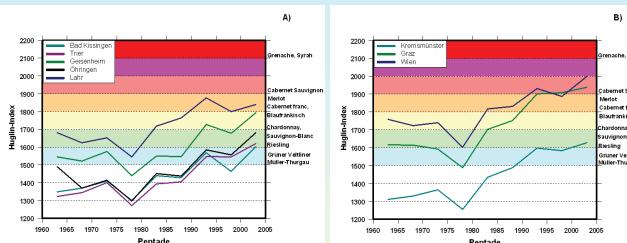
Crop development (Phenology)



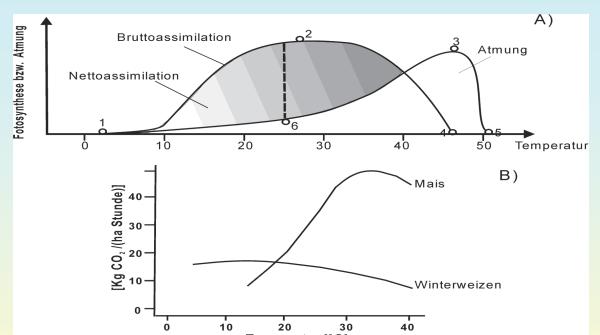
Example: Trend to earlier flowering



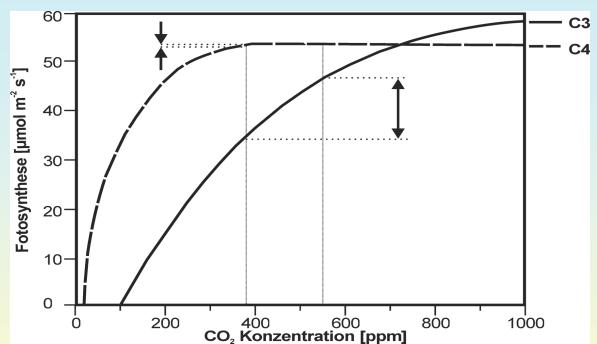
Wine harvest dates trends in Europe



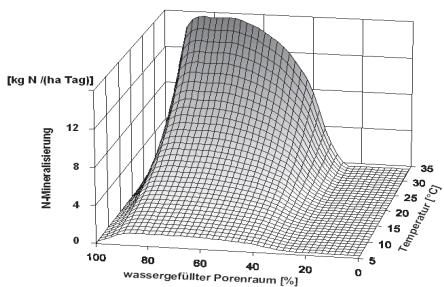
Impact of temperature on photosynthesis rate



Impact of temperature on biomass accumulation



CO₂ impact on photosynthesis



Factors of soil N-mineralization





Crop growth factor: Water and water balance

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Energy balance and water balance

$$0 = R_n - G - H - L.E (- \Delta S)$$

Rn = Net radiation
G = Soil heat flux
H = Sensible heat flux
L.E = Latent heat flux (evaporation)
L = latent heat ($2,45 \cdot 10^6 \text{ J/kg}$)
E = Amount of water
 ΔS = energy stored in biomass
Units : $\text{MJ.m}^{-2} \text{ d}^{-1}$ or W.m^{-2}



Energy balance

$$0 = P - L.E - R - \Delta S_w + K - D$$

P = Precipitation
LE = evapotranspiration
R = Runoff
 ΔS_w = Soil storage change
K = Capillary rise, D = Drainage

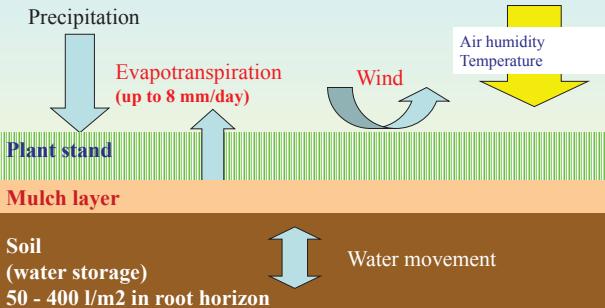
Water balance

Field water balance :

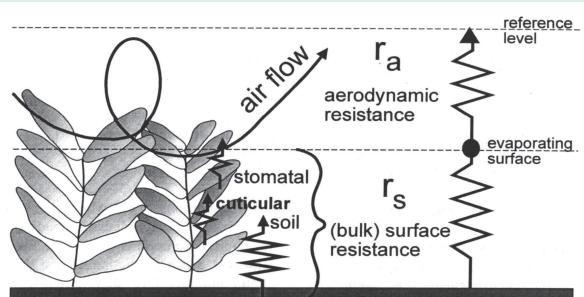
Soil – Plant – Atmosphere Interactions



Radiation, Energy



Resistances on evapotranspiration



Calculation of Evapotranspiration

Penman-Monteith combination equation for vegetative areas

$$\lambda ET = \frac{\Delta (R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma \left(1 + \frac{r_s}{r_a} \right)}$$

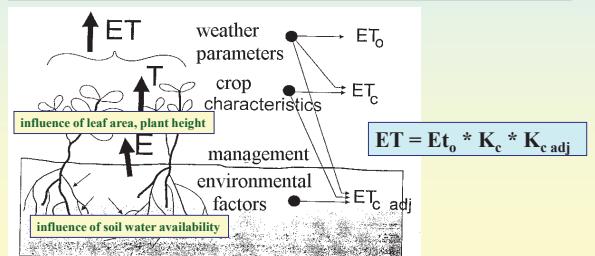
λET = Latent heat flux (evapotranspiration) [mm d^{-1}]
Rn = net radiation [$\text{MJ m}^{-2} \text{ d}^{-1}$]
G = soil heat flux [$\text{MJ m}^{-2} \text{ d}^{-1}$]
es = saturation vapour pressure [kPa]
ea = actual vapour pressure [kPa]
es-ea = vapour pressure deficit of the air [kPa]
Δ = slope of the vapour pressure curve [kPa $^{\circ}\text{C}^{-1}$]
ρa = air density [kPa $^{\circ}\text{C}^{-1}$]
cp = specific heat of the air [kPa $^{\circ}\text{C}^{-1}$]
rs = surface resistance [s m^{-1}]
ra = aerodynamic resistance [s m^{-1}]

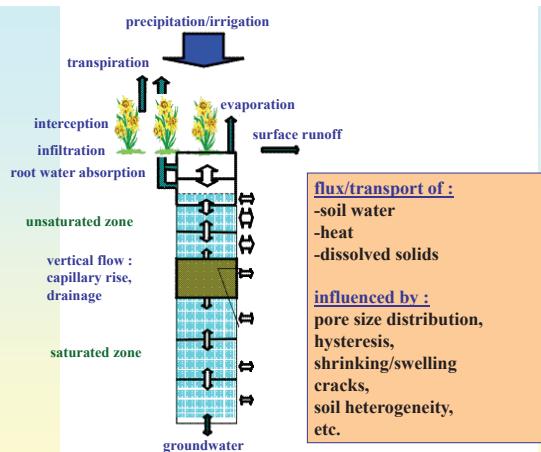
Simplified calculation of the reference evapotranspiration

Purpose : less input parameters - handy use

Example : FAO grass reference ET_0 (Allen, 1998)

$$ET_0 = \frac{0,408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0,34 u_2)}$$





Water balance factors of a plant site (Kroes, 2002)

Concepts of soil water balance calculation

1. Simplified:

Cascade method (simple balance approach of each layer)
(only vertical water flow downwards)

Only for light (sandy etc.) soils, with free drainage, no capillary rise from groundwater

2. Complex:

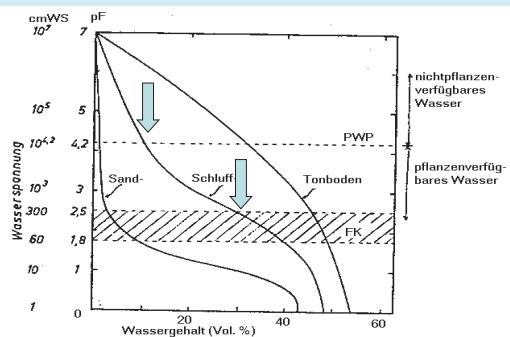
Consideration of hydraulic conductivities and -potentials
(one- to three dimensional fluxes)

- Method of Darcy (1856)
 $Q = K(h)^*(\partial h / \partial z)$

- Method of Richard's (1941)
 $\partial \theta / \partial t = \partial [K(h)^*(\partial h / \partial z + 1)] / \partial z - S(h)$

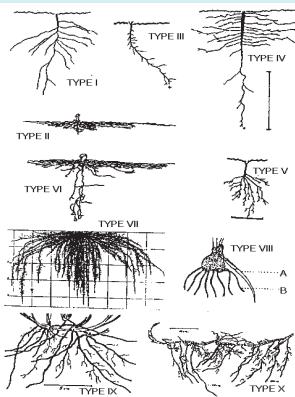
Q - Amount of water/time/area,
 θ - Water content, t - time, S - Source/Sink,
 K - hydraulic conductivity, h - soil water potential, z - vertical distance

Soil characteristics and water balance



Water retention curve:
Relation of soil water content and soil water potential of various soils (pF-curve)
(Scheffer and Schachtschabel, 1982)

Problem root water uptake



$$W = A : (\Phi_{Soil} - \Phi_{Root}) / \Sigma r$$

W = Absorbed amount of water
A = exchange area (in $\text{cm}^2 / \text{cm}^3$)
 Φ = Hydraulic Potential of roots, soil
 r = Hydr. Resistance soil, soil-root contact / plant (Gardner)

Type of roots (Cannen, 1949)

Bodenart	Mittlerer effektiver Wurzelraum bei Getreide (dm)	Pflanzenverfügbare Bodenwassermenge (mm)
Grob sand	5	30
Mittelsand	6	55
Finsand	7	80
Lehmiger Sand	7	115
Schluffiger Sand	8	140
Lehmiger Schluff	11	220
Sandeiger Lehm	9	155
Schluffiger Lehm	10	190
Toniger Lehm	10	165
Lehmiger und schluffiger Ton	10	140

Tab. 1 Effektiver Wurzelraum und pflanzenverfügbare Bodenwassermenge (W_{pf}) in Abhängigkeit von der Bodenart (mittlere Lagerungsdichte)⁴⁵.

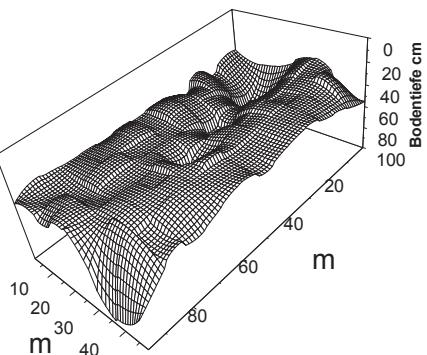
Mean effective root zone depth of crops [dm]
Plant available soil water [mm]
for different soils (mean bulk density)

Spatial effects on water balance

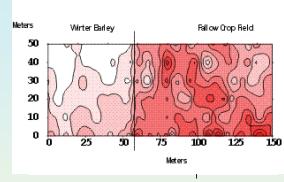
caused by

soil conditions

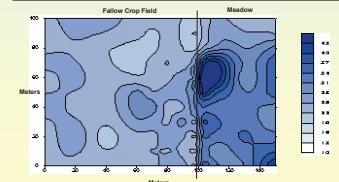
Spatial variable soil conditions



Raasdorf - November 1996
Soil Surface Temperature [°C] by IR-Sensor



Distribution of Soil Moisture
Time Domain Reflectometry (Trase) [% by Vol]



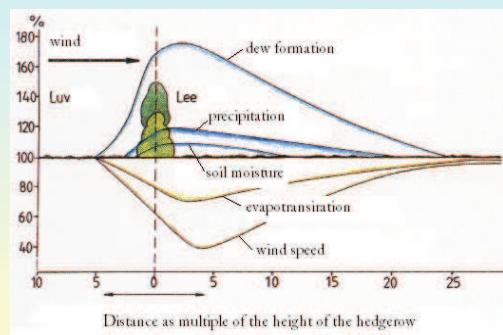
Spatial effects on water balance
caused by
landscape structures

MUBIL: Hedgerows – modification of microclimate of neighbouring fields

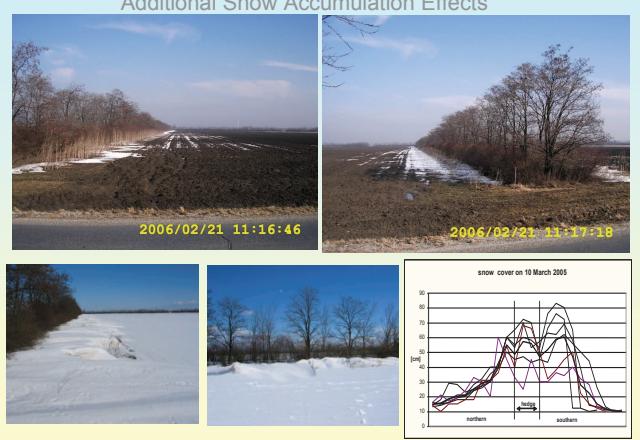
Multiple effects of hedgerows on microclimate

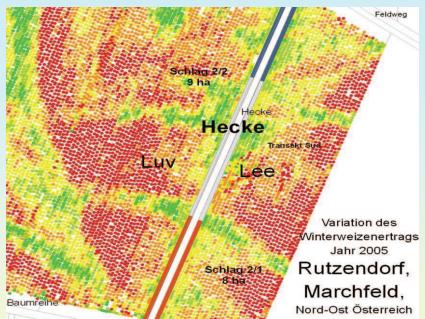
- wind speed reduction
 - higher amounts of precipitation
 - promoting dew formation
 - reducing evapotranspiration
 - reducing soil erosion
- Significant effects on crop water balance, drought damage and crop yield
- Optimization of microclimatological conditions

Sphere of influence



Additional Snow Accumulation Effects





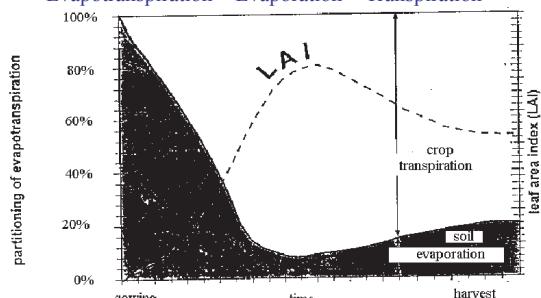
Small scale (within field) yield variations due to soil conditions and hedgerow in Marchfeld – site Rutzendorf (Source : Schauppenlehner)

Water balance of crop stands

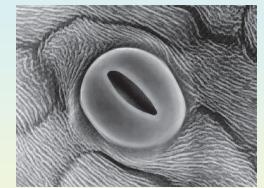
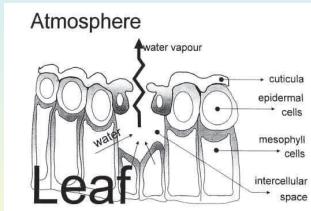
Evapotranspiration of crop stands

FIGURE 22
The partitioning of evapotranspiration into evaporation and transpiration over the growing period for an annual field crop

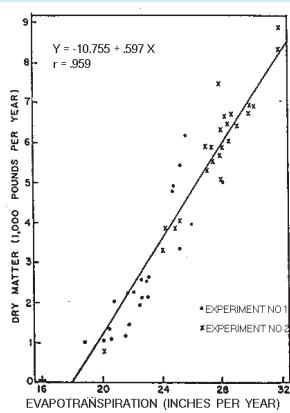
$$\text{Evapotranspiration} = \text{Evaporation} + \text{Transpiration}$$



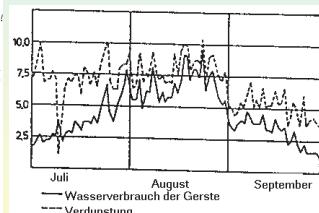
Transpiration (plants)



Transpiration resistance and stomata regulation (Allen, 1998)



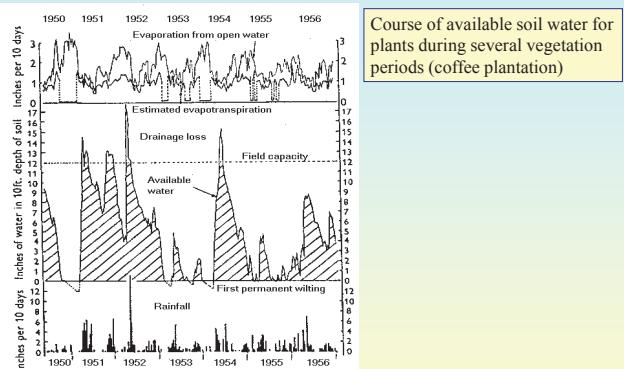
Transpiration coefficient



Water consumption of different plants (meadows, alfalfa, crops, legumes, root crops, maize)

Fruchtart (Nutzung)	Relativer Wasserbedarf 1/kg TS	Absoluter	Wasserbedarf
		mittl. Ertrag mm	hoher Ertrag mm
Wiesen	400 - 700	180 - 300	300 - 510
Luzerne	400 - 500	200 - 340	400 - 1000
Getreide	300 - 400	130 - 210	300 - 510
Hülsenfr.	250 - 350	85 - 135	210 - 340
Hackfrüchte	200 - 300	180 - 270	320 - 480
Mais	150 - 300		

Werte ohne Evaporation!
Relativer Wasserbedarf = Transpirationskoeffizient.



Example : effect of water stress for grapes

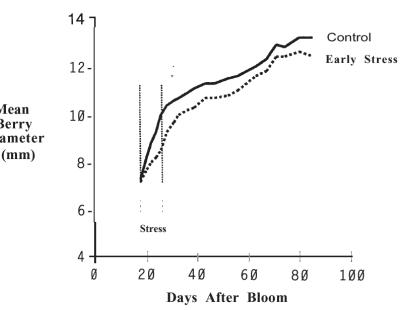
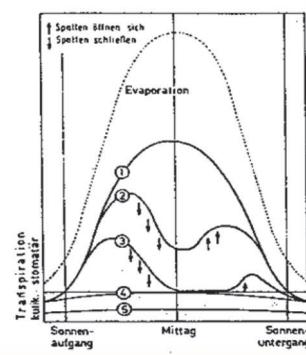


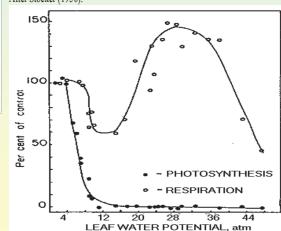
Fig. 1. Growth curves of Pinot Noir grape berries that were well-watered (Control) or were water stressed for only a 10 day period in the cell division growth period after bloom. Data of S. Poni and A. Lakso.



Short-term water stress (< 1 day)

Scheme of a daily course of the transpiration with increasingly reduced water supply. The arrows point to stomata opening movements which are released by a changed water state. The area of cuticular transpiration is shown in the lines 4,5.

- 1 unlimited transpiration
 - 2 typical depression of transpiration after noon by stomatal closure
 - 3 case of fully closed stoma at noon
 - 4 only cuticular transpiration
 - 5 reduced cuticular transpirations by cell shrinking
- After Stocker (1956).



What is drought stress ?

Due to deficit of root uptake the plant has to reduce its potential transpiration, which is determined by the potential photosynthesis and the leaf mass. This may occur for short or long time.

Short-term effects (grapes) :

- reduced photosynthesis
- leaf wilting
- reduced resistance against frost / chill
- metabolism (reduced protein synthesis)

Long-term effects :

- growth retardation
- yield and quality depression
- die back of plant parts
- increased root growth
- diverse other adaptation mechanisms





Novi Sad, June 27 - July 1 2016

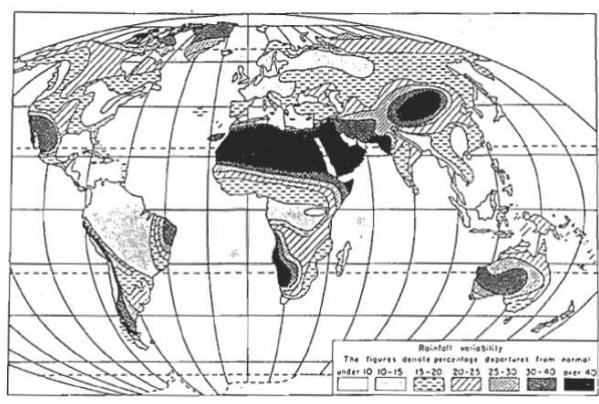
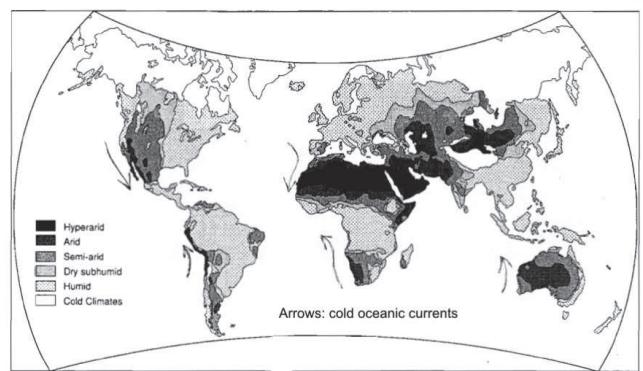
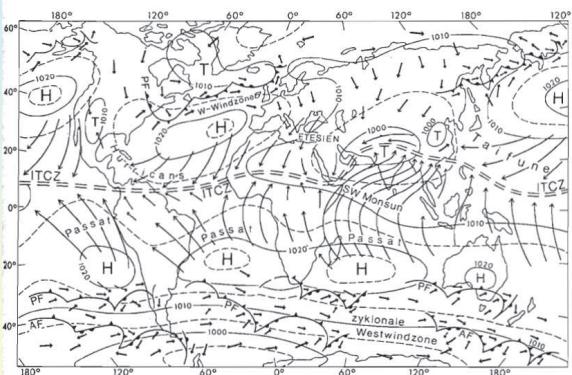
Impact of weather extremes on crop growth and adaptation options

Josef EitzingerInstitut für Meteorologie, Universität für Bodenkultur, Wien
E-mail: josef.eitzinger@boku.ac.at
<http://www.boku.ac.at/>

Climate variability –

a main challenge for agriculture

Driving factors of climates - Global air pressure and wind systems (July)

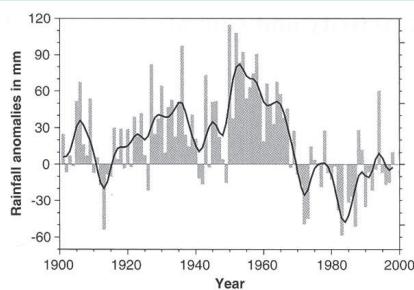


Spatial climate variability:
Strong impact of topography



Monsun climates: high interannual rainfall variability

(relatively increasing with decreasing annual rainfall)



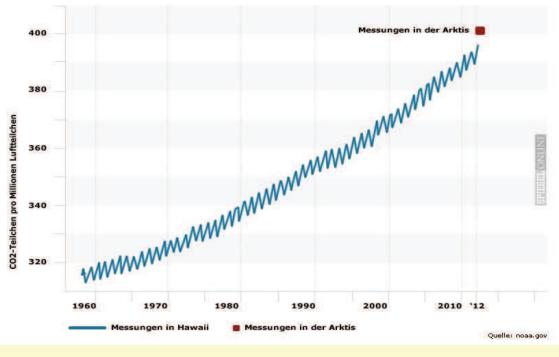
Time series of observed summer monsoon rainfall anomalies in the Sahel Zone (12° – 21° N, 15° W– 20° E) with respect to the 1961–1990 reference period. The thick line is smoothed with a 9-year binomial filter.

Paeth, 2008

The additional challenge:

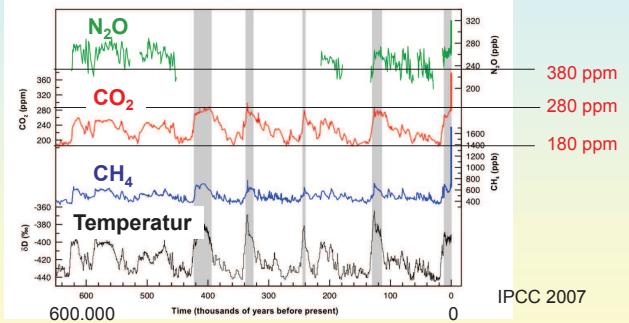
Climate change factors and impacts on agriculture

Treibhausgas: CO₂-Anstieg knackt 400er-Grenze



Spiegel, 2012

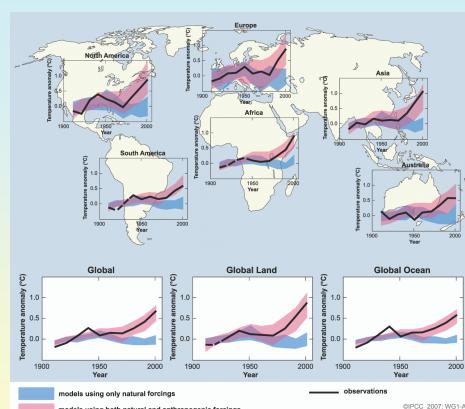
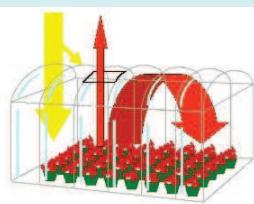
Glacial-Interglacial Ice Core Data



IPCC 2007

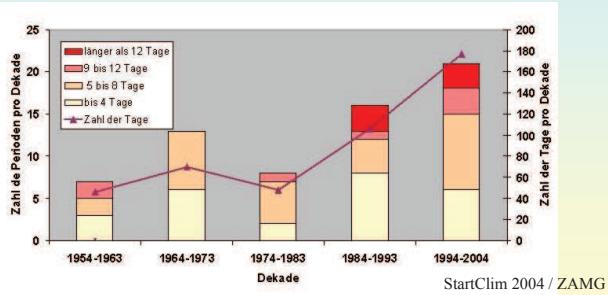
Greenhouse gas impacts

- Warming of atmosphere
- CO₂: Acidification of oceans
- CO₂: Forced plant photosynthesis

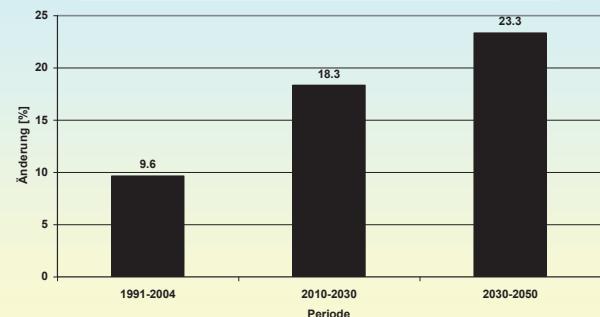


Der „anthropogen“ force of climate change
(Source: IPCC, 2001)

Heat waves in Austria 1954 - 2004

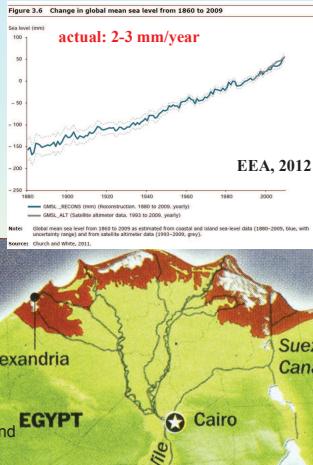


Forced evapotranspiration vs. 1961-1990

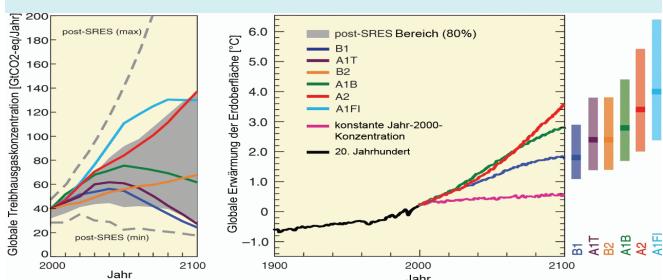


(Eitzinger et al., 2009)

Sea level rise



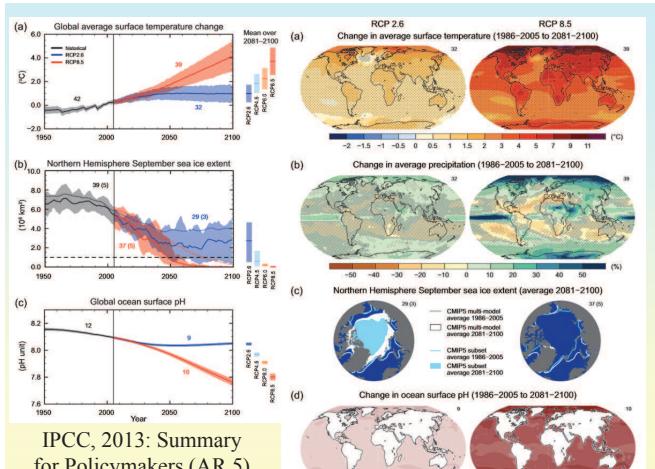
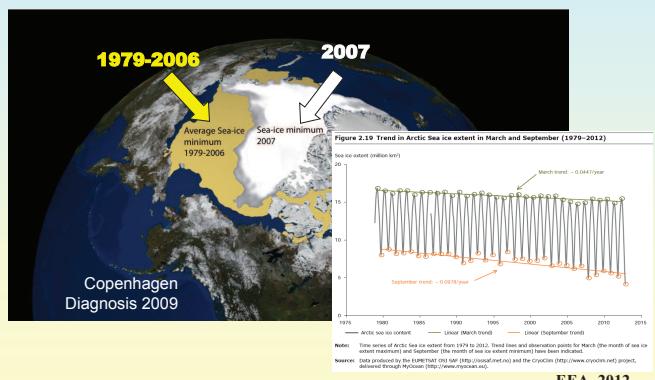
Global climate scenarios (IPCC)

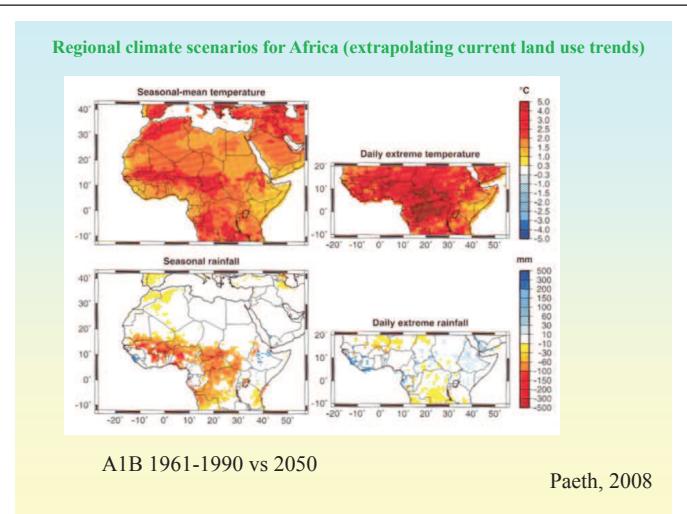
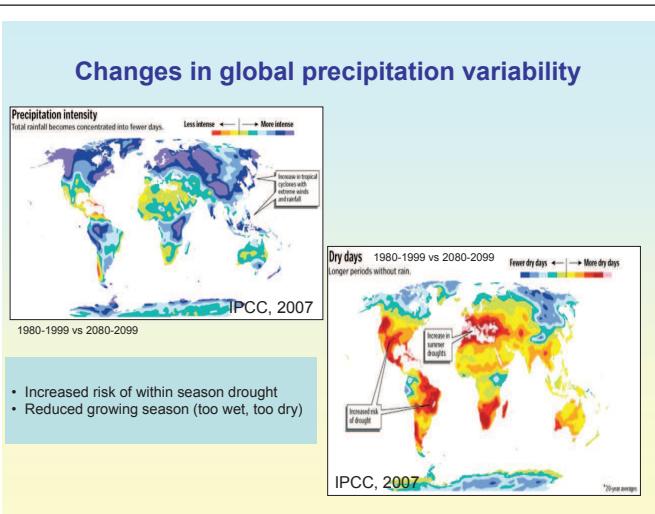
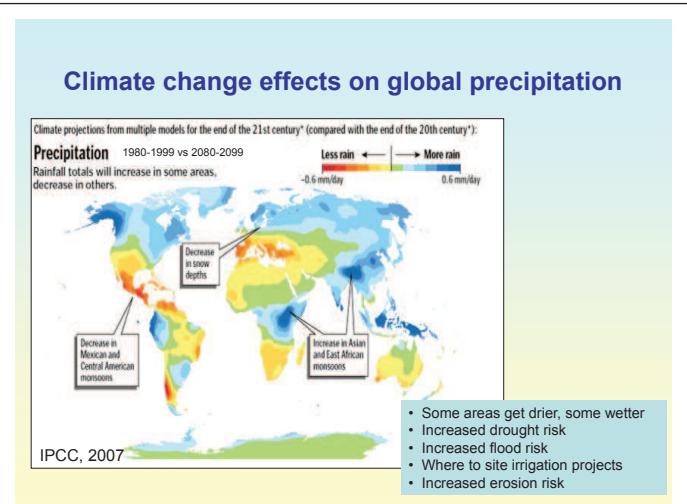
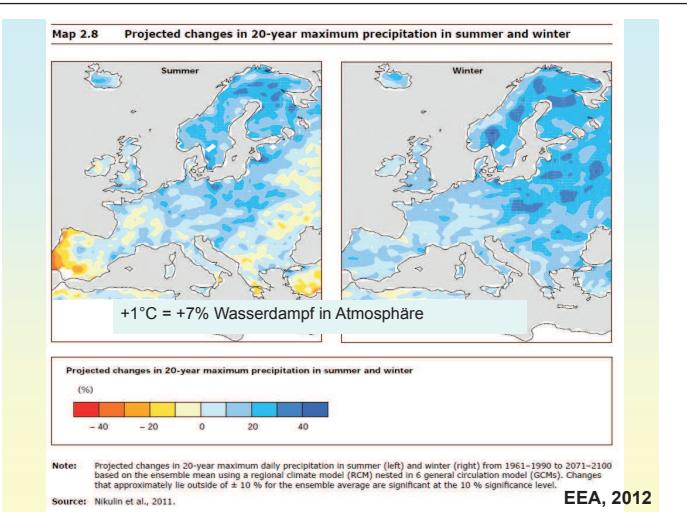
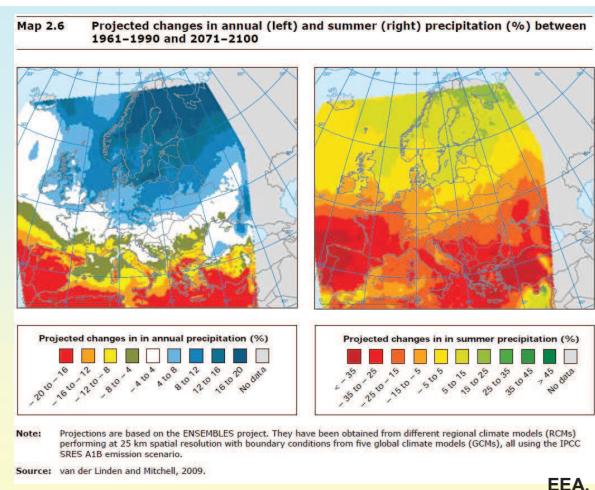
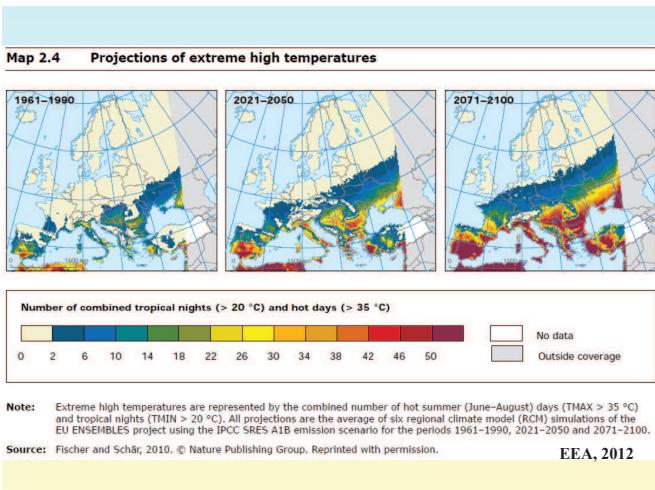


SRES-emission scenarios (left) and resulting temperature scenarios (right) till 2100 (IPCC 2007)

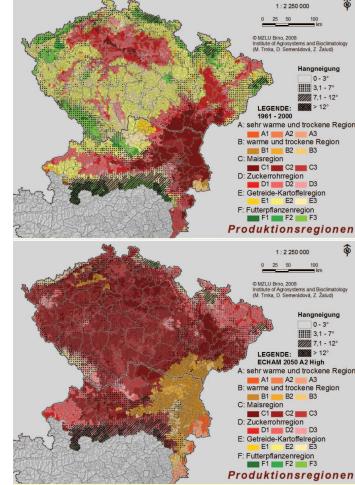
17

Arctic ice sheet depletion

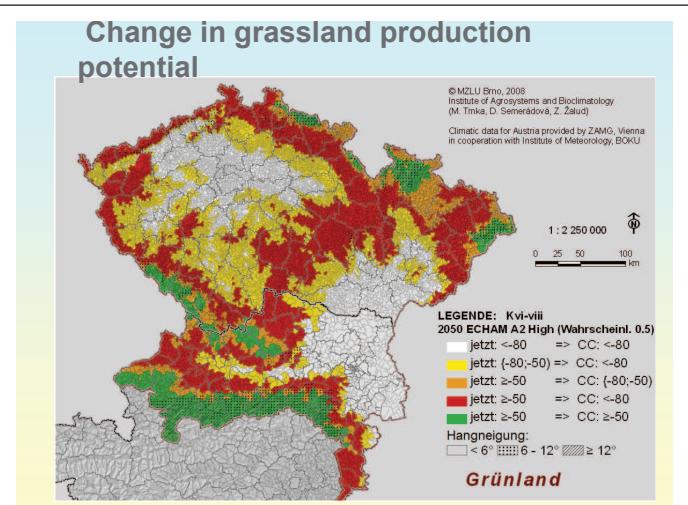
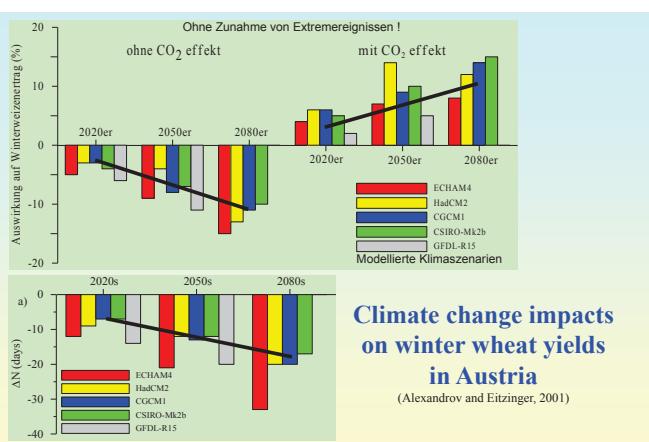
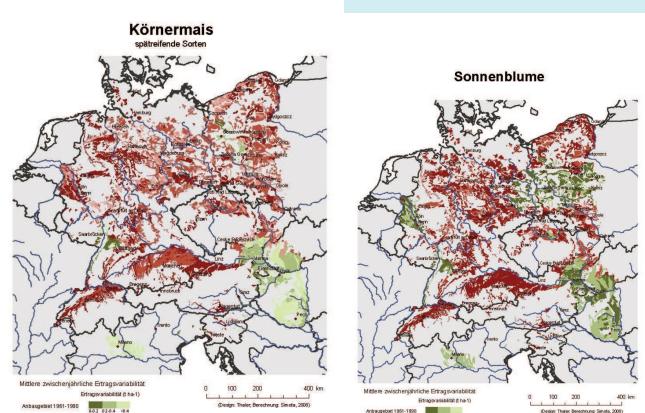
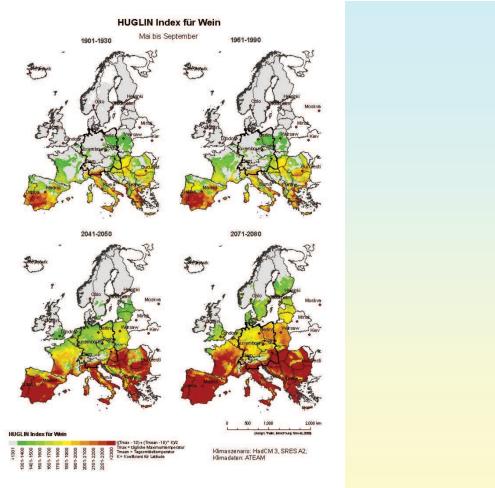




Impacts of climate change on crop productivity factors

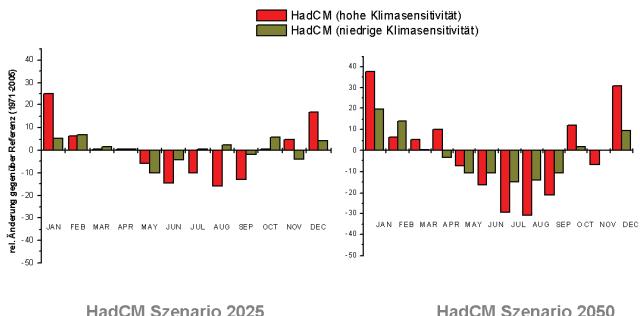


Trnka et al, 2008

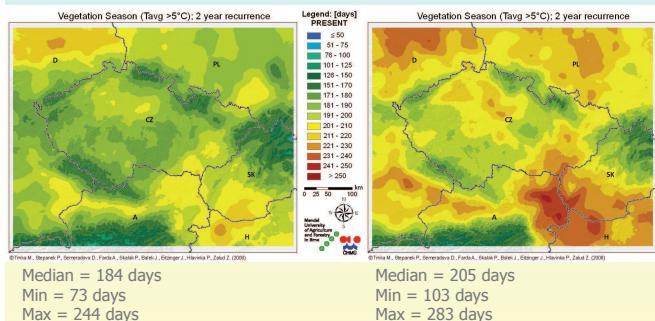


Regional climate scenarios – Central Europe

Seasonal Precipitation Change



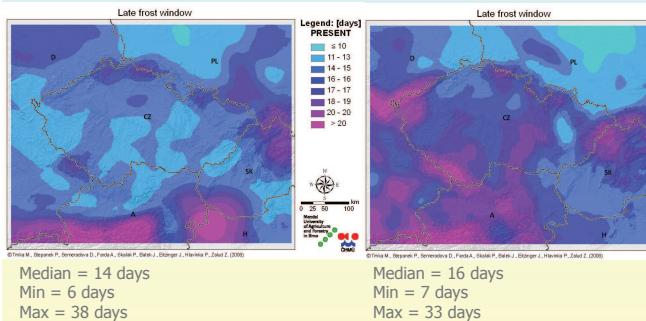
RCM - Vegetation season duration



32

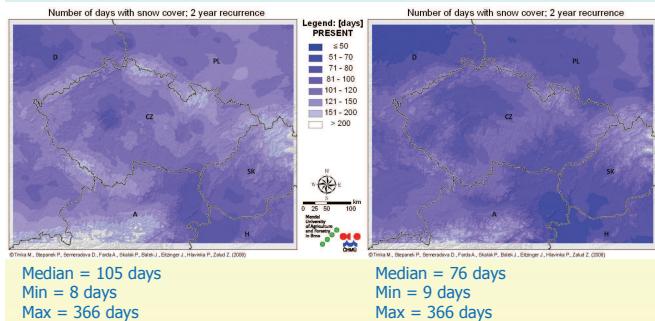
Difference between date of the last frost with the return probability 2 and 20 years

RCM - Frost risk (Agriclim)



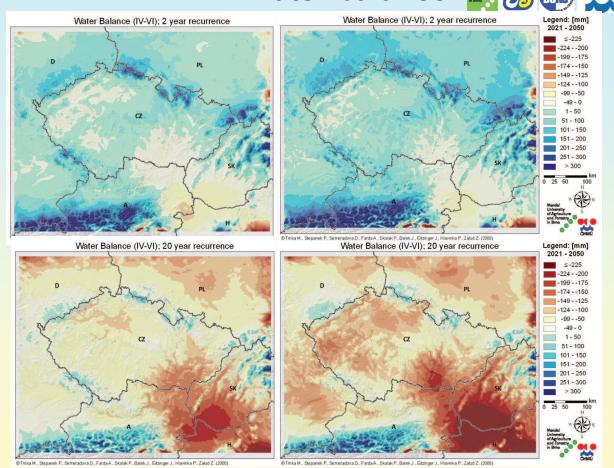
33

RCM - Number of snow days (Agriclim)

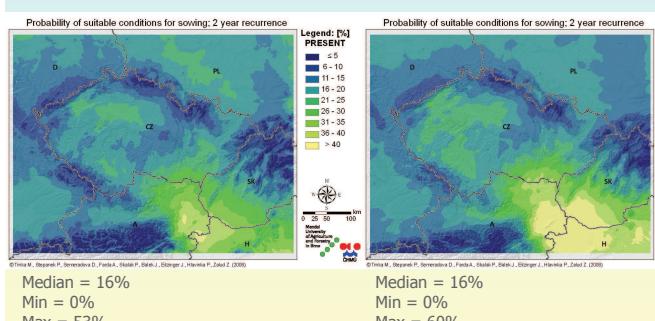


34

RCM - Water balance

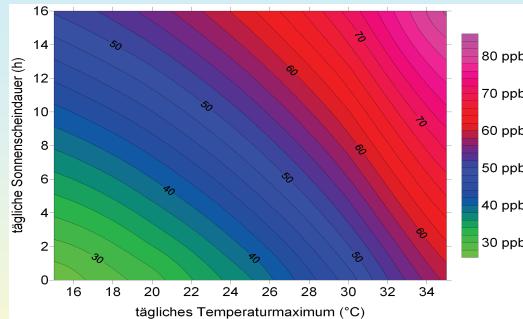
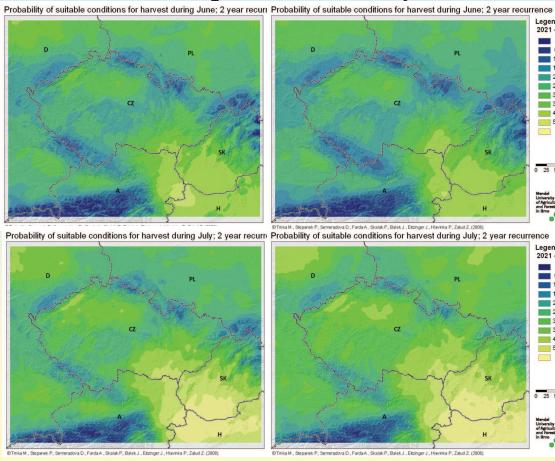


RCM - Sowing conditions (early spring)

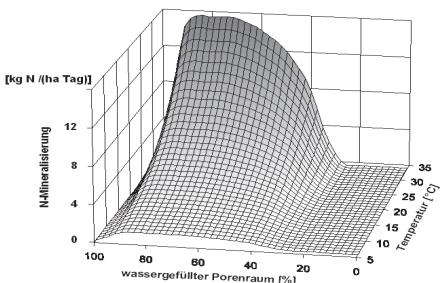


36

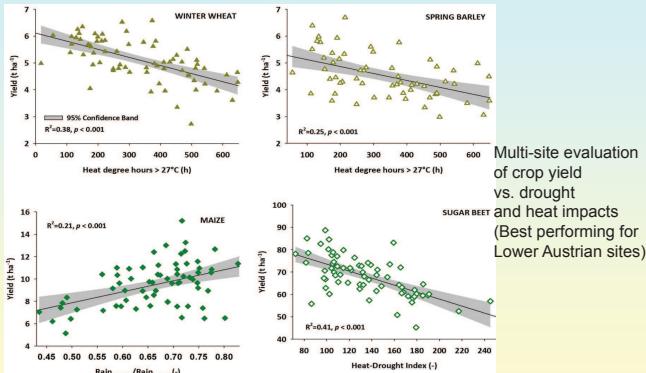
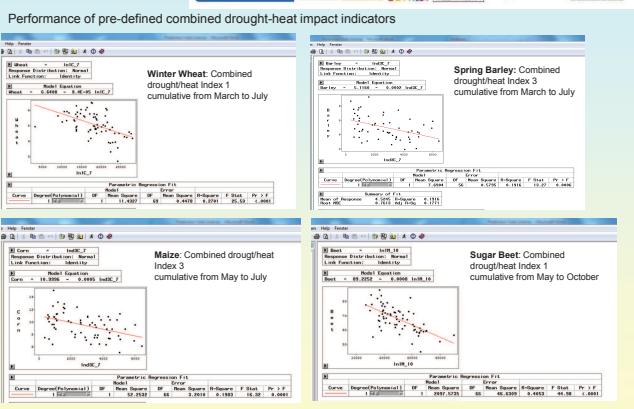
RCM - Suitability for harvest (June & July)



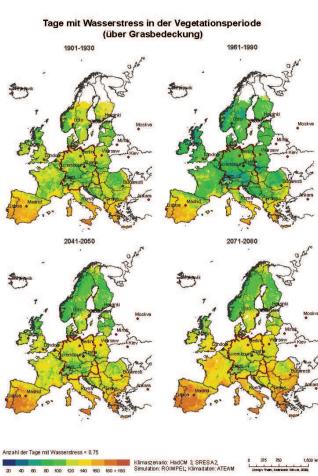
Factors influencing tropospheric ozone



Factors of soil N-mineralization



Multi-site evaluation of crop yield vs. drought and heat impacts (Best performing for Lower Austrian sites)



Simota et al.,
2008

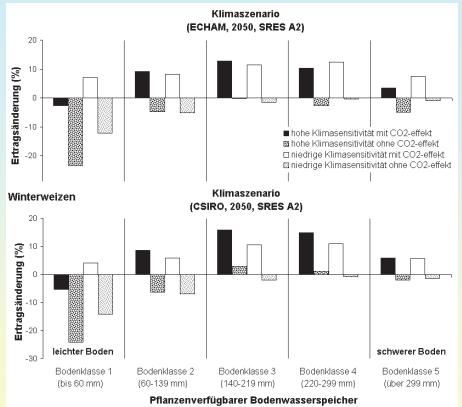
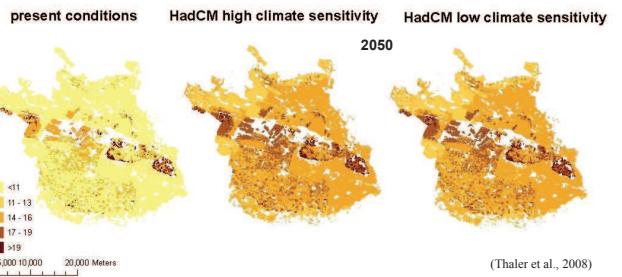
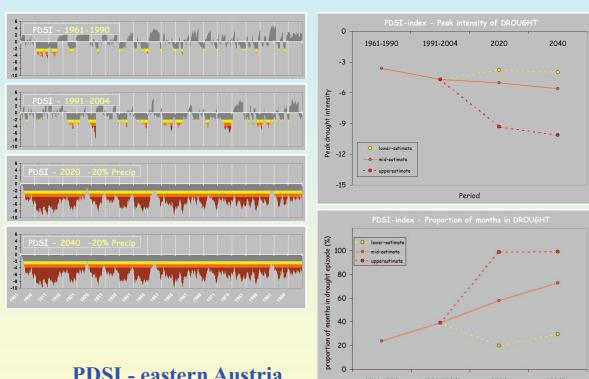
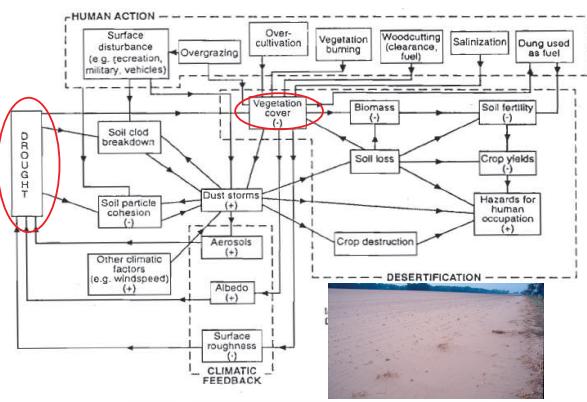


Abb. 2.47: Bandbreite des Ertragspotenzials des Winterweizens im Marchfeld auf verschiedenen Bodenklassen und unter zwei verschiedenen Klimaszenarien der 2050er Jahre aufgrund der Schwankungen und Unsicherheiten im CO₂-Düngungseffekt (Simulation: Thaler, BOKU)

Increase of water stress (simulated for spring barley - eastern Austria)



An increasing global problem: Loosing fertil soils through land desertification



PDSI - eastern Austria





Developement of pests depend on temperature (corn borer)



Diseases: depend on humidity and temperature mainly
Dürrfleckenkrankheit (Alternaria) bei Kartoffel (Quelle: Glauninger)



Weeds : Example Ambrosia

Impacts of climate change on agriculture - World

- physiological effects on crops, pasture, forests and livestock (quantity, quality);
 - changes in land, soil and water resources (quantity, quality);
 - increased weed and pest challenges;
 - shifts in spatial and temporal distribution of impacts;
 - sea level rise, changes to ocean salinity;
 - sea temperature rise causing fish to inhabit different ranges.
- socio-economic impacts:
- decline in yields and production;
 - reduced marginal GDP from agriculture;
 - fluctuations in world market prices;
 - changes in geographical distribution of trade regimes;
 - increased number of people at risk of hunger and food insecurity;
 - migration and civil unrest.

FAO, 2007

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General climate change impacts in European crop production regions (observed)

- Trend to increasing summer droughts and heat days : more drought stress days for crops
- Increasing length of growing season; shortening of growing cycles
- Regional increasing trends in weather extremes (heat, hail, floods) lead to higher production risks
- Forced changes in occurrence of pests, diseases and weeds due to the warming trend (spatial shifts depending on elevation)
- Less snow cover and warmer winter periods can increase disease pressure and change crop timing
- Shift of crop phenology changes timing of farm management (shift of crop management, harvest date etc.)



Impact of "Input" and "Technology" on sustainability

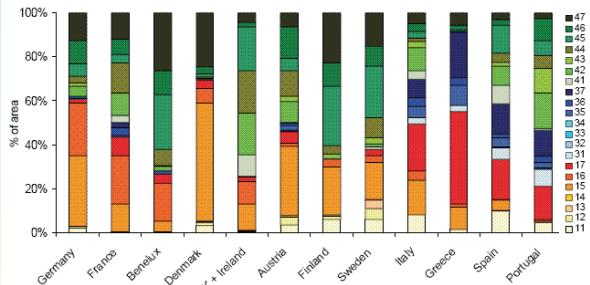
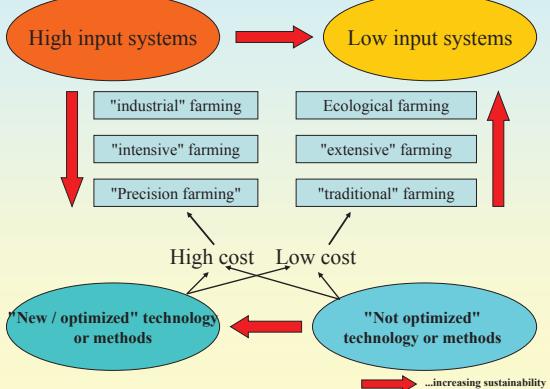


Figure 7.2 (in colour on p.185). The distribution of farm types in different countries in the EU15. Farm type classes are labelled in Table 7.2 and 7.3.

(Reidsma, 2007)

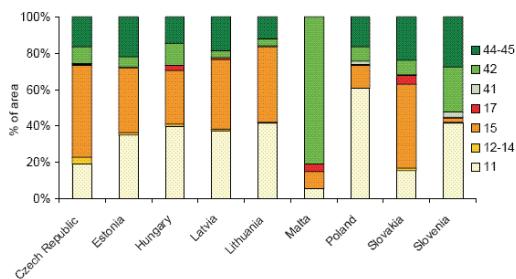
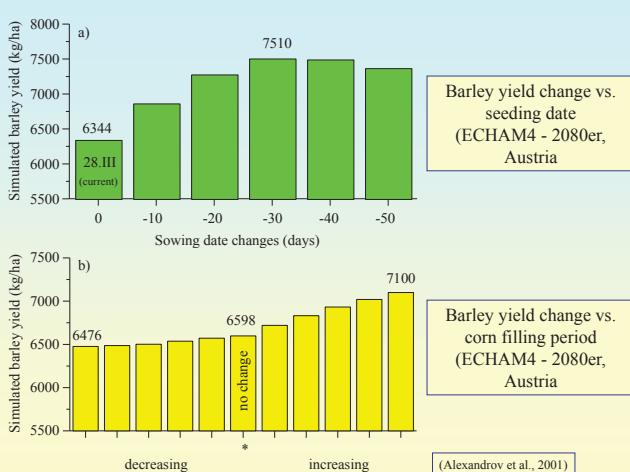


Figure 7.3 (in colour on p.185). The distribution of farm types in different countries in the New Member States. Farm types are not distinguished as much as in the EU15, but they are assumed to be similar to farm types labelled in Table 7.2 and 7.3.

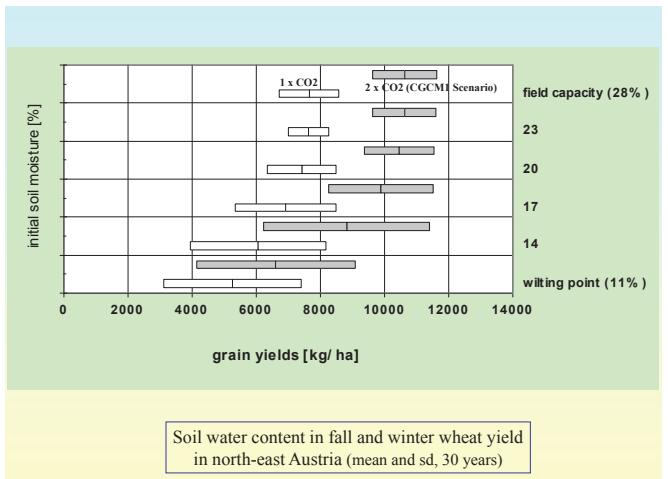
(Reidsma, 2007)

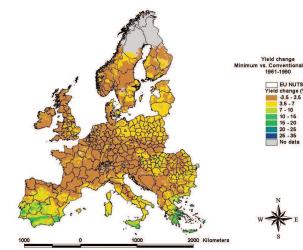


Land use: Austria – CZ (Satellite)



(Alexandrov et al., 2001)





**Spring wheat yield change (%)
between minimum and
conventional tillage for baseline
(1961-1990)
and climate change scenario
(2041-2050 HADCM3-A2)
(Simota, 2009)**

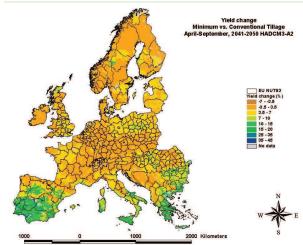
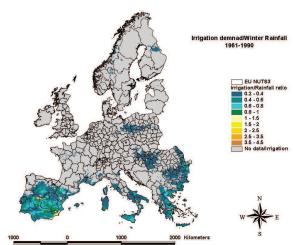
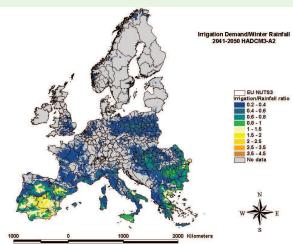


Abb. 3.11: Beispiel einer unsachgemäßen Bewässerung mit hohem Wasserverbrauch im Marchfeld in Österreich, (Foto: Neudorfer)



**Ratio between irrigation demand
and water rainfall during
October-March (winter period);
wheat
(Simota, 2009)**



Adaptation to local climate : Agrometeorological station



Better irrigation scheduling (measuring soil water content)



Terrass cultivation against soil erosion (USA)



Grass soil cover (Mulch) against soil erosion



Improving microclimate : agro-forestry systems



Windbreaks : Improving water balance



Land use feedback to regional climates !

In: Eitzinger et al., 2009

Mitigation options of African Climate Change

"When the land-use changes are switched off in the 21st century simulations, the warming is reduced by 59% and the rainfall reduction can be prevented almost entirely.

Thus, the local protection of vegetation and reforestation measures may be more effective for the mitigation of African climate change than the global reduction in GHG emissions"

Paeth, 2008

Improving traditional farming systems and rural welfare in developing countries should become a global priority (Stigter, 2010)

- Governmental support (weather warning/forecast services, extension services, micro insurances, rural infrastructure, land rights, education, ...)
- Transfer of knowledge: farmers need to understand climate change to adapt
- Successful examples by applying participatory training approaches (bottom up)
- New low cost "high technology" (e.g. pumps, sensors, ...)
- Use of local knowledge and experiences – but adapt traditional (indigenous) techniques or methods to changing climate
- Sustainable farming methods (i.e. mulching, mixed farming, agroforestry, ecological farming ...)



A simple pump, powered by one person, can irrigate acres of land easily. These pumps, produced by Appropedia, are inexpensive and efficient.