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DEPARTMAN ZA RATARSTVO I POVRTARSTVO

UNIVERSITÀ DEGLI STUDI FIRENZE
DISPAA
DIPARTIMENTO DI SCIENZE DELLE PRODUZIONI AGROALIMENTARI E DELL'AMBIENTE

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Workshop 2018

Impact of climate change on plant growth and nutrition

-Small Study Group 2018-

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General introduction

- The increasing world population is putting stress on rising demands for crop production. By 2050, global agricultural production will have to double to meet the future demands.
- Climate projections predict changes in atmospheric CO_2 level, temperature and rainfall pattern.
- There is high concern about direct impact of climate change on agriculture.
- Uncertainties related to representation of higher CO_2 level and temperature demonstrate that further knowledge upon effect of climate change on agriculture is needed.
- To get better insight to impact of climate change on agriculture, different aspects of agricultural production, such as crop growth and nutrition, must be investigated.

1. Spectral measurements and selected vegetation indices in plant production and climate change

Objective

- To discuss aspects, benefits, disadvantages and the practical applicability of **spectral measurements** and selected **vegetation indices** in **plant production** and **climate change research.**

Spectral measurements

- **radiation reflected by** a given **vegetation cover** is detected
- used to calculate algorithms called "vegetation indices" (VIs).

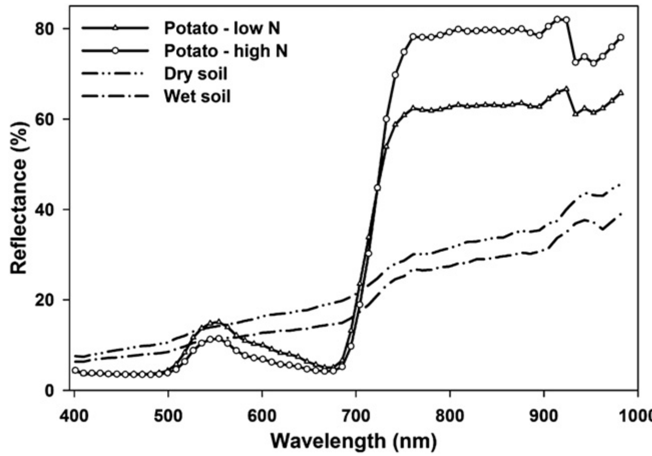
Vegetation indices

numerous applications – e.g. measure plant properties, predict yields, detect weeds and diseases, investigate effects of climate change on crops.

Spectral measurements

General information on radiation

- light reaches an object
  => radiation is absorbed/transmitted/reflected
- spectral measurements detect the **reflected radiation**



Distinct spectral reflectance curve of green plant canopy (Mulla, 2013)

Spectral characteristics of plant canopy

- many plant properties have an impact on spectral reflectance of crops at certain wavelengths

wavelengths < 700 nm: **low reflectance**; light absorption by **chlorophyll**
wavelengths > 700 nm: **high reflectance**; not used for photosynthesis

Platforms for conducting spectral measurements

Conducting spectral measurements using a handheld spectrometer (ASD, 2010)

Differences between platforms

altitude, spatial and spectral resolution, return frequency

Satellites

- return frequency, spatial resolution, cloudy conditions
- estimation of crop biomass and yields on a **regional scale**

Aerial systems

- transition platform, cloudy conditions
- **real-time site-specific** agricultural management decision making

Proximal systems

- active and passive spectrometers
- **on-the-go** detection of plant properties

Selected vegetation indices

NDVI (Normalised Difference Vegetation Index)

- reflectance ratio at near **infrared** (~ 790 nm) and **red** bands (~ 670 nm)
- useful for assessing LAI and plant biomass
- soil reflectance at low canopy densities affects NDVI results

NDRE (Normalised Difference Red Edge)

- reflectance ratio at near **infrared** (~ 790 nm) and **red edge** bands (~ 720 nm)
- sensitive to high levels of chlorophyll content

CCCI (Canopy Chlorophyll Content Index)

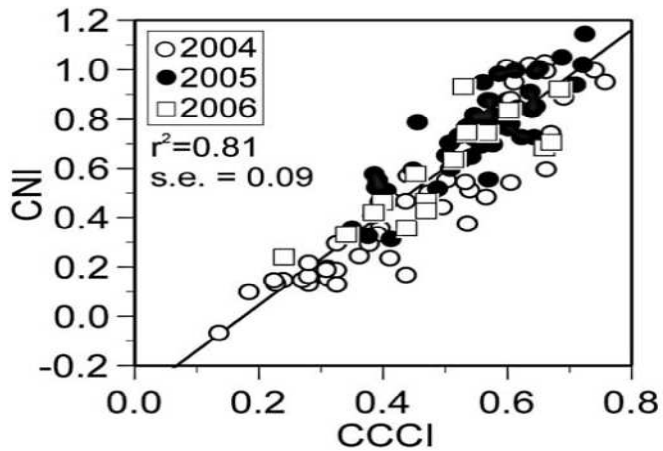
- based on **NDVI** and **NDRE**
- used to measure plant N nutrition

Current BOKU project on spectral measurements and VIs (CCCI)

Goal

Estimating plant N status via CCCI and CNI (**C**anopy **N**itrogen **I**ndex) by combining spectral measurements and crop models for various crops (wheat, maize, potato and sugar beet).

Conducting spectral measurements at BOKU



Relationship between CCCI and CNI in wheat (Fitzgerald et al., 2010)

Spectral measurements and VIs in climate change research

Goal

gather knowledge on the **typical responses of plants** to the various effects of **climate change** and their impacts on crop production

Approach

combining available long-term and large-scale **data on historical weather** as well as indirect measurements of various **plant canopy characteristics based on spectral sensing**

Improvement to resource use efficiency

Optimised farm management based on spectral sensing (fertilization, irrigation, plant protection measures)

Challenges and opportunities of spectral measurements and VIs in plant production

Challenges

- spectra of plant canopies are influenced by **various factors**
- many VI applications need **cultivar and site-specific calibrations**
- only few farmers have **access to spectral data** of their crops

Opportunities

- optimized **farm management strategies**
- increase in **farm profitability**
- reduction in **environmental pollution**
- better estimation of the **climate change effects on crops**

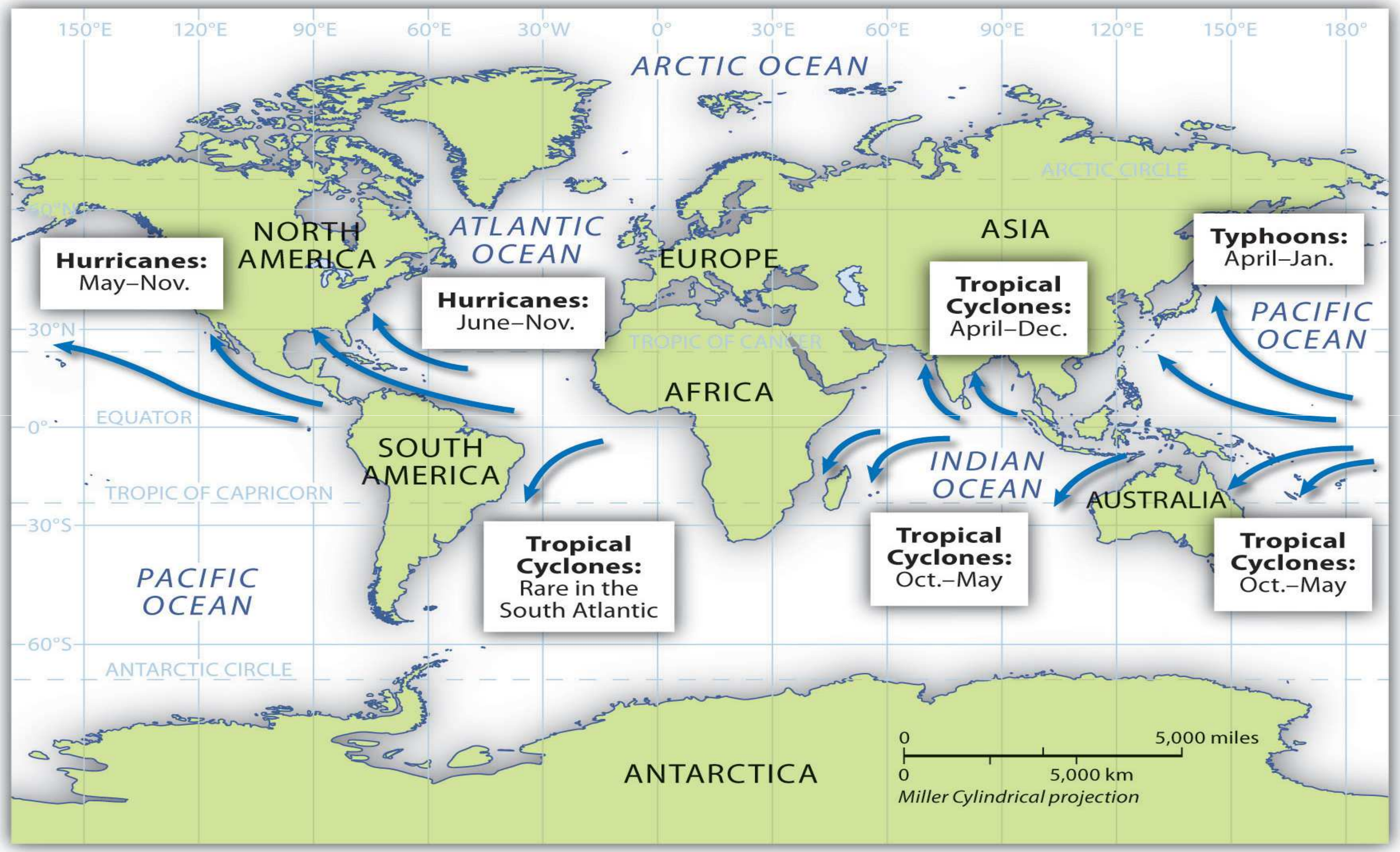
2. Climate change and crop growth

Research questions

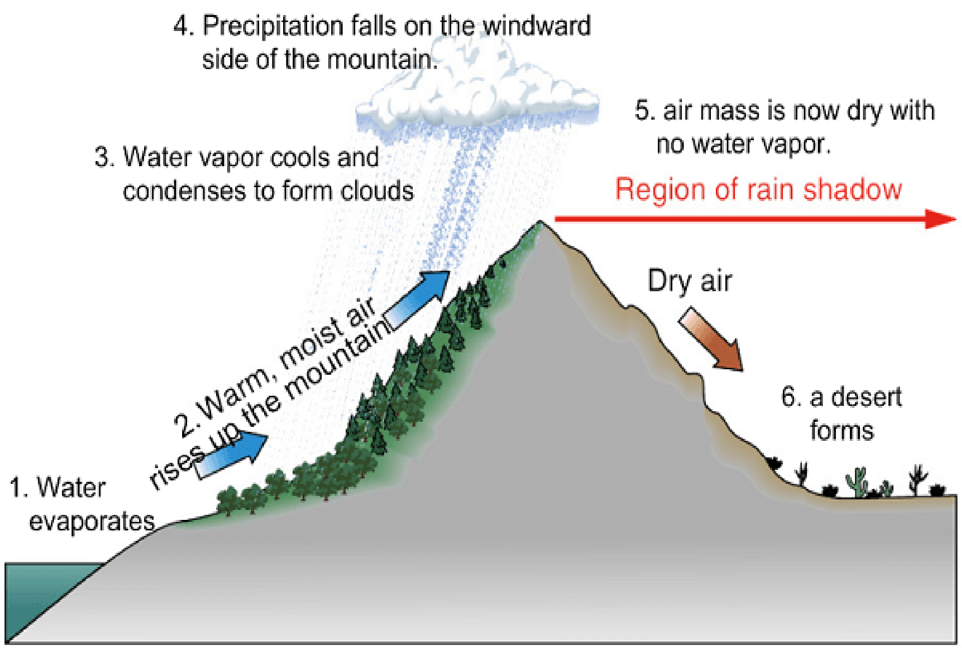
• How was the “behavior” of climate in the last three decades in Thai Nguyen province, the mountainous area in the North of Vietnam (the study area)?

• Did historical climate conditions have positive impact on maize production over the past 30 years in the study area?

“Continued high emissions will increase risks for Southeast Asia. Key issues range from coastal and river flooding, with the potential for widespread damage, to heat-related mortality, to water and food shortages following drought,” said Purnamita Dasgupta, a coordinating lead author of AR5 and one of the speakers at the event.



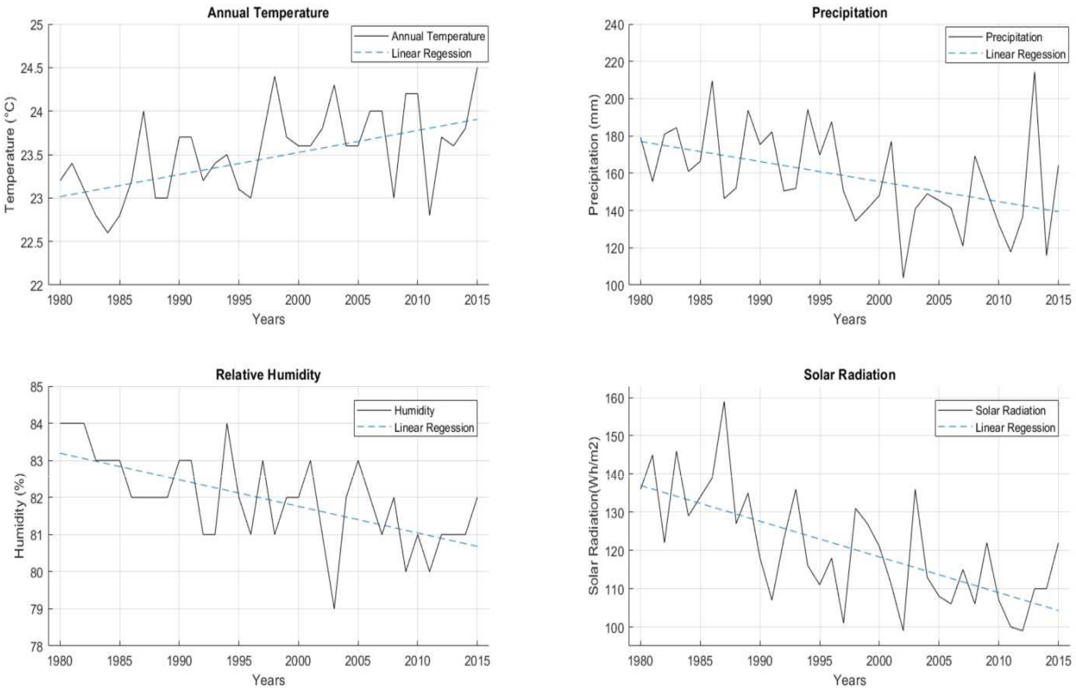
https://catalog.flatworldknowledge.com/bookhub/2657?e=berglee_1.0-ch05_s05

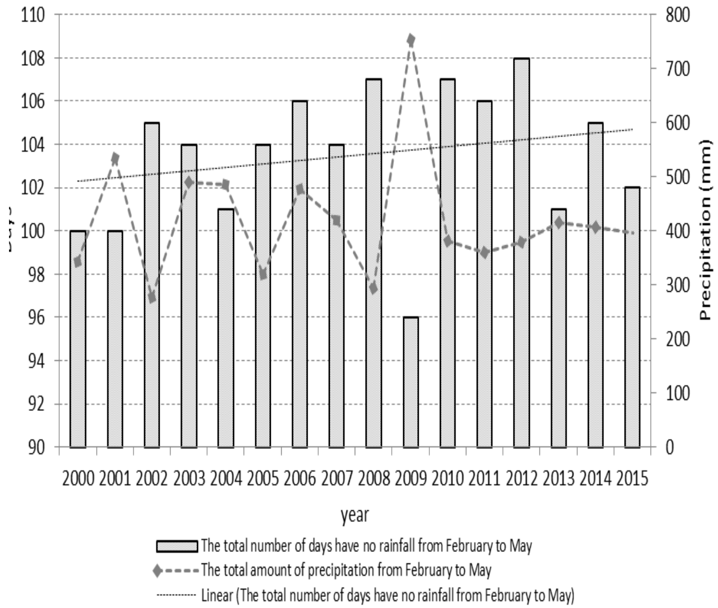


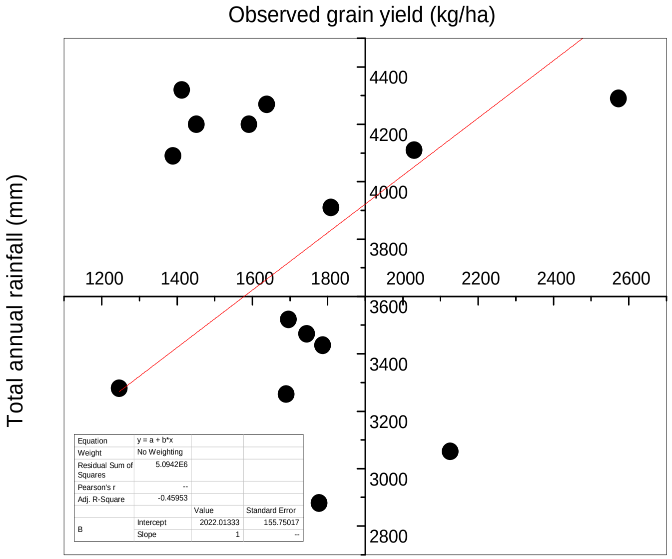
Source: http://www.colorado.edu/geography/class_homepages/geog_3251_sum08/

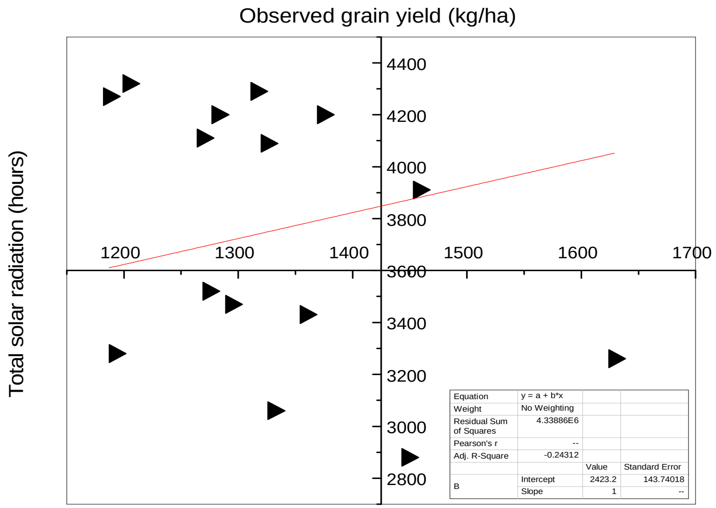
https://www.youtube.com/watch?v=Ik2A0cClXG4

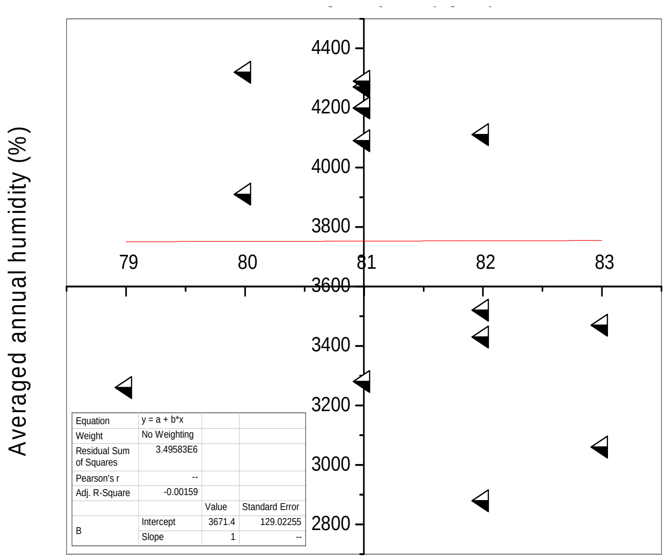
Source: http://cafef.vn/thai-nguyen-nhieu-noi-ngap-lut-nghiem-trong-do-anh-huong-cua-bao-so-6-20170825111338504.chn

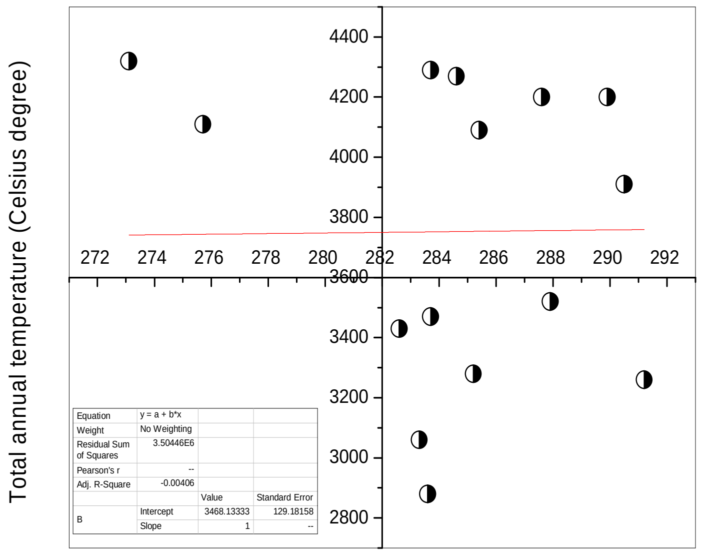

Annual Temperature
Annual Temperature
Linear Regession
Temperature (°C)
Years
Precipitation
Precipitation
Linear Regession
Precipitation (mm)
Years
Relative Humidity
Humidity
Linear Regession
Humidity (%)
Years
Solar Radiation
Solar Radiation
Linear Regession
Solar Radiation(Wh/m2)
Years

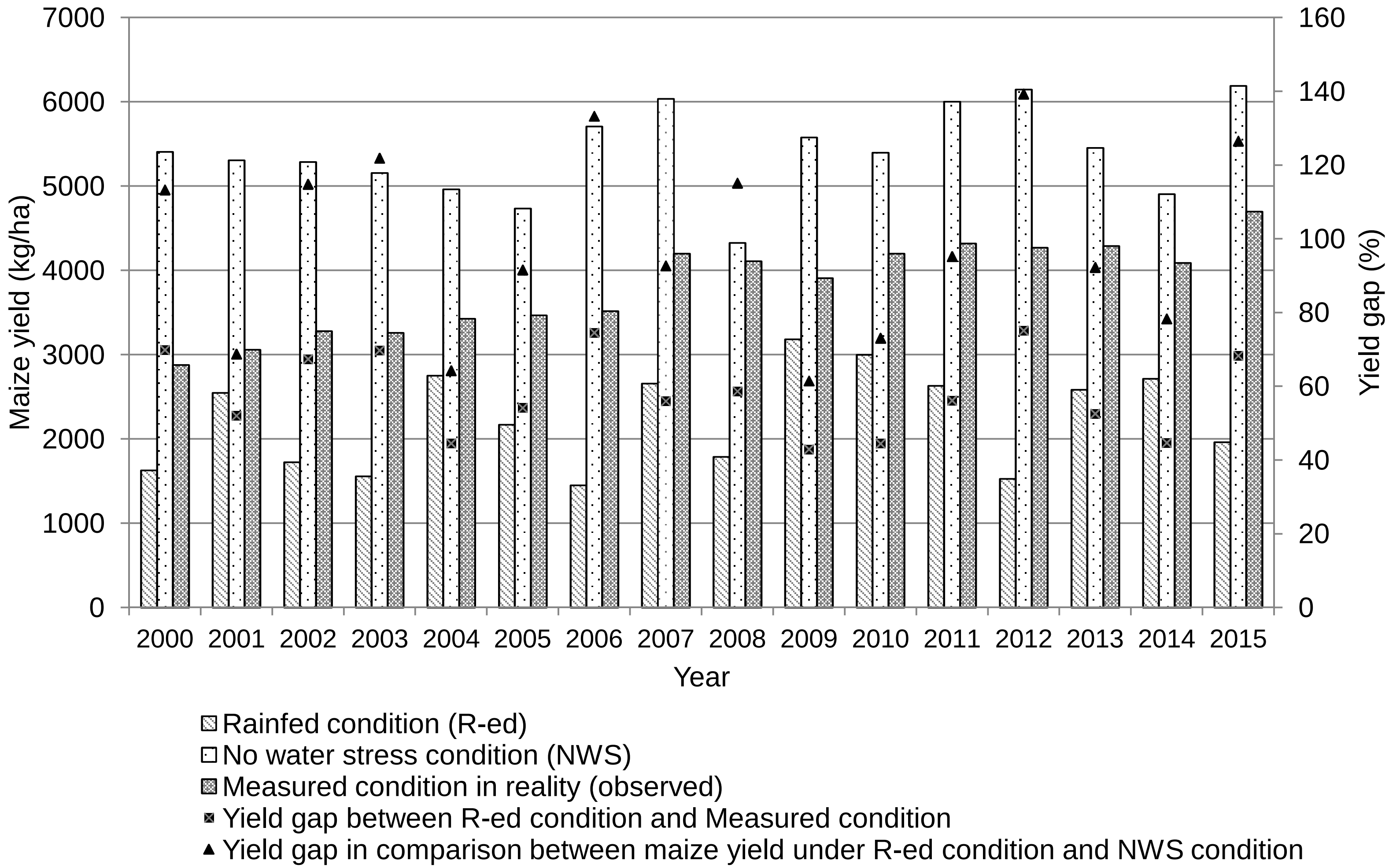

Precipitation (mm)
year
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
The total number of days have no rainfall from February to May
The total amount of precipitation from February to May
Linear (The total number of days have no rainfall from February to May)


Observed grain yield (kg/ha)
Total annual rainfall (mm)
1200
1400
1600
1800
2000
2200
2400
2600
4400
4200
4000
3800
3600
3400
3200
3000
2800
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 5.0942E6
Pearson's r --
Adj. R-Square -0.45953
Value Standard Error
B Intercept 2022.01333 155.75017
Slope 1 --


Observed grain yield (kg/ha)
Total solar radiation (hours)
1200
1300
1400
1500
1600
1700
4400
4200
4000
3800
3600
3400
3200
3000
2800
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 4.33886E6
Pearson's r --
Adj. R-Square -0.24312
Value Standard Error
B Intercept 2423.2 143.74018
Slope 1 --

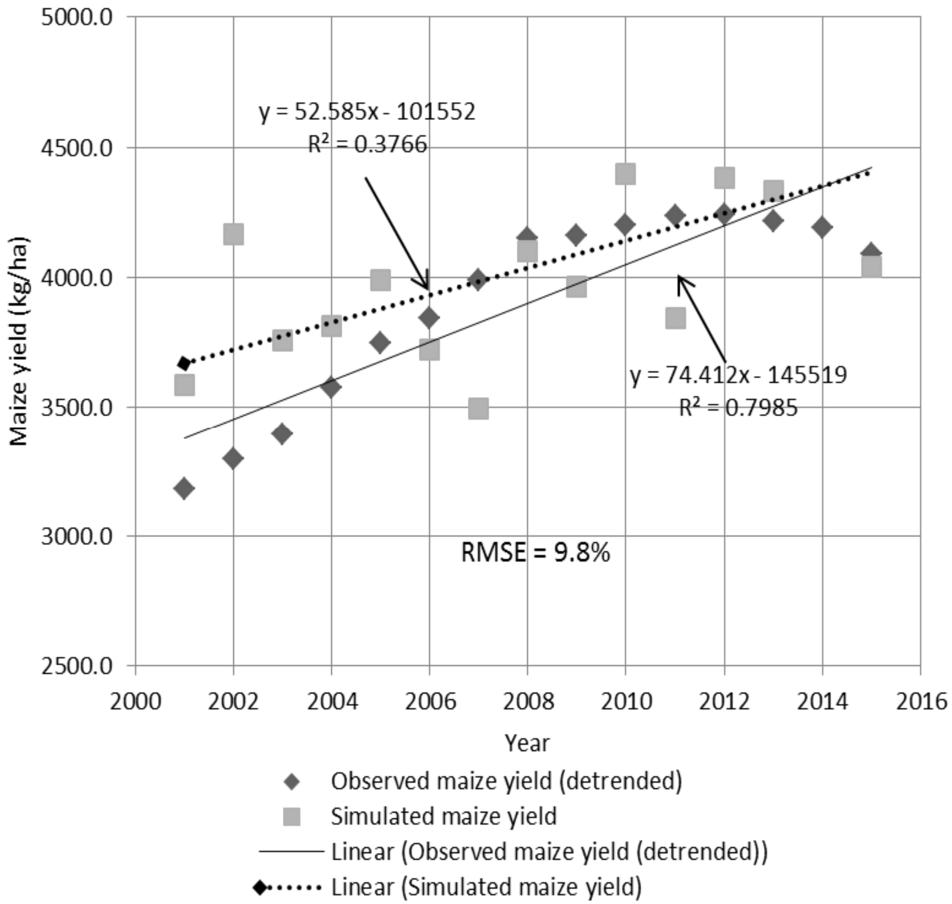

Averaged annual humidity (%)
79
80
81
82
83
4400
4200
4000
3800
3600
3400
3200
3000
2800
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 3.49583E6
Pearson's r --
Adj. R-Square -0.00159
Value Standard Error
B Intercept 3671.4 129.02255
Slope 1 --


Total annual temperature (Celsius degree)
272
274
276
278
280
282
284
286
288
290
292
4400
4200
4000
3800
3600
3400
3200
3000
2800
Equation y = a + b*x
Weight No Weighting
Residual Sum of Squares 3.50446E6
Pearson's r --
Adj. R-Square -0.00406
Value Standard Error
B Intercept 3468.13333 129.18158
Slope 1 --


7000
6000
5000
4000
3000
2000
1000
0
Maize yield (kg/ha)
160
140
120
100
80
60
40
20
0
Yield gap (%)
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
Rainfed condition (R-ed)
No water stress condition (NWS)
Measured condition in reality (observed)
Yield gap between R-ed condition and Measured condition
Yield gap in comparison between maize yield under R-ed condition and NWS condition

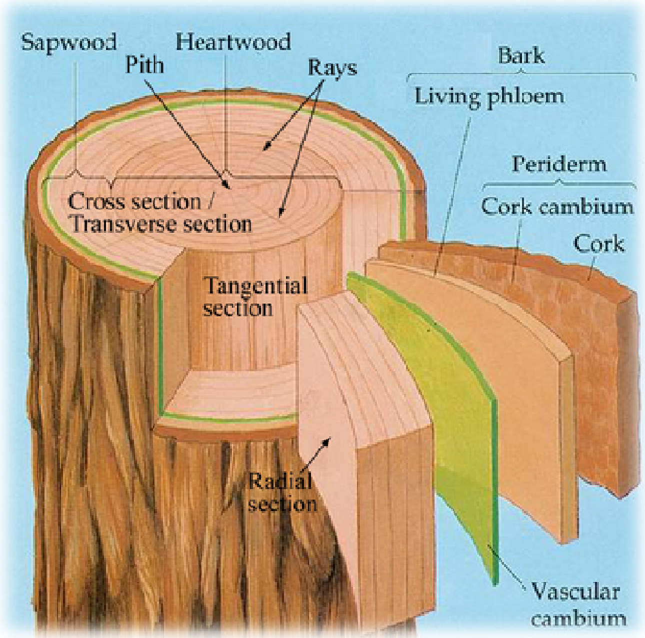
$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(o_i - s_i)^2}$$

(Anh, 2016)



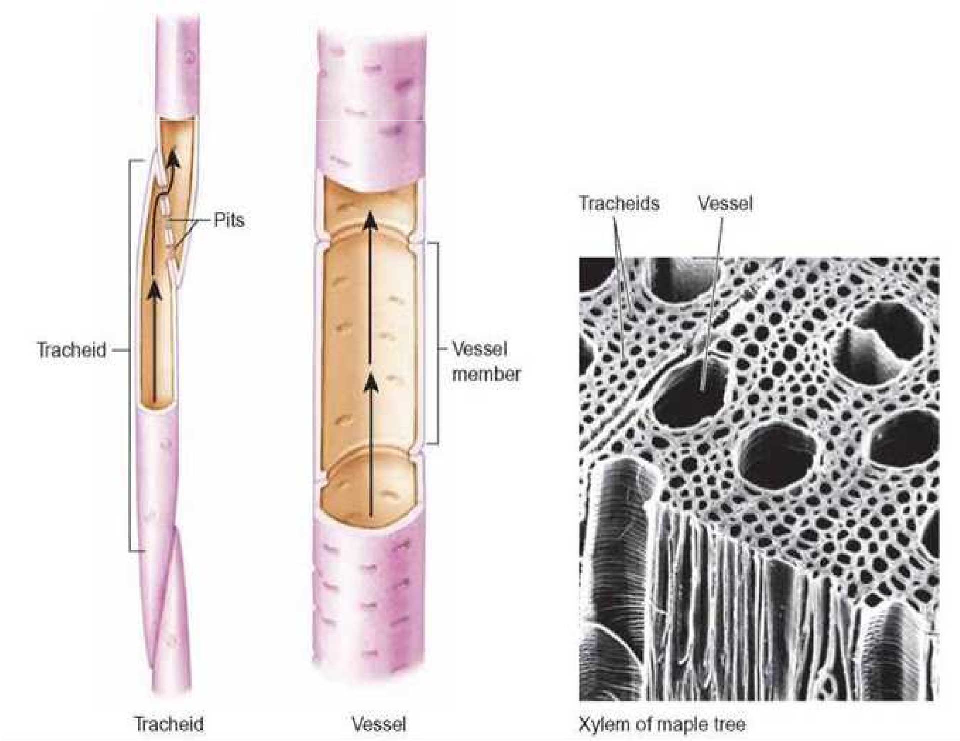
3. Climate impact on xylem tissue in woody plants

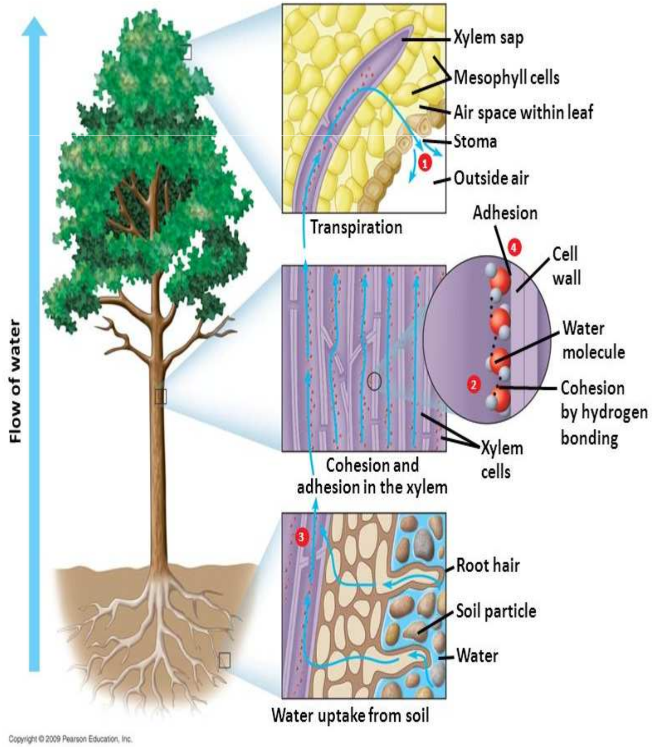
- The importance of wood as a renewable natural resource
- Cambial activity and formation of wood
- Dendrochronology and variability of tree-ring characteristics
- Plants' functional adaptations to climate change and cambium plasticity



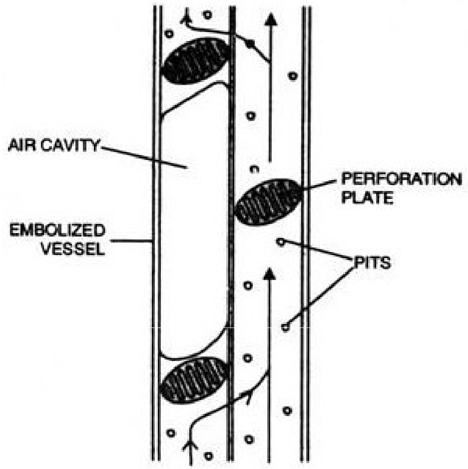
Xylem functioning and its significance for plants' survival

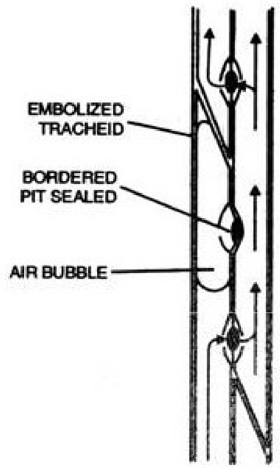
- Transport systems in plants: xylem and phloem tissues
- Continuous network of conduits: root-stem-leaf transport

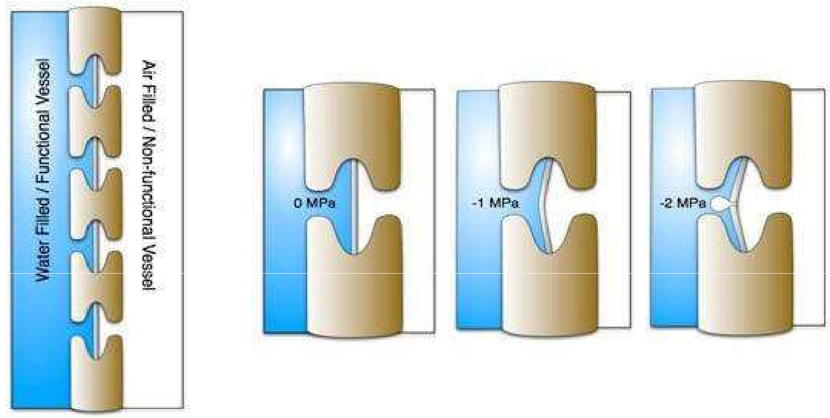


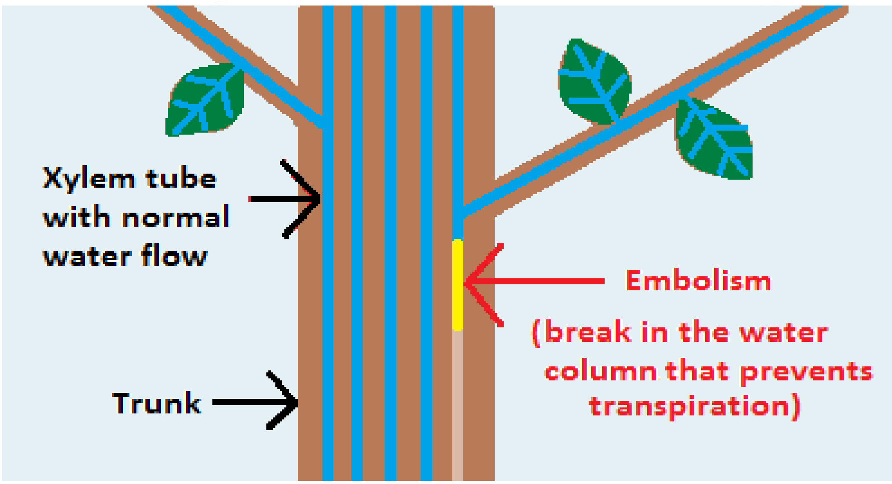


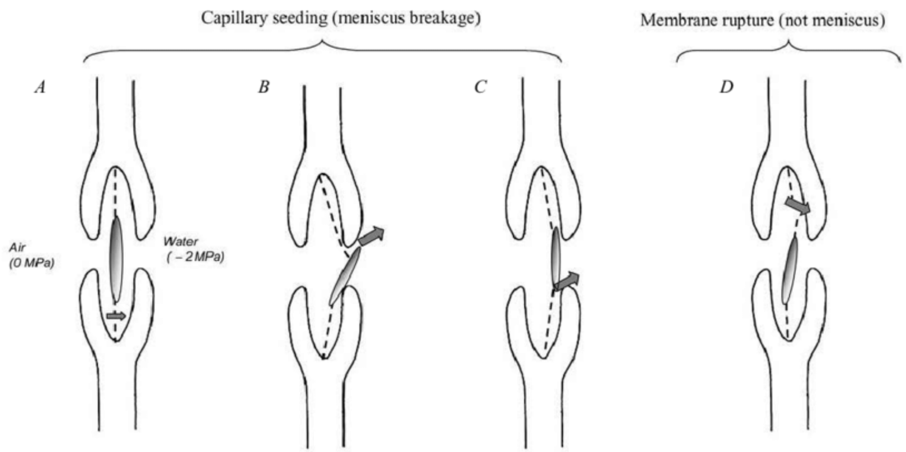
Constant environmental changes - cavitation and embolism occurence





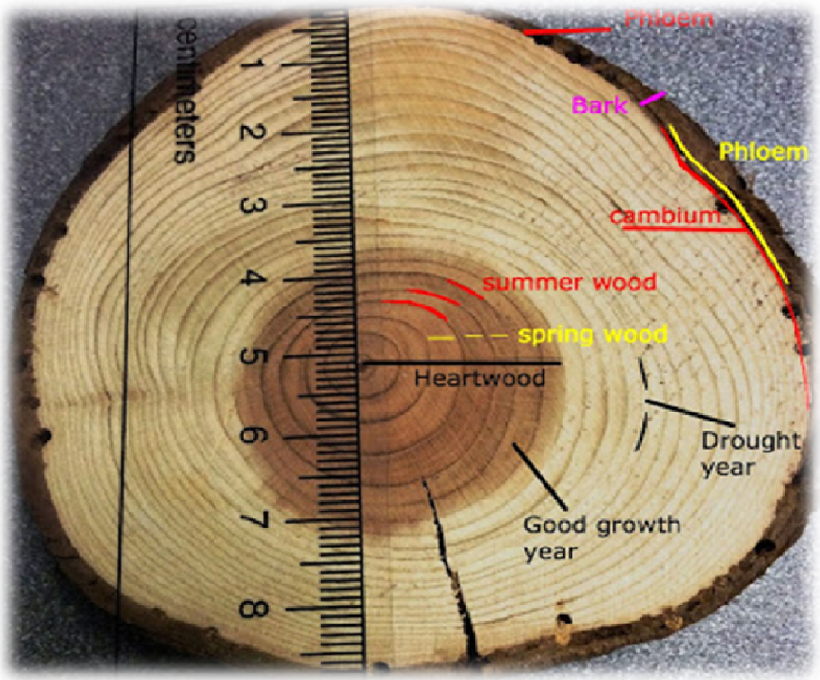


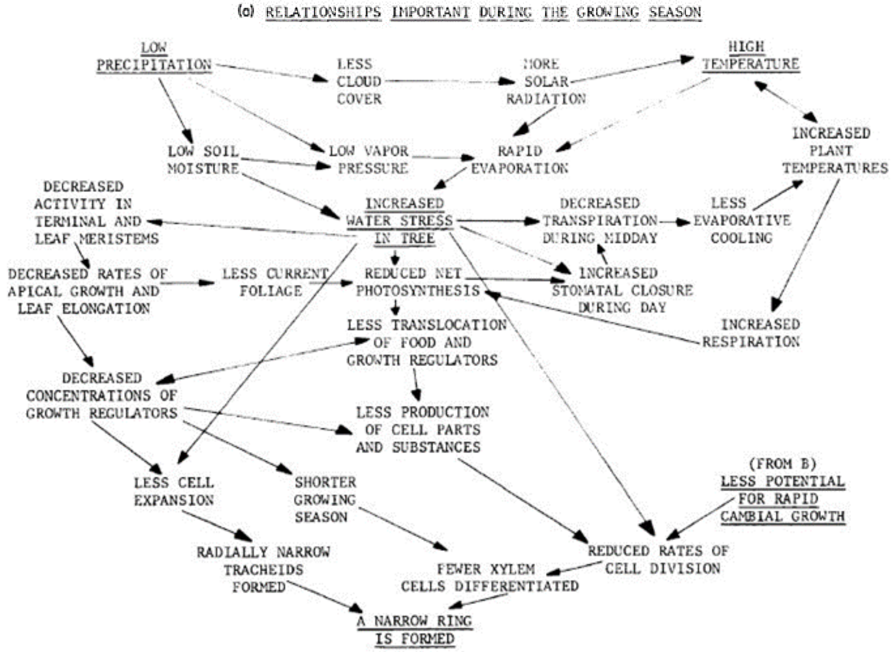




Linking xylem hydraulic properties to environment

- ❑ Tree-ring anatomy – definition and significance of this methodological approach
- ❑ Diagrams and models – simplification of hypothesized physical or physiological interrelationships

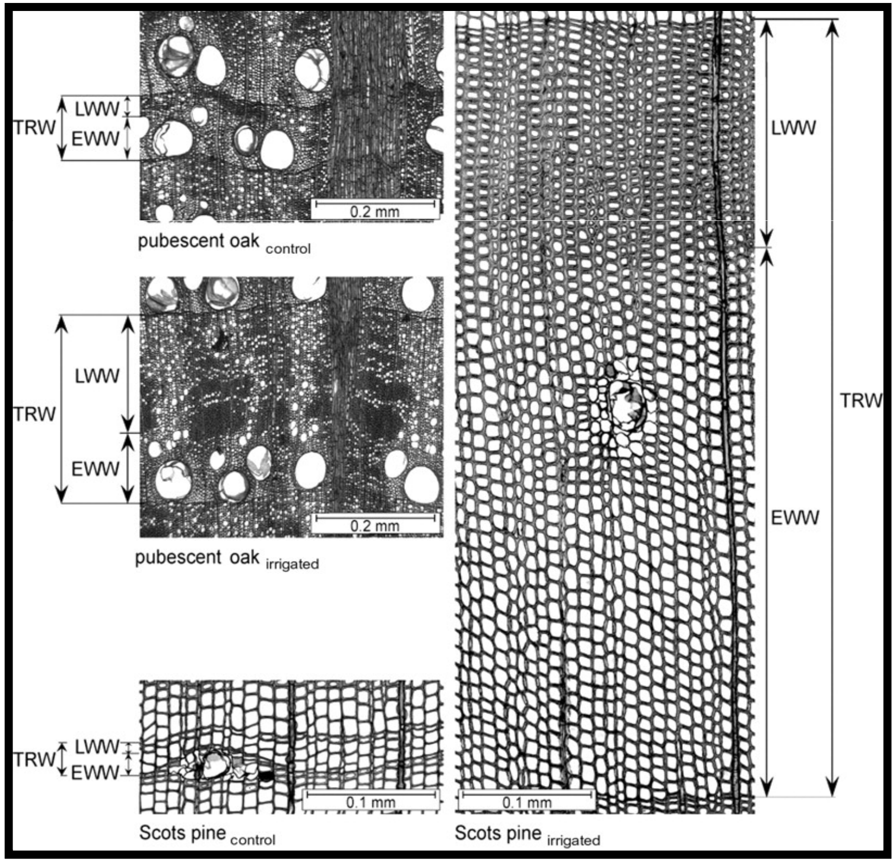


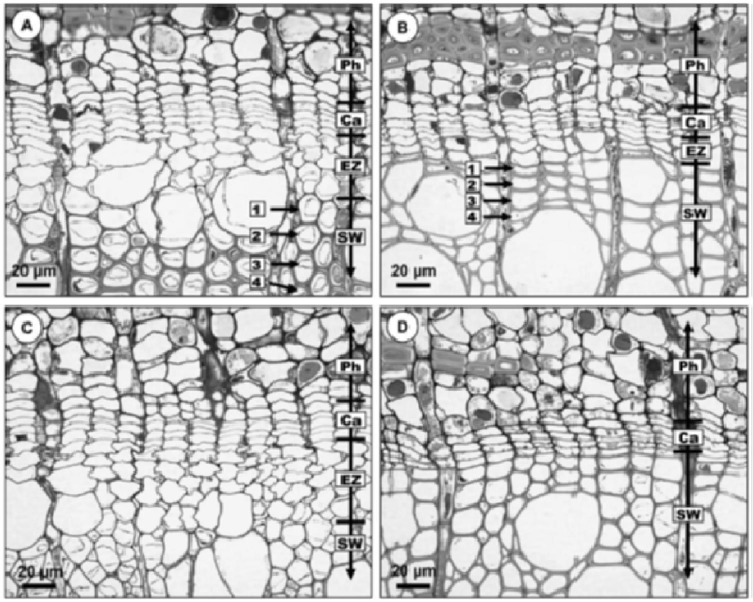


Serbia for Excell

- Wood-anatomical modifications can greatly differ depending on tree metabolism and species specific wood structure, as well as on the timing of the season when the particular environmental event occurs

- Modifications of xylem tissue, regarding cell size, number and shape
- Seasonal pattern of adaptations
- Species-specific responses to contrasting water supply
- Importance of previous growing season conditions
- Bimodal patterns of cambial activity and cell differentiation

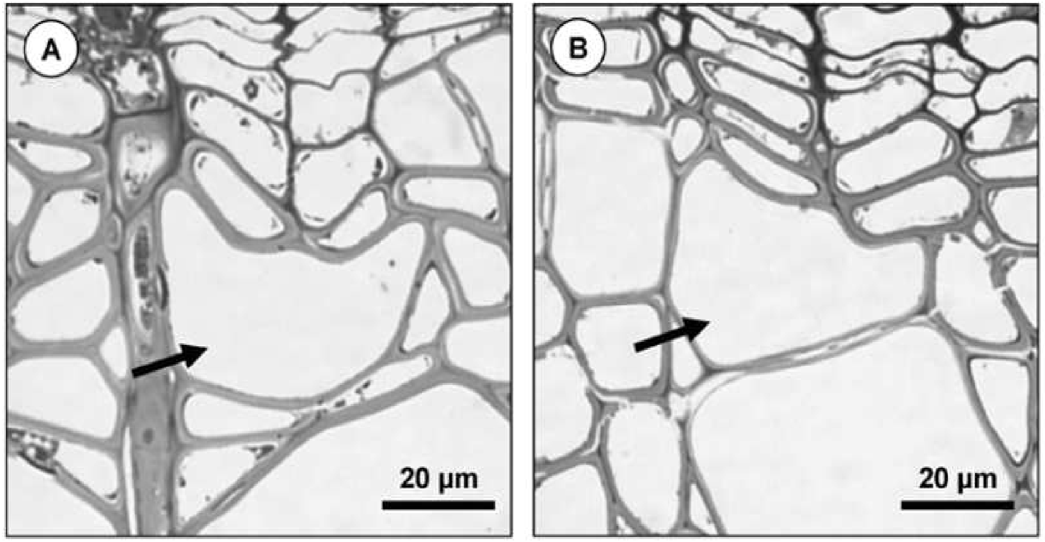




Photomicrographs of cross sections from well-watered control trees in early (A) and late (C) summer compared with those from drought-treated trees in early (B) and late (D) summer. Black lines show the size of the different zones of wood cell development in control and drought-treated trees. Numbered arrows in A and B give examples of newly formed fibers that define the xylem considered for anatomical analysis. Abbreviations: Ph, phloem; Ca, cambium; EZ, xylem cell expansion zone; and SW, secondary cell wall formation (from Arend and Fromm, 2007).

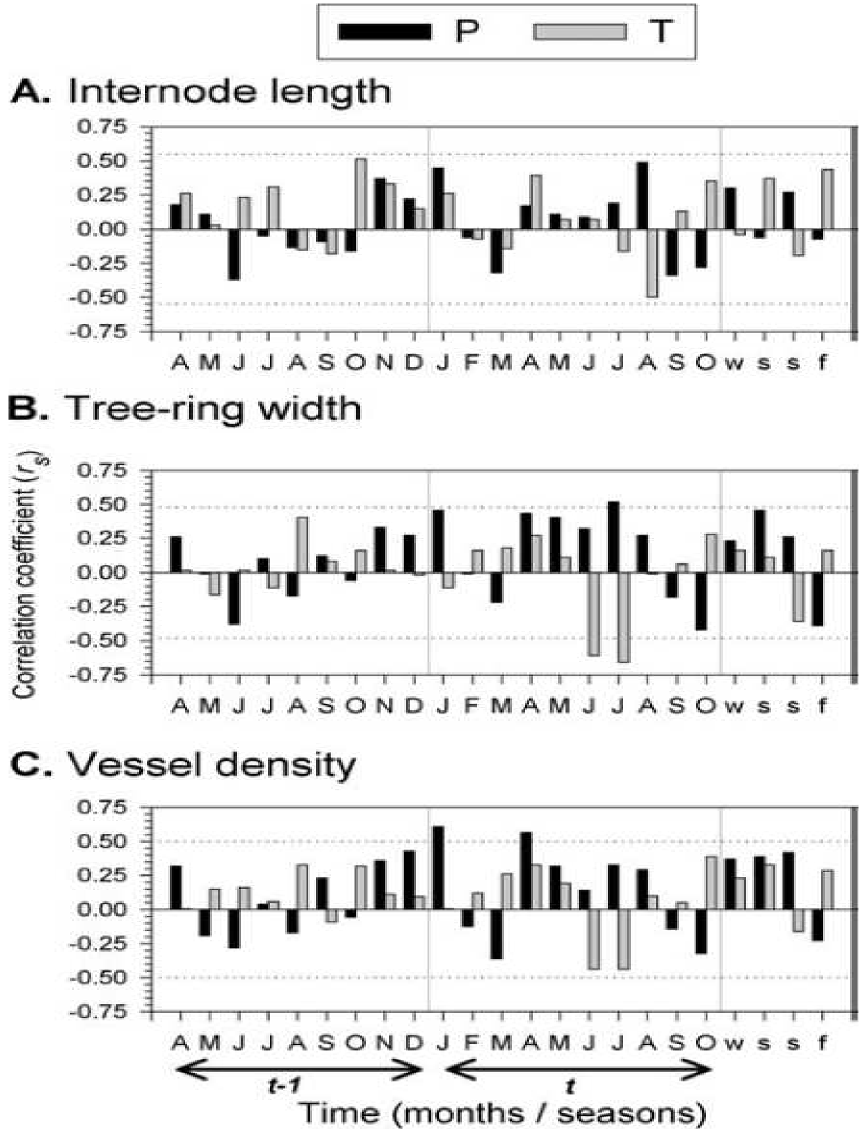
Deformed vessel elements (arrows) in the outermost xylem of drought-treated poplar trees in early (A) and late (B) summer (from Arend and Fromm, 2007).

(Below) Tree-ring width chronologies (n = 15) of control and (at least temporarily) irrigated oak and pine. Black, trees of the irrigation or irrigation stop site; grey, trees of the control site; and arrow, the year irrigation stopped (from Eilmann et al., 2009).



- Cavitation resistance in deciduous vs. evergreen angiosperms and conifers
- Influence of non-climatic factors on xylem attributes – competition, soil, individual tree features

Climate change impacts on plant's functioning will inevitably increase in future and vegetation's responses to drought and other environmental threats are the key factor that will determine plants' survival rate.



4. Managing nitrogen for sustainable development and its role in climate change

Temperature effects on Nitrogen Cycle

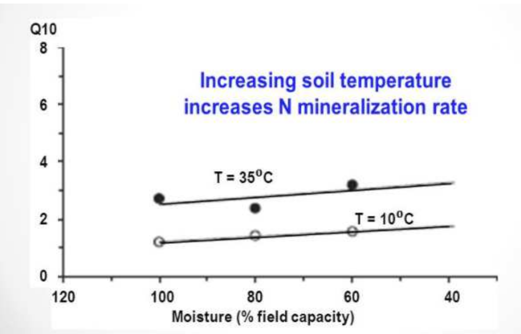
Decomposition of soil organic matter faster with high temperatures

VOLATILIZATION
warm soil with urea broadcast on the surface ideal for ammonia losses

MINERALIZATION
(microorganisms activity)

NITRIFICATION

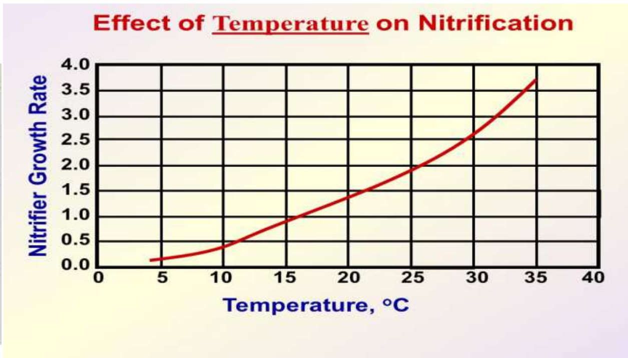
DENITRIFICATION



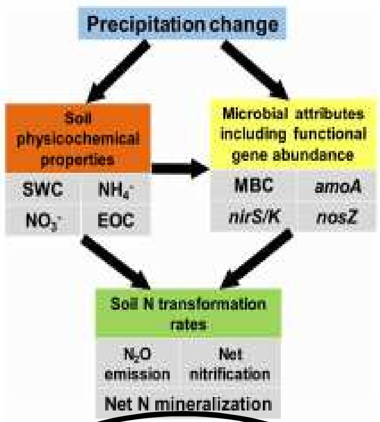
(Guntiñas et al., 2012. Eur. J. Soil Biol.)

Soil Temperature (F)	Days Saturated	Nitrate - N Loss (% of Total N Applied)
55-60	5	10
	10	25
75-80	3	60

Source: Shaver, T.M. and Ferguson, R.B. 2014. Nutrient management for agronomic crops in Nebraska.[3]



Precipitation effects on Nitrogen Cycle



precipitation increase = plant N uptake from the soil increase

soil dry = there is less plant transpiration that results in decreased N uptake

MINERALIZATION and NITRIFICATION

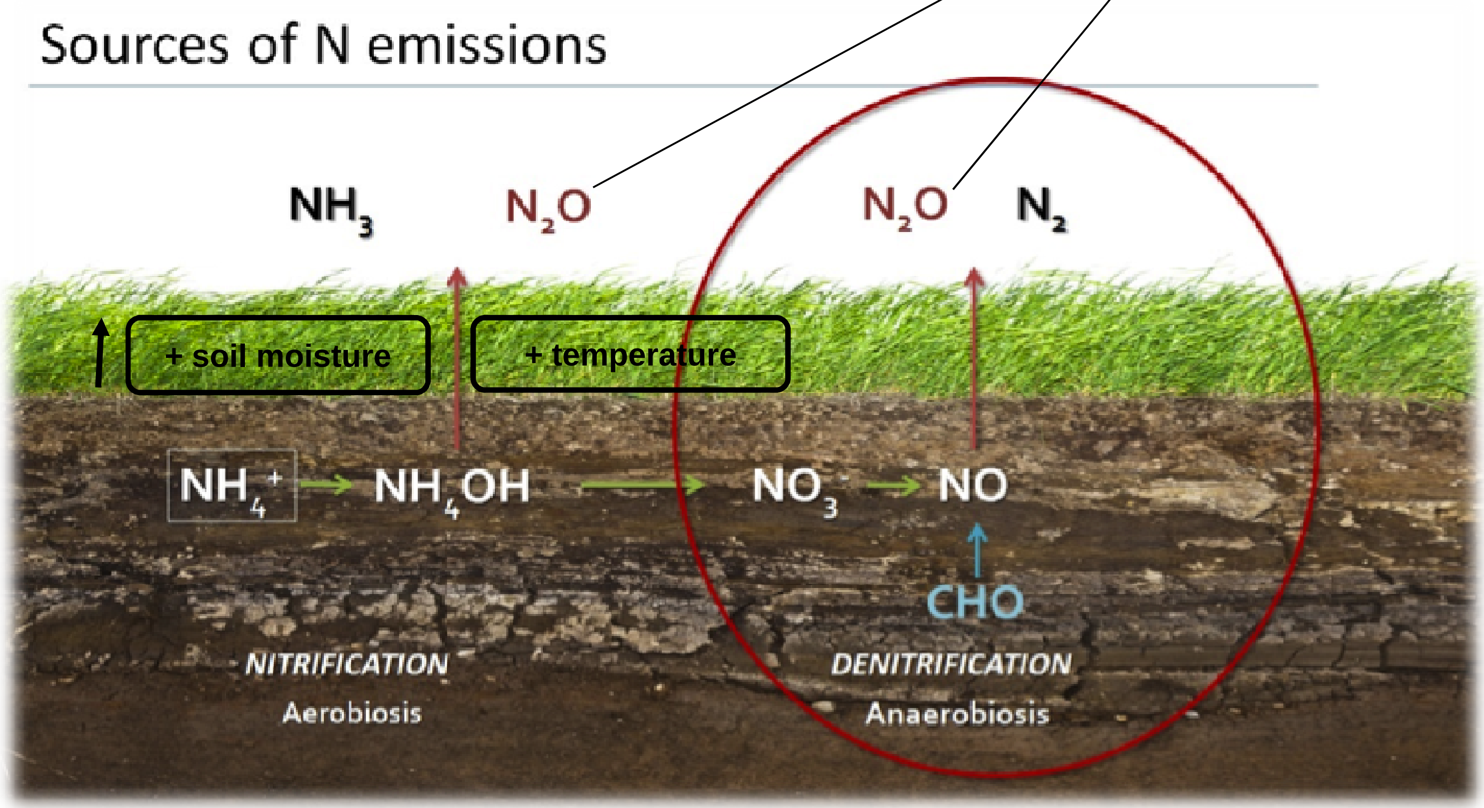
VOLATILIZATION

Conditions of no oxigen: **INCREASED DENITRIFICATION**

Effects of rainfall on N volatilization losses		
Rainfall	Within days after application	N volatilization losses
0.4	2	0
0.4	3	10
0.1 to 0.2	5	10 to 30
0	5	30+

Thermo-rainfall conditions: emission N_2O

N_2O: greenhouse gas with high radiative forcing per unit mass.
Agricultural soils are assessed to produce 2.8 (1.7–4.8) Tg N2O-N year−1



The problem of climate change: Nitrogen cycle

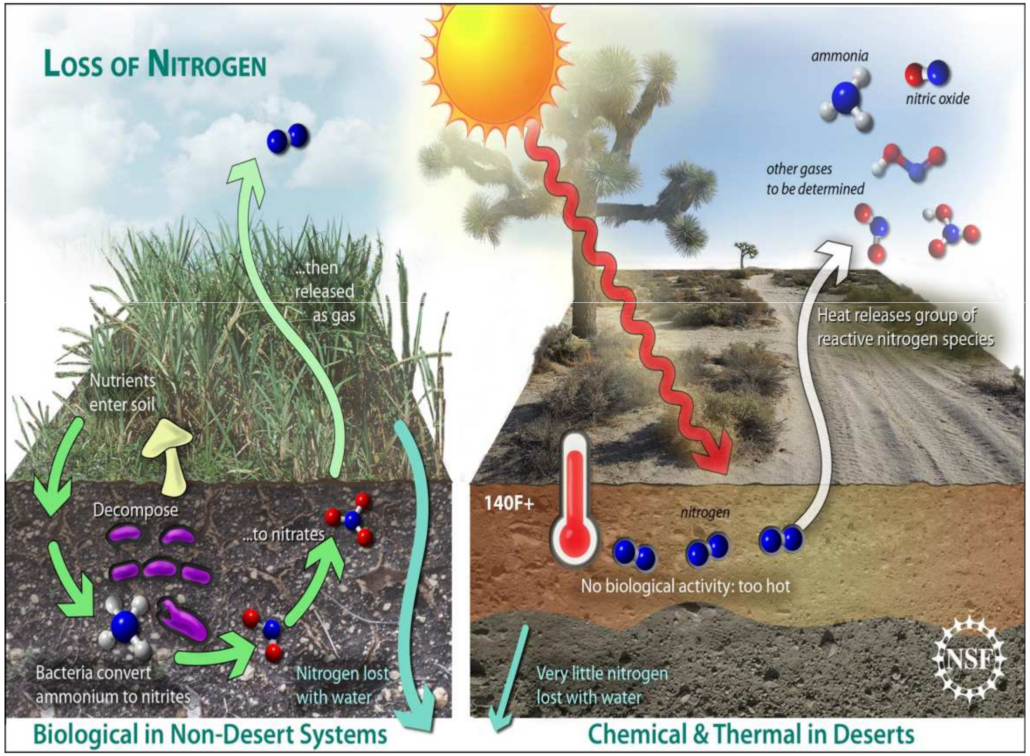
Increase global mean temperature: 1.5°C to 4°C

↓

Changes in the Nitrogen cycle

For example hottest and most humid conditions could:

- ❖ Increase nitrification
- ❖ Increase denitrification rates
- ❖ Increase nitrogen release by mineralization
- ❖ Increase N2O production

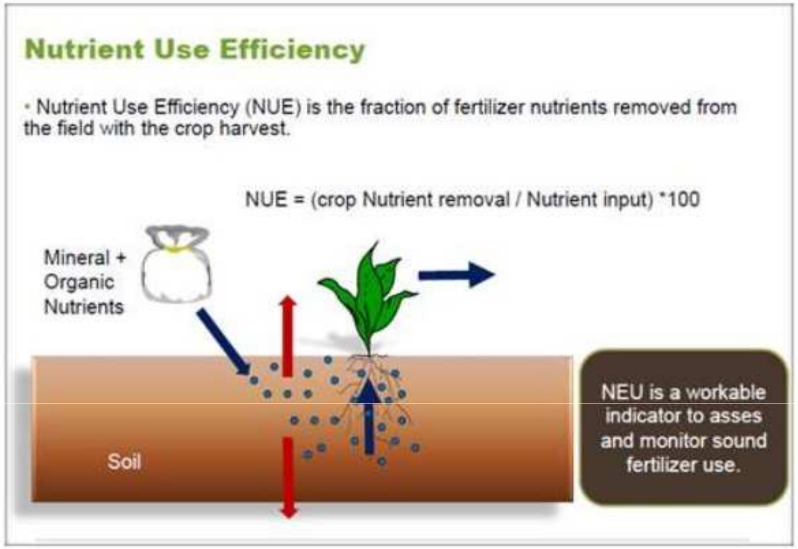


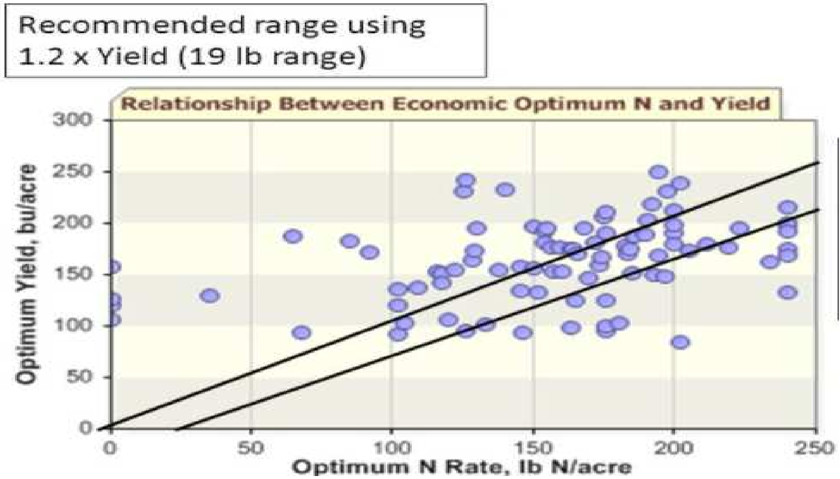
Mitigation strategies for climate change

NUE improved by:

- <u>Rotations with cover crops</u>: improved yield and crop quality,
 enhanced erosion protection, reduced runoff and pollutants
 in runoff, increased soil organic matter, incresed biological
 activity in the soil, reduced soil compaction.

- <u>Better Prediction of Crop Nitrogen and Water Requirements:</u>
 needs of the crops measured with a soil test approach or
 yield goal





Mitigation strategies for climate change

Precision Nitrogen management: the right
time and the right place

- Measuring the concentration of nitrogen in plant sap or plant tissue, or in a laboratory, or directly in the field using a test kit;
- Measuring the chlorophyll content in the leaves using a simple chlorophyll meter;
- Measuring the reflectance of crop foliage through remote sensing

5. Impact of the environment on uptake of micronutrients

Introduction

- Feeding the world's growing population in the present era of climate change is a serious challenge.

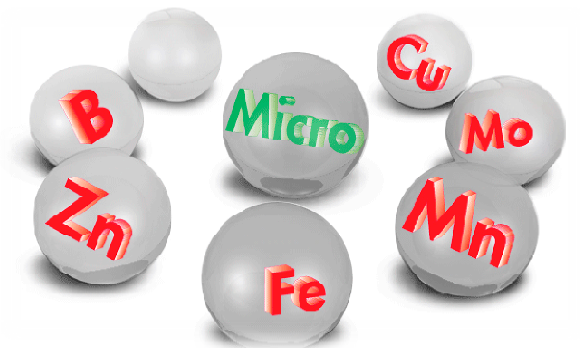
- Climate models predict that warmer temperatures and increases in the frequency and duration of drought during 21st century will have net negative effect on agricultural productivity. Scientific publications on the isolated effects of elevated CO_2 level, temperature rise and water supply, on crop growth and yield synthesis, biomass accumulation and crop yield are necessary to predict impacts of climate change on agriculture

- Elemental composition in plant tissue is expected to change in future high CO_2 world .

- Effects of climate change on soil fertility and the ability of crops to acquire and utilize soil nutrients is poorly understood, but it is essential for understanding the future of global agriculture.

Micronutrients in plants

	Function
Boron	• Carbohydrate synthesis & sugar transport in plants. • Cell wall formation
Chlorine	• Helps stomata opening • Helps plant growth & regulating water loss • Improve crop quality
Copper	• Important for carbohydrate & nitrogen metabolism, results in stunting growth of plants • Needed for cell wall strength
Iron	• Involved in production of chlorophyll • Component of enzymes • Lignin formation • Increases iron availability for plants
Manganese	• Important in photosynthesis • Nitrogen metabolism • Low manganese= delayed maturity
Molybdenum	• Nitrogen metabolism & protein synthesis & sulfur metabolism • Affects pollen formation positively • Seed treatment with molybdenum= economical
Zinc	• Important part for enzyme systems for energy production, protein synthesis & growth regulation • Helps with delayed maturity • Helps with decrease in leaf size



Drought effect on micronutrient acquisition

- Crop yields on soils in developing countries decrease exponentially with increasing aridity. Soil moisture deficit directly impacts crop productivity and also reduces yields through its influence on the availability and transport of soil micronutrients.

- Drought increases vulnerability to nutrient losses from root zone to erosion. Because nutrients are carried to the roots by water, soil moisture deficit decreases nutrient diffusion over short distances.

- Reduction of root growth and impairment of root function under drought thus reduces micronutrient acquisition capacity of root system.

- In wet soils. **Fe^{2+}/Fe^{3+}** ratio is higher, which results in greater Fe availability for plants. Under drought condition, the greater presence of O_2 in the soil induces a decrease in the Fe^{2+}/Fe^{3+} ratio, leading to a decrease in available Fe for plant absorption, since Fe^{2+} is more soluble then Fe^{3+} .

- The conversion of **Mn** to its reduced and more soluble forms is increased in moist soil conditions

Drought effects on micronutrient acquisition

- Mahonachi et al. (2006) found an increase of **Cl^-** concentration in leaves and roots of papaya after 34 days of water stress. Hence, together with organic solutes these ions contribute to osmotic adjustment in plants and therefore, under conditions of low supply, symptoms are visible mainly in aerial meristems, young leaves and reproductive organs.

- **Cu** critical free concentration in the media ranges from 10-14 M to 10-16 M. Below this range Cu deficiency occurs.

- According to Reddy (2006) **B** deficiency is mainly seen in soils with high pH and under drought conditions.

- The lower diffusion of **Zn** in dry soil restricts uptake of Zn and may exacerbate Zn deficiency.

- Higher **Ni** mobility was also reported in the soils with lower humus content, lighter granulometric composition and higher moisture content.

Effect of intense precipitation on micronutrient acquisition

- Surface erosion during intense precipitation events is a significant source of soil nutrients loss in developing countries.

- Agricultural areas with poorly drained soils or that experience frequent and/or intense rainfall events can have waterlogged soils that become hypoxic.

- The change in soil redox status under low oxygen can lead to elemental toxicities of Mn, Fe, B, Ni, which reduces crop yields and the production of phytotoxic organic solutes that impair root growth and function.

- Hypoxia can also result in nutrient deficiency since the active transport of ions into root cells is driven by ATP synthetized through the oxygen dependent mitochondrial electron transport chain.

Effect of high temperature and elevated CO2 level on micronutrient aquisition

- If under dry conditions higher temperatures result in extreme vapor pressure deficits that trigger stomatal closure (reducing the water diffusion pathway in leaves), then nutrient acquisition driven by mass flow will decrease.

- Temperature driven soil moisture deficit slows nutrient acquisition as the diffusion pathway to roots becomes longer as ions travel around expanding soil air pockets.

- Projections to the end of this century suggest that atmospheric CO_2 will top 700 ppm or more, whereas global temperature will increase by 1.8–4.0 °C, depending on the greenhouse emission scenario.

- Crops sense and respond directly to rising CO_2 through photosynthesis and stomatal conductance.

- The net effects of climate change will be negative for agricultural production.

- Drought induced by higher temperatures and altered rainfall distribution would reduce nutrient acquisition.

- More intense precipitation events would reduce crop nutrition by causing short-term root hypoxia, and in the long term by accelerating soil erosion.

- Increased temperature and elevated CO_2 level will reduce soil fertility by increasing soil organic matter decomposition, and may have profound effects on crop nutrition by altering plant phenology.

General conclusion

- In previous sections, climate change impact on different aspects of crop production was described. The question which arises is how can crop productivity be increased while ensuring the sustainability of agriculture and the environment for future generations?
- Changes in environmental conditions may substantially alter N balance and cycling, which links geosphere, biosphere and atmosphere, thus producing considerable challenges in terms of nitrogen management.
- Additional studies that investigate plant hydraulics over space and time are greatly needed to assess the vulnerability of crops to climate change and possibilities to improve plant resilience.
- The results suggest that the indices will become even more valuable tool for researches to gain better understanding of global climate change effect on agriculture.
- Given the potential adverse impacts on agriculture that could bring about climate change, it is worthwhile to conduct more in-depth studies and analyses to gauge the extent of problems that agriculture may face in the future.