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**Impact of climate change on plant growth and  
nutrition**

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## **General introduction**

The increasing world population is putting stress on rising demands for crop production. By 2050, global agricultural production may need to be doubled to meet increasing demands (Tilman et al., 2011). For food security, several studies have recommended that increasing crop growth and yield rather than clearing more land for food production, is the most sustainable way (Rosenzweig and Perry, 1994). Climate projections have also continued to predict increasing atmospheric carbon dioxide (CO<sub>2</sub>) along with the changes in surface temperature and rainfall patterns (IPCC, 2013). The most prominent climatic change is an increase in temperature resulting from increase in levels of greenhouse gases, particularly CO<sub>2</sub>. Because of the changing temperature, CO<sub>2</sub> level and rainfall pattern, there is much concerns about future changes in our climate and their direct impact on agriculture. Worldwide agricultural production is governed by the combination of climate, soil properties, technology and farm management decision such as fertilizer applications. Uncertainties related to the representation of CO<sub>2</sub> and high temperature effects demonstrated that further research is needed to better understand effects of climate change on agricultural production and to devise targeted adaptation strategies. To accomplish this, different aspects of agricultural production, related to crop growth and nutrition need to be investigated. Very important aspects of plant production which may be affected by changing climate are i) mineral nutrition and acquisition of nutrients in plants which is directly related to managing N cycle in the environment and ii) plant growth and overall vegetation cover. In addition, measurements of different spectral vegetation indices are useful and promising tools for monitoring of climate impact on plants and prediction of their development. Remote sensing, including multispectral and multi-temporal observations, are conducted to monitor vegetation changes due to climatic or anthropogenic stress more and more successfully. Assessing how environmental changes affect the distribution and dynamics of vegetation is becoming increasingly important for scientists to enable better predictions of the effects of global warming. Moreover, plant hydraulic traits are important for understanding and forecasting climate change impacts on woody plants (Choat et al., 2012).

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

## 1.1. Objective

The goal of this SSG 2018 contribution is to outline important aspects, benefits, disadvantages and the practical applicability of spectral measurements and vegetation indices in plant production and climate change research. Moreover, spectral sensing platforms and a few selected vegetation indices are presented in greater detail.

## 1.2. Introduction

In the course of conducting “spectral measurements” the radiation reflected by a given vegetation cover is detected using various sensing systems, e.g. satellites as well as aerial and ground-based systems. This data is used to calculate algorithms called “vegetation indices” (VIs). Two exemplary vegetation indices are NDVI (Normalised Difference Vegetation Index) and NDRE (Normalised Difference Red Edge), which are discussed in greater detail in following chapters.

Spectral measurements and vegetation indices provide information on various plant properties of a given crop canopy, for instance plant growth, development, plant water status, salinity stress and plant nutrition (Tucker, 1979; Jackson, 1983). They are also utilised in the detection of weeds, diseases and pests (Hatfield and Pinter, 1993). Therefore, monitoring of various plant characteristics, that can be measured indirectly using spectral measurements and VIs, enables farmers to adapt their agricultural management strategies, e.g. fertilisation, irrigation and plant protection, accordingly. Another important application of spectral sensing is the prediction of crop yields (Pinter et al., 2003) at small or large scales.

In the context of climate change and agriculture, spectral measurements and VIs are used to detect effects of climate trends and extreme weather events on crop status and estimate the climate change impacts on yields. Moreover, the resource efficiency of agricultural production systems concerning water, fertiliser and energy in general can be estimated (Schepers and Francis, 1998) in order to develop adaptation options.

## 1.3. Spectral measurements

As already mentioned, “spectral measurements” are defined as measurements of radiation at certain wavelengths reflected by a vegetation cover. Here, various different aspects

concerning the topics “general information on radiation” and “spectral characteristics of plant canopy” are discussed.

#### 1.3.1. General information on radiation

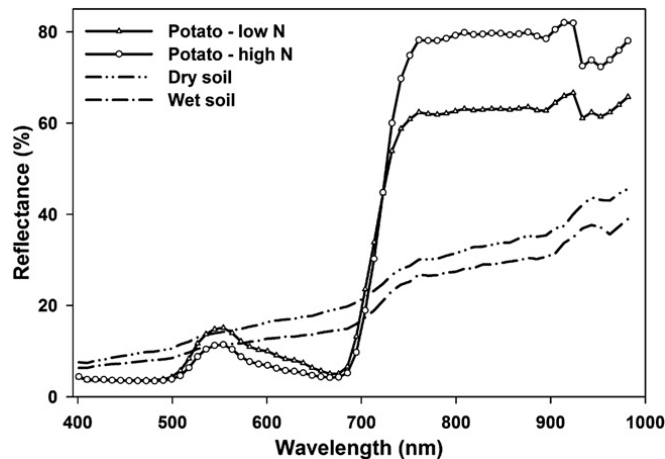
The electromagnetic spectrum of the sun can be divided into several wavelengths, spectral ranges or bands: UV (300-400 nm), visible (400-700 nm), near infrared (700-3000 nm), middle infrared (3000 – 6000 nm), thermal infrared (6000 – 20000 nm) and far infrared (20000 – 100000 nm) radiation.

When light reaches an object, radiation can be absorbed, transmitted and/or reflected. The reflected part of radiation can be measured via spectral measurements. The usual unit for measuring reflectance is “% reflectance”, also called “albedo”. This is defined as the actual radiation reflected by the surface divided by the radiation incident on the target.

Important reflectance factors are, for example, chemical and physical surface characteristics of plants, the wavelength of radiation, the angle of incidence and the number of cavities. Solar radiation also interacts with the atmosphere. Particles or large gas molecules cause scattering of radiation. For example, water vapor strongly influences the incoming solar spectrum especially at the wavelengths 1400 to 1900 nm. Carbon dioxide absorbs radiation in the thermal range at wavelengths of 2000 to 2200 nm. This leads to thermal heating of the atmosphere, which is an important factor concerning the ‘greenhouse’ effect. Ozone in the stratosphere absorbs harmful UV radiation. Clouds represent a high spatially and temporally variable amount of atmospheric condensed water vapor (fog) and lead to an increasing proportion of diffuse light. Interaction of radiation with vegetation depends on the canopy structure, e.g. the shape, area, angle and number of leaves, as well as the optical properties of leaves and other vegetative or non-vegetative components within and below the canopy, for instance the soil (Mulla, 2013).

#### 1.3.2. Spectral characteristics of plant canopy

Figure 1 shows the distinct pattern of spectral measurement curves of green plants.



**Figure 1.** Distinct spectral reflectance curve of green plant canopy and soil

The reflectance curves for dry and wet soils as well as for potato canopy with low and high rates of N fertiliser application are shown.

Source: (Mulla, 2013)

Various plant properties have an impact on the spectral reflectance of plants at certain spectral bands, e.g. the plant N nutrition. At wavelengths lower than 700 nm, reflectance is mainly determined by the absorption of light by chlorophyll for photosynthesis. Chlorophyll shows the highest absorptions of radiation at the wavelengths of blue light (~ 450 nm) and red light (~ 650 nm). Green light (~ 550 nm) is not used for photosynthetic activity. Therefore, less green light is absorbed by plants, leading to an increase in reflected green light and the generally visible green colour of photosynthetic active plant surfaces (Pinter et al., 2003).

Radiation of wavelengths above 700 nm (infrared spectral range) is noticed for photosynthesis. Therefore, plants absorb drastically decreasing amounts of radiation at higher wavelengths. This leads to an extreme increase in reflectance as well as transmission (“red shadow” below canopies) at spectral bands above 700 nm. The reflectance of a canopy cover at these wavelengths is determined by e.g. the number of cells, the cell structure characteristics, leaf density and canopy structure effects. A higher reflectance of radiation at wavelengths above 700 nm occurs, when for instance the quantity of plant cells increases (Sripada et al., 2006).

#### 1.4. Platforms for conducting spectral measurements

The general advantage of using spectral measurements and vegetation indices for various agricultural applications is the non-destructive, remote way of collecting information on different plant properties. However, the different platforms, e.g. proximal-, aerial- and satellite-based sensing systems, also feature their individual benefits and disadvantages

(Pinter et al., 2003). The main differences between the various platforms relate to their altitude, the spatial resolution and the return frequency of measurements. Moreover, the spectral resolution varies between the different spectrometers available. The spatial resolution describes the area, that is detected by an individual pixel. The spectral resolution defines the wavelength bands, that can be detected by a given spectrometer. The return frequency refers to the time, that passes between two consecutive spectral measurements (Mulla, 2013).

The mentioned factors can lead to different limitations. The spectral resolution of spectrometers can restrict the number of different vegetation indices, that are applicable. This is caused by the necessary reflectance values at specific wavelengths needed for the calculation of specific vegetation indices. Poor spatial resolution limits the use of vegetation indices for various site-specific applications, since the heterogeneity of soil and plant characteristics increases with larger pixels. The ideal spectral and spatial resolution of collected data differs between the specific applications (Mulla, 2013).

#### 1.4.1. Satellites

Satellites are equipped with spectrometers, among other instruments. These devices are used to measure the solar radiation reflected by the earth's surface. An important aspect of spectral data collected using this platform is the return frequency. It describes the number of days necessary for a given satellite to orbit the earth once in between two consecutive spectral measurements of a specific location (Mulla, 2013). For example, the satellite Landsat 1, launched in 1972, can detect the reflectance at green, red and two infrared wavelength bands at a spatial resolution of 56 x 79 m every 18 days.

The factors spectral and spatial resolution as well as return frequency are especially important for satellites. For instance, the exchange of a satellite's spectrometer is not possible, which limits the adjustment of spectral resolution. The extreme altitude of spectral measurements from satellites leads to the highest demands on spatial resolution among all sensing systems. Therefore, restrictions concerning the use of this spectral data for site-specific applications can occur (Mulla, 2013). Moreover, the combination of poor return frequencies and cloudy conditions can lead to long periods of time without any useable spectral measurements. (Moran et al., 1997).

Current technological developments show improvements concerning the aspects spectral and spatial resolution as well as return frequency (Mulla, 2013). Therefore, the applicability of spectral data from satellites for agricultural practice increases. Potential uses are, for instance,



the estimation of crop biomass and yields as well as the optimisation of fertiliser application, irrigation scheduling and plant protection measures.

#### 1.4.2. Aerial systems

Airplanes and Unmanned Aerial Systems (UAS), or simply drones, represent the transition platform for spectral measurements between satellite and proximal sensing with medium altitude and high spatial resolution.

The potential of this systems lies in the introduction of relatively low-cost methods for spectral sensing (Colomina and Molina, 2014) and the use of high spatial and spectral resolution aerial systems for real time site-specific agricultural management decision making (Mulla, 2013).

Similar to satellite systems, spectral measurements using the aerial platform are affected by cloud cover (Moran et al., 1997) as reflectance measurements are normally calibrated to the spectral characteristics of sunlight rather than to diffuse light conditions.

#### 1.4.3. Proximal systems (tractors, handhelds)

Proximal sensing is the use of handheld spectrometers or devices attached to e.g. tractors for conducting spectral measurements. This platform is the solution to the major drawbacks of satellite-based systems, since proximal sensing allows the of collection data and adaption of agricultural management strategies in real time and on a site-specific level (Mulla, 2013).

Proximal spectrometers can be divided into two groups, active and passive sensors. Active spectrometers feature their own source of light. Passive devices rely on solar radiation. The advantage of active spectrometers is the ability to conduct spectral measurements independently from solar radiation. However, the presence of sunlight can lead to unwanted distortions in collected data using active sensors, since the initial lighting conditions based on the device's light source are altered by sunlight. Passive spectrometers usually detect the reflected solar radiation from a given target and divide it by the energy of reflected solar radiation incident.

When spectral measurements are conducted using passive spectrometers, many factors need to be addressed. For example, the device's angle of view as well as the distance between the instrument and the vegetation cover define the area of measurement. Moreover, passive spectrometers depend on the incident solar radiation, as already mentioned. This is detected by measuring the reflected radiation of a diffuse white panel, which reflects nearly 100 % of sunlight.

The measured signal using a passive spectrometer can be divided into different sub-signals, which need to be accounted for. These are the true signal, the dark current, the stray light and random noise. The dark current is a systematic noise from the device's electronics. Stray light is a constant systematic noise from diffraction and internal scattering (ASD, 1999).

The potential of ground based spectral sensing for farm applications lies in the on-the-go monitoring of plant properties, e.g. N nutrition or water stress (Mulla, 2013) steering in real time fertilising or irrigation equipment.

## 1.5. Selected vegetation indices

### 1.5.1. NDVI

The vegetation index NDVI (Normalised Difference Vegetation Index) is defined as the reflectance ratio at near infrared bands ( $\sim 790$  nm) and red wavelengths ( $\sim 670$  nm) (Rouse et al., 1974). This VI is especially useful for assessing the Leaf Area Index (LAI, the green leaf area per unit ground area). It needs to be mentioned, that the LAI shows a distinct canopy and crop type related correlation to plant biomass. Therefore, calculation of NDVI using large-scale spectral data from satellites or aerial systems is frequently used to assess crop biomass (Yang et al., 2000) and potential crop yield (Doraiswamy et al., 2003) on a regional level.

There are two major limitations of NDVI. On the one hand, soil reflectance at low canopy densities affects the results of this vegetation index. On the other hand, leaf chlorophyll content changes in mature plants and high LAI values cannot be detected using NDVI (Thenkabail et al., 2000). The reason for this is that radiation at red wavelengths is absorbed by chlorophyll. Therefore, the top layer of a photosynthetically active plant canopy quickly absorbs most of the light at  $\sim 670$  nm (Pinter et al., 2003).

### 1.5.2. NDRE

The vegetation index NDRE (Normalised Difference Red Edge) is defined as the reflectance ratio at near infrared bands ( $\sim 790$  nm) and red edge wavelengths ( $\sim 720$  nm) (Barnes et al. 2000).

As already mentioned, radiation at wavelengths above 700 nm are not used for photosynthesis. Therefore, light at red edge bands ( $\sim 720$  nm) is absorbed much less by plants. Therefore, reflected radiation at these spectral bands provides more useful information on canopy cover, when a high number of leaf layers is present, compared to e.g. light at red wavelengths. As a result, the potential of NDRE lies in its sensitivity to high levels of chlorophyll content (MicaSense, s.a.). It is also a measure of the chlorophyll activity and can

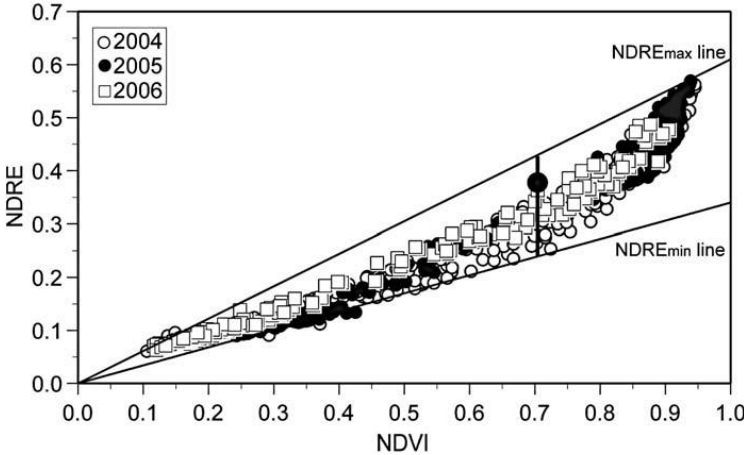
detect changes, thus identifying periods where crops are under stress, e.g. nutrient deficiencies, or damaged by various factors, such as pests or drought.

1.5.3. CCCI (Fitzgerald et al., 2010)

The CCCI (Canopy Chlorophyll Content Index) is based on NDVI and NDRE. NDRE is used to measure the N nutrition of plants. NDVI is involved to compensate for soil cover. CCCI is calculated using the following formula:

$$CCCI = \frac{NDRE - NDRE_{min}}{NDRE_{max} - NDRE_{min}}$$

Here,  $NDRE_{min}$  and  $NDRE_{max}$  are the maximum and minimum limits of NDRE at given NDVI values, which are based on (calibrated by) experimentally collected (ground truth) data. Figure 2 displays the relationship between NDVI and NDRE used to derive the  $NDRE_{min}$  and  $NDRE_{max}$  limits for the calculation of CCCI.



**Figure 2.** Relationship between NDVI and NDRE (from Fitzgerald et al., 2010)  
 It needs to be noted, that this relationship is specific to wheat.

The goal of CCCI is to separate the soil signal from the plant signal by compensating for soil cover via NDVI to allow relative measurements of plant N nutrition, that are independent from soil cover, and if no other stresses occur at the same time.

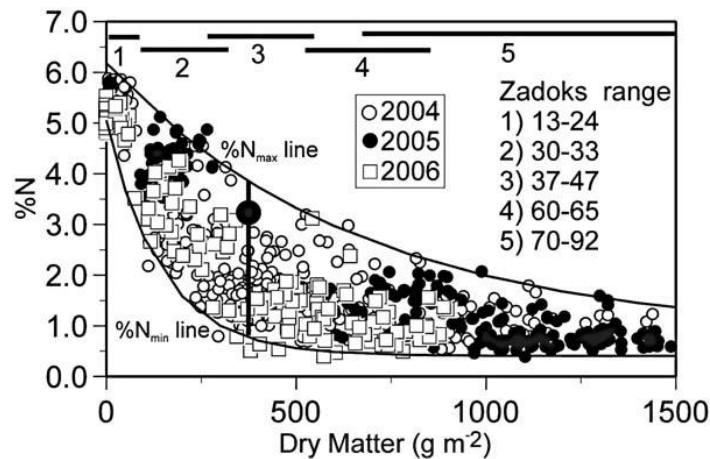
1.6. Current work concerning spectral measurements and vegetation indices at the University of Natural Resources and Life Sciences Vienna (BOKU)

Fitzgerald et al. (2010) demonstrates the application of CCCI in combination with CNI (Canopy Nitrogen Index) to estimate plant N nutrition. CNI quantifies canopy N. It is calculated using the following formula:

$$CNI = \frac{\%N - \%N_{min}}{\%N_{max} - \%N_{min}}$$

Here,  $\%N_{min}$  and  $\%N_{max}$  are the maximum and minimum limits of plant nitrogen concentration at given dry mass values, which are based on experimentally collected data.

Figure 3 displays the relationship between dry mass and plant N concentration used to derive the  $\%N_{min}$  and  $\%N_{max}$  limits for the calculation of CNI.

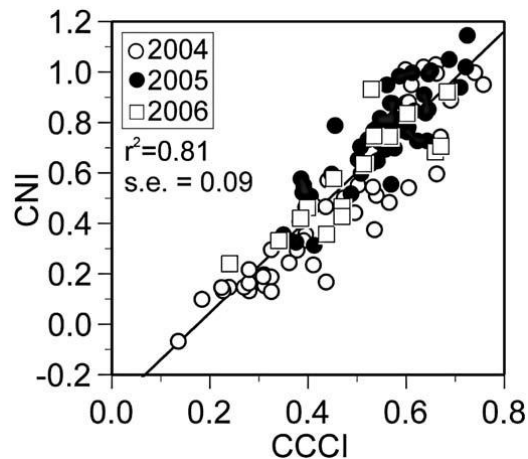


**Figure 3.** Relationship between dry mass and N concentration (from Fitzgerald et al., 2010)

It needs to be noted, that this relationship is specific to wheat. Zadoks range represent crop phenology phases.

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Moreover, CCCI and CNI show a linear relationship. This is shown in Figure 4 for wheat.



**Figure 4.** Relationship between CCCI and CNI in wheat (from Fitzgerald et al., 2010)

It needs to be noted, that this relationship is specific to wheat.

Therefore, CCCI can be used to assess the N nutrition of plants. The necessary inputs to do so are spectral measurements at the wavelengths needed for calculation of NDVI and NDRE, measured/estimated dry mass and the crop specific coefficients for  $\%N_{\min}/\%N_{\max}$ ,  $NDRE_{\min}/NDRE_{\max}$  and CNI.

Our goal at the University of Natural Resources and Life Sciences Vienna (BOKU) is to estimate the plant N status via CCCI and CNI by calculating the necessary dry mass input values using crop models for various crops, e.g. wheat, maize, potato and sugar beet.

#### 1.7. Spectral measurements and vegetation indices used in climate change research

Climate change results in average change of climate parameters, e.g. increase in average temperature over the years, changes in precipitation or change in frequency and severity of extreme climate events, e.g. droughts and floods. They influence crop production and natural ecosystems in different ways (Tan et al., 2015). Therefore, it is important to gather knowledge on the typical responses of plants to the various effects of climate change and their impacts on crops productivity (Seneviratne et al., 2012). This can be done by 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, to monitor the climate change effects on various vegetation properties (Zhang et al., 2014). Possible plant properties, that are measured indirectly using spectral measurements and can be used in this context, are for example vegetation coverage (Piao et al., 2011), plant growth (changes in vegetation cover in the course of a season) crop phenology (Zhang et al., 2014) and, especially at regional level, final crop biomass and yields.

Additionally, spectral measurements and vegetation indices can be used to improve the resource use efficiency of agricultural production systems concerning the application of chemical substances for plant protection, water, fertiliser and energy in general. This will contribute to develop tailored mitigation and adaptation options in agriculture and to reduce agricultural emissions in general.

In agricultural practice, the information on various plant properties provided by spectral sensing is used by farmers for optimisation purposes concerning many aspects of their agricultural management strategies, e.g. fertilisation, irrigation and plant protection measures. An example is the prediction of the current N nutrition of certain crops using vegetation indices to improve the N use efficiency. The farmer then adapts the application of N fertiliser according to the collected information. This leads to individually optimised fertilisation management strategies, the reduction of expensive N surpluses and the prevention of N losses, that would otherwise cause environmental pollution.

#### 1.8. Challenges and opportunities for application of spectral measurements and vegetation indices in crop production

The potential sources of errors in current spectral measurements are numerous, since the results are influenced by many factors. Examples are the variability of incoming solar radiation, soil conditions, crop management, plant development and various abiotic (heat, drought, frost, etc.) and biotic stresses (weeds, diseases and pests) that influence the spectra of crop canopies. In addition, cultivar and site-specific calibrations are necessary for many agricultural applications of spectral measurements and vegetation indices. Moreover, currently only few farmers have access and are trained to use spectral data of crops on a regular basis (Pinter et al., 2013). A general problem of strongly technology based smart precision farming methods is the exclusion of poor farmers and farmers in developing countries due to still relatively high costs or investments (Mulla, 2013). However, also low-input farming systems, which comprise the largest food production share globally, can benefit from precision farming technologies.

In general, spectral measurements and vegetation indices will influence farming in the future, especially if reliable results independent from mentioned sources of errors at high spatial and timely resolution can be provided. Moreover, a reduction in costs will help the dissemination of these techniques among farmers (Moran et al., 2003).

Also, the approach of combining spectral sensing with improved forecasting methods and modelling of agroecosystems, such as crop models, has potential to improve the power of predictions and the agricultural applicability in crop production.

The goal is to develop consistent products for farmers, that deliver valuable and useful information on plant properties and allows them to adapt their strategies for agricultural production depending on their current site-specific conditions (Pinter et al., 2013).

## **2. Climate change and crop growth**

### 2.1. Introduction

Climate is one of the environmental factors which have been strongly influenced by human beings for centuries. Climate adversely impact on human being in various ways. The influence of climate is more and more notably nowadays because of its changing and its variability. Worldwide, the common change of climate can be easily seen is the higher temperature in the atmosphere. Global warming is commonly known as the main consequence of climate change. Global warming refers to the gradual increase, observed or projected, in global surface temperature, as one of the consequences of radiative forcing caused by anthropogenic emission (IPCC, 2007). There are various reasons leading to climate change. Among them, organic carbon particles are considered as one of main reasons (Steffen et al., 2015).

Lots of evidences of climate change and its impacts on natural systems have being proved in the reports of the intergovernmental Panel on Climate Change (IPCC). IPCC was established in 1988 under the chairmanship of Prof. Bert Bolin (Houghton et al., 1995). Since the first assessment report was completed in August 1990, the proofs of climate change has been more clearly in the other continuous IPCC reports (Houghton et al. 1995; Metz and Davidson 2007; Stocker et al., 2013) which are used widely for policymakers, scientists and other experts by hundreds of specialists all over the world. There was an increase of temperature and precipitation in Columbia Plateau by the mid-21<sup>st</sup> century (Sharratt et al., 2015). Climate change causes more frequent droughts in summer, as well as flash-flooding, leading to uncontrolled discharges from urban areas to receiving water courses and estuaries (Whitehead et al., 2009). Climate change is projected to increase soil erosion as well as soil loss because of wind (Sharratt et al., 2015). Besides, climate change leads to a maximum monthly stream-flow while decreasing organic nitrogen (El-Khoury et al., 2015), has an inverse impact on

fresh water (Bates et al., 2008) and leads to the sea ice melting in high latitudes which is considered specifically as the consequence of higher temperature (Steffen et al., 2015).

Moreover, extreme events such as droughts, floods, heat waves and fires have been increasing in many regions. Globally, extreme weather events are expected to increase worldwide (Powell and Reinhard, 2015). El Niño is arguably the most well-known climate phenomenon worldwide because of the local and regional weather events that are often associated with this climate anomaly. For example, El Niño is frequently linked to monsoon failures in India, drought in Indonesia, flooding rains in the southwestern United States, and warmer- and drier-than-normal weather in Australia. Indeed, during the most recent 26 El Niño events, 17 have brought widespread drought to Australia (Johansson et al., 2015).

## 2.2. Climate change and maize growth

Global production of annual crops will be affected by the increases in mean temperatures of 2–4°C expected towards the end of the 21st century (Wheeler et al., 2000). Over the last three decades, annual GHG emissions have increased by an average of 1.6 % per year and are expected to increase in coming decades due to demands on food and shifts of diet (IPCC, 2007), CH<sub>4</sub> and N<sub>2</sub>O emissions have increased by nearly 17% from 1990-2005. N<sub>2</sub>O are projected to increase 35-60% up to 2030 contributed by larger herds of beef cattle, increasing of fertilizer application (IPCC, 2007).

Evidences exist that climate change will shift the mean and variance of crop yields, challenging the stationarity assumption (McCarl et al., 2008).

For many regions, climate change may have some positive effects, frost frequency and cold waves will be reduced and food production are potentially improved (IPCC, 2001). The high concentration of carbon dioxide has a positive effect. Mina et al. carried out a study in 2017 and found that elevated CO<sub>2</sub> has a ameliorative interaction with maize growth showing via crop Health Index (CHI) (Mina et al., 2017). The whole plant biomass was increased by the high temperature. However, the response varied among plant parts (Suwa et al., 2010). In mountainous areas, an appropriate sowing date could improve the maize yield up to 300%. In these regions, the warmer condition for maize growing is more suitable than normal conditions. But generally, climate change will markedly reinforce the trend towards to more extremely negative influence on agriculture (Muldowney et al., 2013).

Temperature is a primary factor affecting plant growth. The major impact of warmer temperatures was during the reproductive stage of development (Hat and Prueger, 2015). Excessive temperature which is too low or too high, both bring negative effect on maize



growth. Heat stress would occur in any stage of maize growth. Over 50% yield loss is considered as the consequence of extending heat stress leading to a significant damage on maize in the period of kernel setting (Liu et al., 2018).

In cool-temperate climates, potential maize grain yields are variable and often small. Low temperature prolongs growth duration, reduces crop growth rate, and increases the risk of frost terminating grain filling prematurely. On the other hand, low temperature prolongs growth duration, reduces crop growth rate, and increases the risk of frost terminating grain filling prematurely (Wilson et al., 1995). In cool-temperate climates, potential maize grain yields are variable and often small. Low temperature prolongs growth duration, reduces crop growth rate, and increases the risk of frost terminating grain filling prematurely (Wilson et al., 1995).

Likewise, warmer temperature either influences significantly critical episodes such as pollination period of maize growth (Wheeler et al., 2000), or during silking episodes which are both considered as having an inordinately significant effect on maize grain yield (Suwa et al., 2010), decreases the grain potentials or shorten the maturity days. The grain yield is therefore reduced as a consequence of those negative effects from hot temperature (Wheeler et al., 2000), for example, heat stress at early grain formation stage severely affects the physicochemical properties of starch (Lu et al., 2016). In term of grain yield, maize grain yield was significantly decreased in comparison with derived yield from a normal temperature regime under warmer regimes in the case study by Hat and Prueger (2015). Similarly, a study in France also indicated a decline in maize yield and production during the 2003 heat wave and associated drought, partly minimized by irrigation. National 2003 maize yield loss equalled  $\sim 1.5 \text{ t ha}^{-1}$  compared to the 2000–2006 average (van der Velde et al., 2010). In addition, maize production in Sub-Sahara Africa is also figured out as the most vulnerable crop because of more intense and frequent droughts with high parallel possibilities of ramifications by another study (Epule et al., 2017). Therefore, heat stress is the main reason leading to maize yield reduction by a negative influence on pollen variability and kernel number afterwards.

The influence of high temperature will become more extremely when it accompanies by low amount of rainfall. This condition leads to the deficiency of water in the soil if it happens in long term of a seasonal crop. In the central of Vietnam, maize yield got a decrease in drought season which led farmer had to change the land use system to other crops such as peanut, cassava or green bean (Uy et al., 2015). In the North China Plain, the weather data over the past six decades showed an increase of temperature while solar radiation and precipitation had

the decreasing trend. These conditions led the maize yield having some negative influence. As a result, the climate changes declined the maize yield (Shim et al., 2017), particularly in the field of short growing cultivar and the long growing cultivar was better to adapt under climate change conditions, notably in case of high growing density, 97500 plant ha<sup>-1</sup> (Huang et al., 2018). Another study in Dutch investigated that the number of days with extreme high temperatures has significantly increased since the early 1900s, while the number of extreme low temperature events has fallen over that same period. The effects of high temperature events and precipitation events were found to significantly decrease wheat yields (Powell and Reinhard, 2015).

However, in some regions, heat stress does not affect silking stage, at least in the range of temperature up to 42.9 °C on the field and 52.5 °C in the greenhouse (Lizaso et al., 2018) or have no effects on the silking-anthesis interval (Shim et al., 2017). Warmer temperature is considered as the consequence of climate change and has some potential effects to plant growth. Warm temperatures increased the rate of phenological development and have no effect on leaf area or vegetative biomass compared to normal temperatures (Hat and Prueger, 2015). Another positive impact on agriculture such was found in the study case in southwestern Ontario, Canada. An increase of temperature and precipitation varieties led to a decrease of mean yield and increased its variance over a period of 26 years. However, average crop yield will increase with warmer temperatures and a longer growing season (Cabas et al., 2010). On the other hand, under an increasing air temperature, maize yield in South Africa is increased when increase production inputs such as labor, seed, fertilizer, especially irrigation which is considered as the most important driver of maize yields, shown by a reduction of maize yield of 4% if the mean of irrigation is reduced 10% (Akpaluet al., 2003).

### 2.3. Water stress and the influence of EL NIÑO

Regarding to impact of extreme weather on agriculture, in Australia, scientists use El Niño analyses as the tools to predict crop production because crop yield variation is proportional with precipitation and temperature deviation. For instance, during the 2002 and 2006 growing seasons, El Niño-related droughts plagued portions of the Australian wheat belt, slashing national wheat production by nearly 50% relative to the previous year. However, not all El Niño events lead to notable precipitation and temperature anomalies on local and regional levels. In 1997, despite one of the strongest El Niño events on record, near-normal rainfall in southeastern Australia favored winter wheat development, leading to a relatively good yielding crop compared with historical production (Johansson et al., 2015). Agriculture in

North America, Central America, and the Caribbean has been impacted by number of natural disasters related to climate in recent decades. The episodic events are expected to increase with climate change, requiring farmers active to prevent their livelihoods from climate risks to agriculture (Shannon and Motha, 2015).

In conclusion, water shortage has been a challenge to sustainability of maize production in many irrigated agriculture regions. Adoption of drought-tolerant (DT) hybrids could be a management strategy for maize production under water-limited conditions. The results of this study demonstrated that effective use of soil water during grain filling is important for maintaining high yield under water limited conditions (Zhao et al., 2018). In South Africa, maize yield is increased when the maize yield reduces 4% if the mean of irrigation is reduced 10% (Akpalu et al., 2003). Supplementary irrigation through rainwater harvesting was found to be a more promising option for maize growers to mitigate dry spell and stabilize maize production in rainfall deficient agro-ecological conditions not only in Rwanda, but in sub-Saharan Africa (Uwizeyimana et al., 2018).

#### 2.4. Adaptation to climate change

In the IPCC third assessment report (IPCC, 2001) defined adaptation as adjustment in natural or human system in response to actual or expected climatic stimuli or their effect, which moderates harm or exploits beneficial opportunities.

To combat climate change, irrigation is considered as a strategic adaptation to mitigate the impact of climate change in Switzerland combined with some simple adaptation options such as shifts in sowing dates (Finger et al., 2011). In most countries in the south of Europe, irrigation is responsible for over 60 per cent of the total number of water use, while in northern Members it ranges from zero to over 30% (Brouwer et al., 2000). Irrigation is even more important under climate change perspective, especially in South Asia (Döll, 2002; Bates et al., 2008). Multi-cropping is considered as the adaptation option to cope the warming which need to be applied by farmers (Döll, 2002). Drip-irrigation was found as the adaptation solution for enhance maize yield in a sub-humid region, China. Maize yield could increase at least 14% through drip-irrigation systems in Heilongjiang Province in comparison to rainfed conditions (Liu et al., 2018). The adaptation option would be more efficient if combined with shifting the sowing date. Earlier sowing dates are also considerable to get higher yields by rising the length of growing season, especially in cold mountainous regions, as the results from a case study in southwestern US (Myoung et al., 2015). Besides, increase production inputs such as labor, seed, fertilizer, especially irrigation which is considered as the most

important driver of maize yields (Akpalu et al., 2003). However, there is a big gap between the poor and rich societies and households. The wealthier societies would more capable to adapt to a changing climate because of their ability in term of farming investment while poor societies will face difficulties in agricultural production such as technologies, financial instruments (Burke and Lobell, 2010). Conservation agriculture enhances the adaptive capacity of maize production in sub-Saharan Africa under drought and/or heat stress. However, in very wet seasons and on clay-rich soils, conservation agriculture yields less compared to conventional practices (Steward et al., 2018). Land use change contributed to reduce the global annual temperature in range of 0.13-0.35°C (IPCC, 2007).

Genetic and agronomic strategies to adapt climate changes were proposed as one of efficient options. Cultivar with a long growing period has a larger potential to adapt changing climate. However, a long growing also has a disadvantage in term of improving yield because it is low tolerant of high growing density. In order to solve the conflict between climate change adaptation and high plant density in maize, plant architecture in space and in time improvement is proposed as the effective option (Huang et al., 2018). In Vietnam, after five years conducting evaluations and risk assessments on genetically modified maize, scientists created successfully new genetics producing doubled yield compared to conventional hybrid varieties (Dang et al., 2002).

Besides, in order to reduce the impact of climate risks, local farmers in North America, Central America, and the Caribbean put efforts on various strategies such as farming in multiple locations, diversifying crops and varieties, seeking alter-native sources of income, and purchasing crop insurance. Such efforts often help farmers maintain a more stable income while also protecting and preserving the productivity of the land. However, some of them have failed to implement basic risk management strategies despite the clear benefits. Reasons for these failures can be attributed to inadequate farmer education and training, a lack of tools to help facilitate the practical application of risk management concepts, and poor communications between the agrometeorological and farming communities (Shannon and Motha, 2015). Abraha and Gårn (2016) investigated asubstantial potential for mitigating these effects of climate change and possibly even increased output through conventional technologies such as flexible planting and rainwater harvesting (Abraha and Gårn, 2016). Under projected climate, in South America, heat-tolerant varieties could minimize yield loss (relative to current maize varieties) by up to 36 and 93% in 2030 and 33 and 86% in 2050 under rainfed and irrigated conditions, respectively. Heat-tolerant maize varieties, therefore,

have the potential to shield maize farmers from severe yield loss due to heat stress and help them adapt to climate change impacts (Tesfaye et al., 2016).

### **3. Climate impact on xylem tissue in woody plants**

#### 3.1. Introduction

The importance of wood as a renewable natural resource is indisputable (Funada et al., 2016; Begum et al., 2017). It is produced by the vascular cambium of tree stems which is defined as the actively dividing layer of cells that lies between, and gives rise to, the secondary xylem and phloem (Begum et al., 2017). The formation of wood and the anatomy of water conducting cells are decisive factors in plant performance which strongly affect tree survival rate due to the importance of water transport (de Luis et al., 2011; Bryukhanova and Fonti, 2013). Those conducting cells are coupled with the environment and their characteristics are naturally archived in the wood (Bryukhanova and Fonti, 2013). Cambial activity in trees is regulated both by internal factors (e.g. plant hormones) and by environmental factors (e.g. temperature, rainfall and photoperiod) (Begum et al., 2017). In well-adapted woody plants, the annual rhythm of cambial activity parallels or overlaps that of the climatic rhythm. This correlation is used as indicator of the origin of arborescent species (Waisel and Fahn, 1965). Plants from tropical areas usually exhibit active cambium throughout the year while cambial activity in plants from temperate regions, and from other climatic regions with an uninterrupted growth season, is delayed during the unfavourable season. The cambial rhythm in evergreens is preserved even when climatic conditions differ basically from those of their natural habitat, which indicates that the control of cambial activity in such trees and shrubs is endogenous (Fahn, 1959). Deciduous trees are distinguished by a rapid adaptation to new environmental conditions, e.g. upon transfer of northern species from the Northern to the Southern hemisphere (Waisel and Fahn, 1965).

Until recently, most of the information about radial growth of trees was obtained from dendrochronological studies, the discipline that can be defined as the systematic use of tree-ring “cross-dating” procedure (Fritts and Swetnam, 1989; de Luis et al., 2011). In this procedure variability of tree-ring characteristics is used to establish the exact year in which each ring was created. Fonti et al. (2010) have stated that long records of shifting environmental conditions are essential for evaluating climate change scenarios and the consequences for species and plant performance. Some authors have emphasized the importance of proxy data as a supplement to instrumental records in order to provide a

complete picture of dynamics in past climates. Hence, trees represent important natural archives which can be used for the study of global changes throughout the last millennium (Fonti et al., 2010). Although the tree-ring chronologies provide data on interannual to multi-centennial time scales, studies on wood formation and experiments in controlled environments are necessary to better understand impact of specific environmental variables on cell division in the cambium and cell differentiation that conjointly determine tree-ring characteristics (de Luis et al., 2011).

Climate and plants are closely linked, which result in various plants' functional adaptations and a large morphological and taxonomic diversity (Fonti and Jansen, 2012). Due to constant environmental changes, the hydraulic architecture of trees is being adjusted to fit different hydraulic requirements. The extraordinary plasticity of the cambium is considered as an effective way to ensure timely response to annual variation of climate conditions characteristic for particular habitat (Bryukhanova and Fonti, 2013).

### 3.2. Xylem functioning and its significance for plants' survival

Water is the most limiting abiotic (non-living) factor that affects plant growth and productivity and determines vegetation distributions worldwide (McElrone et al., 2013). Considering the fact that more than 90% of the water taken up by plants is lost by transpiration through the leaf, while CO<sub>2</sub> is absorbed simultaneously, the importance of water becomes evident (Kramer and Boyer, 1995). Hence, the developmental success and the competitiveness of trees depend greatly on their capability to adjust and optimize their hydraulic architecture to their specific environmental conditions (Fonti et al., 2010). Important functional trait represents water transport capacity through the xylem tissue, which further influences water use strategy of plant and net primary productivity in a given surrounding (Fonti and Jansen, 2012). Because of the role water transport plays in plant's functioning, variability in xylem anatomy is of interest to plant scientists (Fonti et al., 2010).

To transport water and sap, plants evolved two transport systems. One transport system distribute concentrated, sugar rich sap in the phloem from leaves to growing meristems. Phloem transport is a positive pressure system that uses a standing-gradient osmotic flow mechanism that occurs at very high pressures (up to 3 MPa). The other transport system moves water from the soil throughout the plant via the xylem tissue (Tyree and Sperry, 1989). The cohesion-tension mechanism of xylem water transport is a passive process and no direct metabolic input from the plant is needed (Hacke and Sperry, 2001). The main force for xylem water transport is generated by transpiration of water from the leaves, which creates a

negative vapour pressure in the cells that surround the stomata. This leads to a negative hydrostatic pressure in the conducting cells and the water is pulled through the continuous network of conduits (Fonti et al., 2010).

The structure of xylem is connected to their function in transporting water by bulk flow under negative pressure (Hacke and Sperry, 2001). In conifers, water flows from tracheid to tracheid, while in angiosperm trees, water is transported through longitudinally connected vessel elements that form pipes up to several metres in length (Fonti et al., 2010). Mature tracheids and vessel elements are dead cell wall structures. Conduit walls are lignified in order to withstand the compression caused by negative pressure. Their secondary role is to support the plant body in some plants – particularly in the case of conifer stem wood. All conduits are mutually linked and form complex continuum from the roots to the leaves. In this conduits' system water flows through pit connections which function as check valves, allowing water to pass between functional conduits, yet also preventing air from leaking inside the conduit system in the event of damage (Hacke and Sperry, 2001). The structure of xylem conduits are different from phloem conducting cells' structure. In order to maintain the osmotic gradient and to protect the system from leakage, phloem cells must remain alive, but the protoplast is otherwise as empty as possible to allow maximum hydraulic conductance through the cell. Phloem cell walls are thin and non-lignified which enables phloem to resist tensions caused by positive pressure. As in xylem, the connections between conduits function as check valves, they facilitate flow between conduits, yet protect against outward leakage upon damage (Münch, 1930; van Bel, 1999; Hacke and Sperry, 2001). Water in the xylem conduits exist under negative (sub-atmospheric) pressures, typically of 1 and -2 MPa, and sometimes as low as -10 Mpa, which means that water must remain liquid at pressures well below its vapor pressure. In this 'metastable' state, nucleation of vaporization, or cavitation, must be prevented, to maintain continuity of the water column in the xylem conduits. Result of cavitation is vapor-filled conduit that eventually fills with air. The air-filled conduit is embolized and such conduit is not available for water conduction. Hence, water supply of plants depends on an inherently vulnerable transport system (Tyree and Sperry, 1989).

Structural requirements for minimizing cavitation and those needed to achieve maximum efficiency of transport and construction, are conflicting. Different climate scenarios could cause cavitation, including freezing and drought. Cavitation by freeze-thaw events is triggered by in situ air bubble formation, and possibility for its occurrence increases with conduit diameter rise. That creates direct conflict between conducting efficiency and sensitivity to freezing induced xylem failure. On the other hand, cavitation by water stress occurs by air

seeding at interconduit pit membranes. Trade-off between conducting efficiency and cavitation by drought is much less pronounced than by freezing, due to fact that pit membrane structure is at least partially uncoupled from conduit size. Although wider conducting structures are generally more susceptible to drought-induced cavitation within an organ, it is noticed that across organs or species this trend is very weak. Increasing porosity of pit membranes should enhance conducting efficiency but also make conduits more prone to air seeding. Similarly, conductance is enhanced by increasing the size or number of pit membranes, while the strength of the conduit wall against implosion may be weakened. The need to avoid conduit system failure under negative pressure creates a significant trade-off between the resistance to cavitation and xylem construction cost, as revealed by relationships between conduit wall strength, wood density and cavitation pressure. Those trade-offs may contribute to better understanding of correlations between wood anatomy, cavitation resistance, and the physiological range of negative pressure experienced by species in their native environmental settings (Hacke and Sperry, 2001).

Efficient transport of water through plants leads to optimal growth, while low investment of construction costs secures the xylem system, mechanical support in assimilating leaves and storage of water and nonstructural carbohydrates for defence and resistance to different stresses. Thus, the functional balance between adequate water transport rate and minimum investment of construction costs, is reflected in the xylem structure (von Arx et al., 2012). Entirely developed and functional water conducting cells are dead but before cell death, still developing xylem acclimates to the changing climate conditions. That feature is particularly relevant in perennial plants which is characterized by long generation cycle (Fonti and Jansen, 2012). The properties of xylem hydraulic architecture - the arrangement, frequency, length, diameter, wall thickness and pit characteristics of conduits differ on inter- and intraspecific level, and reflect differences in the way trees adapt or adjust to environmental variability. Considering different resistance to cavitation within the same tree and species which is related to diameter of conducting structures, the risk of system failure is higher in tree rings where a large amount of the total hydraulic conductivity is caused by a few wide conduits (Fonti et al., 2010).

### 3.3. Linking xylem hydraulic properties to environment

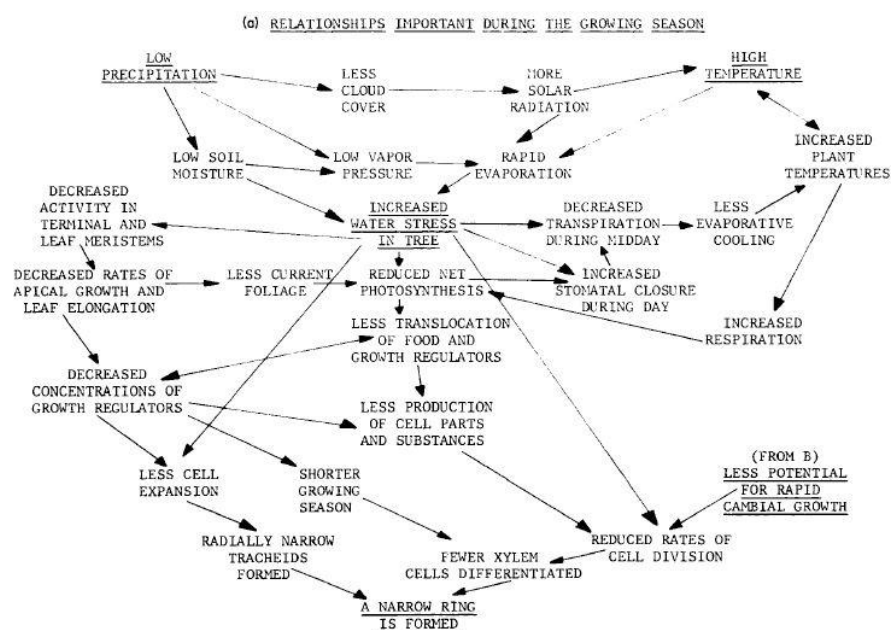
The remarkable genotype's trait to adjust the phenotype during the tree's life is an outcome of short-term to long-term physiological responses to environmental variability and can be used to link environment with xylem structure (Fonti et al., 2010). Number of studies have



highlighted this strong connection of wood-anatomical variables with seasonal climatic conditions.

Tree-ring anatomy is a methodological approach based on dendrochronology and quantitative wood anatomy used to explain the relationships between tree growth and various climatic conditions. It serves to assess cell anatomical characteristics (conduit size and density, cell wall thickness, tissue percentage etc.) along series of dated tree-rings and to analyse them through time (at the intra- and/or inter-annual level). Tree-ring anatomy complements reconstructions of past environmental conditions based on tree-ring analysis with novel understanding about the range and strategies of various species' responses and their likelihood of success. Hence, this approach contributes to the evaluation of the impact of predicted climate change on future vegetation dynamics (Fonti et al., 2010).

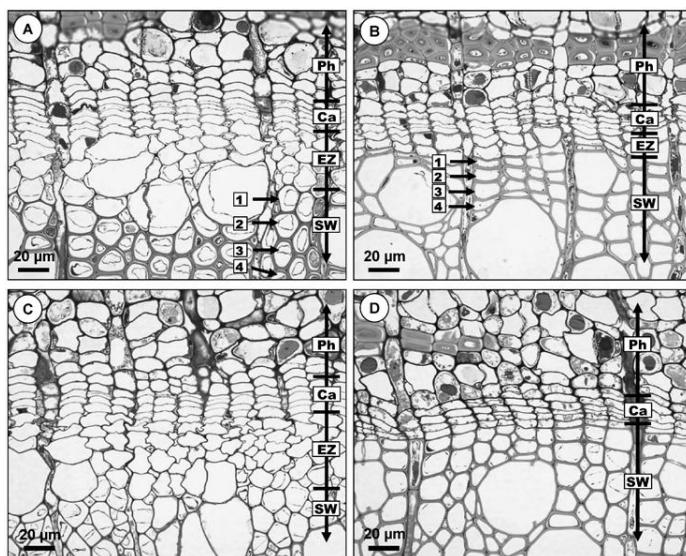
As in other scientific fields, it is favorable to construct models that describe hypothesized physical or physiological interrelationships. First efforts at dendrochronological modeling resulted with diagrams (Fig. 5) (Fritts and Swetnam, 1989). Fonti and Jansen (2012) have emphasized the value of modelling approach that clarifies the complexity of the xylem–phloem system, and enables mechanistic understanding of the carbon–water balance. Some authors stated that integration of tree functioning with internal and external factors through models offer great benefits for climate reconstruction from xylem related signals, as well as for prediction of plant distribution as response to climate disturbances.



**Figure 5.** Model diagram represents some of the relationships indicated by climatic factors of low precipitation and high temperature during the growing season which lead to the formation of a narrow tree-ring in arid-site trees. Arrows display the net effects and point out to various processes

and their interactions. It is assumed that the effects of high precipitation and low temperature are the opposite (that ring width will increase in that conditions) (from Fritts, 1976).

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. Accordingly, occurrence of drought early in the growth season results in different wood-anatomical modifications from those induced by a drought event at the end of the summer, when trees might merely respond by interrupted wood formation (Arend and Fromm, 2007). To investigate drought effects on wood growth, Arend and Fromm (2007) have studied fiber and vessel element development in drought-treated Poplar (*Populus nigra* L. × *P. Maximowiczii* Henry, clone *Kamabuchi*), a diffuse-porous, temperate-zone hardwood species. Their anatomical analysis revealed that both fiber and vessel element development was affected by drought, which resulted in noticeable modifications of xylem tissue, regarding cell size, number and shape. Strong seasonal pattern was observed, concluding that development is more sensitive to drought in early than in late summer (Fig. 6). The drought-affected differentiation of cambial cell derivatives was consistent with the 46 and 24% drought-induced reductions in xylem radial increment in early and late summer, respectively. The decrease in vessel size was fully compensated for by an increase in vessel number and deformation of vessel cells that was observed in the newly formed xylem of drought-treated trees.



**Figure 6.** 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. Scale bars in each panel represent 20 μm.

analysis. Abbreviations: Ph, phloem; Ca, cambium; EZ, xylem cell expansion zone; and SW, secondary cell wall formation (from Arend and Fromm, 2007).

Eilmann et al. (2009) investigated species-specific responses to contrasting water supply, with Scots pine (*Pinus sylvestris* L.), threatened by drought-induced mortality, and pubescent oak (*Quercus pubescens* Willd.), which shows no connection between drought events and mortality. This two co-occurring tree species were analyzed, growing either along an open water channel or at a drought-characteristic site. Drought noticeably reduced the conduit area of pubescent oak, while the radial lumen diameter of the conduits in Scots pine increased; both species decreased their radial increment under drought. Irrigated trees responded less negatively to high temperature (conduit area in pubescent oak was increased and the limitation of cell division by high temperatures was removed). After irrigation stopped, xylem features responded unfavorably with a few years of delay. Scots pine optimized the carbon-per-conduit-costs under drought by increasing conduits diameter while decreasing cell numbers. That modification might lead to a complete loss of tree rings under severe drought. Advantageously, pubescent oak's tree-ring width is less affected by summer drought due to earlywood formation in early spring.

Xylem cell features can be strongly influenced by previous growing season conditions. Castagneri et al. (2015) emphasized the importance of winter precipitation for tree growth and pointed out that outcomes and inferences of studies on xylem dynamics and modelling could be improved by incorporating not just climate information of the current growing season, but also of several months prior to cambial reactivation. De Luis et al. (2011) suggested that bimodal patterns of cambial activity and cell differentiation could be genetically defined (study on *P. halepensis* saplings) since, even under continuous irrigation, in summer period cambial activity and wood formation slow down. However, such a bimodal pattern could be anticipated or delayed depending on climatic conditions and possibly the state of the cambium in spring. Accordingly, cambial activity and cell differentiation under wet (irrigated) summer conditions only occur if spring is dry (no irrigation) while if the amount of water in spring was sufficient for cambial activity, cell division stopped or slowed down in summer, even if the trees were irrigated. Further, same authors concluded that *P. halepensis* saplings are characterized by high plasticity, being quite able to adapt its radial growth rhythm to the availability of water. Bimodal pattern of activity refers to the fact that if water is available during summer, saplings can resume cambial activity and wood formation in autumn.

Maherali et al. (2004) have concluded that high cavitation resistance is a key component of drought tolerance, while studying the hydraulic architecture and water relations of nine co-occurring woody species in a Spanish evergreen oak forest over the course of a dry season. They observed that for deciduous vs. evergreen angiosperms and conifers, cavitation resistance is likely to have different ecological and evolutionary consequences. For example, analysis of independent contrasts indicated that specific hydraulic conductivity increased with decreasing rainfall in deciduous angiosperms, whereas there was no association between specific hydraulic conductivity and water availability for evergreen angiosperms and conifers. Hence, the evolution of increased specific hydraulic conductivity may be a critical adaptation to water limitation in deciduous angiosperms.

In the study of ring-porous *Quercus canariensis* Willd. xylem traits, Gea-Izquierdo et al. (2012) investigated how they adjust to spatio-temporal variability in climate. Xylem traits responded to short-term (high-frequency) variability in climate and trees at lower elevations showed a higher response to all water stress indices. Interesting finding is that inter-tree differences in xylem traits were higher than those between altitudes, which could be prior to a strong impacts of individual genetic features or micro-site conditions. Further, differences in xylem attributes between sites can occur due to non-climatic factors, where characteristics such as competition and soil, and individual tree features could be included.

### 3.4. Conclusion

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. Understanding of xylem tissue modifications in woody plants can contribute to the development of woodland preservation models which will serve to design different strategies for wide range of climate regions.

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

### 4.1. Introduction

Nitrogen is the most important element in atmosphere and is naturally present in various forms: in air, in soil, in water and in all living things. Nitrogen is the principal component of numerous biological compounds (proteins, amino acids, nucleotides, coenzymes ...) and also participates in numerous metabolic processes. It is abundant in the atmosphere as dinitrogen gas (N<sub>2</sub>), it is largely inaccessible to most organisms in this form, making nitrogen a scarce

resource for plants and often limiting primary productivity in many ecosystems. Nitrogen is useful for plant growth, but it can only be available in some forms, like ammonia ( $\text{NH}_3$ ), ammonium ( $\text{NH}_4$ ), nitrite, ( $\text{NO}_2$ ), or nitrate ( $\text{NO}_3$ ). Animal manure and other organic waste can be important sources of these elements for plant growth. Crop residues from non-leguminous plants also contain N, but in relatively small amounts compared to legumes and it is difficult to absorb. It is known that soil have about 2,000 pounds of nitrogen in organic forms for each percent of organic matter (Lamb et al., 2014).

The main processes of nitrogen cycle through the biosphere, atmosphere, and geosphere are nitrogen fixation, nitrogen uptake through organismal growth and precipitation, nitrogen mineralization through decay, nitrification, and denitrification.

In general, the nitrogen cycle processes of fixation, mineralization and nitrification increase plant available nitrogen. Denitrification, volatilization, immobilization, and leaching lead to a loss of nitrogen permanent or temporary from the root zone (Johnson et al., 2005). Other nitrogen losses from the soil system are crop removal and soil erosion.

Nitrogen fixation: is the way in which the plants obtain nitrogen from the atmosphere, because it converts  $\text{N}_2$  to ammonium or  $\text{NH}_4^+$ . This process is carried out by nitrogen-fixing bacteria. In legumes and some other plants, the bacteria live in small growths on the roots called nodules. Within these nodules, nitrogen fixation is carried out by the bacteria and they produce  $\text{NH}_3$  that is absorbed by the plant. Legumes fix nitrogen in the form of a partnership between a bacterium and a plant. The amount of  $\text{N}_2$  fixed by legumes into available nitrogen can be huge, with a potential for several hundred pounds N per acre per year to be fixed in an alfalfa crop.

Organic N that is present in soil organic matter, crop residues, and manure is converted to inorganic nitrogen (ammonium) through the process of mineralization. Soil nitrogen mineralization, in combination with nitrification, is also an important factor controlling the availability of soil nitrate for leaching and nitrous oxide emissions. The rates of mineralization vary with soil temperature, moisture and the amount of oxygen in the soil (aeration). The occurrence of mineralization is favoured by aerobic, moist, and warm soil, with semi-neutral pH levels. The amount of mineralization is also dependent on the type of organic matter present. Fresh manure or crop residue are eliminated faster than humus (Jones et al., 2001).

Nitrification is a microbial process by which reduced nitrogen compounds (primarily ammonia –  $\text{NH}_4$ ) are sequentially oxidized to nitrite ( $\text{NO}_2$ ) and then nitrate ( $\text{NO}_3$ ). The latter is the most plant available form of nitrogen, but it is also highly susceptible to leaching losses.

This process only occurs in the presence of oxygen, so generally it will be slow or non-existent in water-logged, anaerobic soils. It manifests most rapidly at pH levels between 6.5 and 8.5 (Jones, 2001).

Denitrification is the stepwise reduction of nitrogen oxides with gaseous products such as  $N_2O$  or  $N_2$  under conditions of limited  $O_2$ , because it is an anaerobic process. From the soils we have about 20% of global  $NO_x$  emissions. Agricultural soils are responsible of 2.8 Tg of N per year, 15.3% of the total amount of emissions, or 41.8% of anthropic emissions (Denman et al., 2007). These emissions occur when the soil is saturated and the bacteria use nitrate as an oxygen source.

Depending on the amount of oxygen in the soil, the gas emitted is either in the nitrous oxide or nitrogen gas form. Nitrous oxide is considered a greenhouse gas that can remain in the air for over 100 years.

Volatilization is the loss of N through the ammonium conversion into ammonia gas. Losses of volatilization increase to a higher soil pH and favourable conditions evaporation (for example hot and windy). Losses due to volatilization are higher for fertilizers and applied fertilizers on the surface and are not incorporated (for cultivation or for rain) in the ground.

Immobilization is the opposite of mineralization, where inorganic nitrogen ( $NO_3$  or  $NH_4$ ) is converted biologically into organic nitrogen. Immobilization occurs more easily at high altitudes C:N ratio (above 30:1) because microorganisms eliminate any nitrogen available in the ground as they help to break down the organic material relatively free of nitrogen. Because immobilisation is controlled from the growth of microorganisms, it occurs more quickly in warm, moist soil with near neutral pH levels (Jones, 2001).

Leaching is a way of dispersing nitrogen in drainage water. Nitrate levels in fresh water have become an important indicator of pollution, related to water quality. Soil particles do not retain nitrate very good because both are negatively charged. As a result, the nitrate easily moves with water in the soil. The leaching rate depends on the drainage of the soil, precipitation, quantity of nitrate present in the soil e crop absorption.

Other nitrogen losses, like we said, are represented by crop removal. For example, a 250 bushel per acre corn crop, removes as 175 pounds of nitrogen with the grain. Soil erosion represents a small part of nitrogen loss, but it is important for water quality. The incorporation of fertilizer and conservation tillage can help to protect against erosion (Lamb et al., 2014).

## 4.2. Thermo-rainfall conditions and their influence on the nitrogen cycle

Soil moisture, temperature, and precipitation conditions are important in the regulation of the soil nitrogen cycling (Bell et al., 2008). In particular temperature and precipitation were the strongest climatic factors for soil nitrogen processes. Although each of these climatic variables may impact differently on the various soil processes.

### 4.2.1. Temperature effects on nitrogen

Air temperature has effect on the nitrogen cycle, and consequently on crop productivity as well. Indeed, many biological and physiological processes of plant growth are related to temperature. For example, some processes of the nitrogen cycle are carried out by micro-organisms, which act according to the temperature of the soil. These processes occur very slowly, when soil temperatures are below 50° F, but their rates increase rapidly as the soil becomes warmer. With higher average temperatures, organic soil matter decreases, because the decomposition of organic matter is faster and it causes the solubilisation of products, which can leach from soil easily.

The process of mineralization is very influenced by temperature, because the chemical and enzymatic reactions that occur during decomposition depend on temperature (Davidson and Janssens, 2006).

The process of nitrification is slowed down at low temperatures, until it stops below 0° C. The nitrification speed increases with the increase in temperature, up to a maximum, above which it returns to a decrease (around 95 °F to 100 °F bacterial viability is reduced).

The process of denitrification increases with temperature between 40 and 80° F and is relatively constant above 80° F (Havlin et al., 1999). Denitrification losses from the saturated soil vary according to the temperature (for example 3 days with 75/80° F temperature corresponds to 6% nitrogen losses).

The potential for ammonia volatilization is influenced by temperature, warm soil with urea broadcast on the surface, which are ideal conditions for ammonia loss. Volatilization losses of urea are highly dependent on the rate of hydrolysis which in turn is also influenced by soil temperature. A past study conducted by Overdahl et al. in 1987 revealed that volatilization losses are of little relevance (less than 6%) within a 10-day period when soil temperatures are less than 60° F.

In addition, immobilization is influenced by temperature, it is related to the duration of the nitrate depression period during this process.

#### 4.2.2. Precipitation effects on nitrogen

The importance of nitrogen biogeochemical processes is variable with changes in soil water dynamics, which are largely determined by soil and rainfall characteristics. Large amounts of rain directly change nitrogen cycle, with the effects on the soil (impact and water availability), like erosion and leaching and indirectly change the nitrogen cycle by influencing plant N uptake as well as plant productivity. This could increase nitrogen loss and decrease its retention (Nearing et al., 2005).

Where there is an area characterized by dry weather, it is easy to see that the N uptake from the soil is limited by water availability. Thus, when precipitation and soil water availability increase, plant N uptake from the soil and whole plant productivity also raise creating a lower presence of nitrogen in the soil (Knapp et al., 2008). Otherwise when the soil is dry, there is less plant transpiration that results in decreased N uptake by the roots and increased nitrogen accumulation in the soil (Weltzin et al., 2003; Melissa A. Cregger et al., 2014).

Less precipitation in the dry season reduces nitrification and nitrogen mineralization rates by 13–20 %, while the addition of precipitation in the wet-season increases both rates by 50 % (J. Chen et al., 2017). Denitrification occurs primarily in wet soils where the water makes it difficult for microorganisms to get oxygen.

Also, nitrogen volatilization is dependent on precipitation. In a 1981 study, Fox and Hoffman found that  $\text{NH}_3$  volatilization loss from top-dressed urea fertilizers would be insignificant if at least 10 mm of rainfall occurred within 48 hours of nitrogen application; moderate nitrogen losses would occur in 3-5 mm of rain fall within 5 days; and substantial nitrogen losses would occur if no rain fell within six days. For what regards leaching there are different reactions in base of different rainfall conditions.

The processes of nitrification and denitrification are related to the emission of GHG (greenhouse gasses). Emissions of nitrogen seem to correlate best with water-filled pore space and temperature (Hudman et al., 2012). In fact, for example, the main factors influencing emissions of  $\text{N}_2\text{O}$  from nitrification are temperature and soil density. In general,  $\text{N}_2\text{O}$  emissions increase with raising soil temperatures (0-50° C) in an exponential way (Liu et al. 2011; Diana Signor et al., 2013). It is demonstrated that  $\text{N}_2\text{O}$  produced by nitrification increases with increasing soil moisture and decreases with increasing temperature. Otherwise the production of  $\text{N}_2\text{O}$  ratios from denitrification is more influenced by increasing soil moisture.



#### 4.3. The role of climate change in the nitrogen cycle

The global nitrogen cycle has been largely altered by human activities. Anthropogenic activities, including the production of synthetic fertilizers and the production of fossil fuel combustion (NO<sub>x</sub>), add 210 Tg N per year of Nr (Fowler et al., 2013). It is known that the current rate at which anthropogenic nitrogen is added to the environment, radically changes the structure and the function of many ecosystems globally. These anthropogenic emissions cause emissions of greenhouse gases and an increase in the global mean temperature of 1.5 ° C to 4 ° C, and a significant one displacement in the quantity and distribution of precipitation. These changes can alter the Earth's climate system; it means that both the climate and the nitrogen cycle could soon cross or have already crossed the threshold for a fundamental alteration of the structure and function of global ecosystems. Warming involves changing the hydrological cycle: with more frequent and intense heavy rain events; probable lengthening of dry periods; alteration in melting snow; and changes in evapotranspiration. These changes will affect the microbiological activity of the soil, changing the transformation of nitrogen such as decomposition, mineralization, nitrification, denitrification and biological fixation nitrogen.

Atmospheric nitrogen deposition (for example, NH<sub>x</sub>) caused by climate change, can indirectly cause acidification by increasing inorganic nitrogen availability enough to induce nitrification. In fact nitrification will also increase with an increased nitrogen supply caused by increased weathering or decomposition. (Greaver et al., 2016).

With regard to denitrification, the hottest and most humid conditions under climate change would facilitate higher denitrification rates, while warmer and drier areas may present reduced denitrification (Greaver et al., 2016).

The increasing temperature stimulates nitrogen release by mineralization, which may be driven more by temperature effects on moisture. In this case increased nitrogen from mineralization may cause N-induced inhibition of decomposition, a feedback mechanism that might decrease the amount of nitrogen released. Climate changes also change decomposition by altering both the available soil moisture and microscale dependence between microorganisms, and water and nutrients within the soil matrix.

The balance between warmer temperatures and the increasing/decreasing rainfall will be important to understand if there is an increase or decrease in emissions of nitrogen gases (N<sub>2</sub>O, NO<sub>x</sub>) per unit of fertilizer applied to cropping systems. Several studies suggest increased N<sub>2</sub>O emissions in response to climate change: this is because of the stimulation of nitrifies and denitrifies activity and nitrogen supply through mineralization; however, global

warming can have a reducing power on N<sub>2</sub>O emissions through soil drying and an increase in nitrogen uptake (Luo et al., 2013).

The prospect of high atmospheric CO<sub>2</sub> and high nitrogen supply could greatly increase the emission N<sub>2</sub>O due to the increase in soil moisture (Dijkstra et al., 2012).

#### 4.4. Agricultural strategies mitigating environmental impact

Increased climate variability will make the need for adaptive nitrogen management even more adaptive. Moreover, the increase in the combustion of fossil fuels and the growing demand for nitrogen in agriculture and industry has led to a drastic increase in available biological nitrogen in the biosphere. The bad management of nitrogen has over time contributed to an environmental degradation, with acidification of water and soil systems, eutrophication and atmospheric heating (IPCC, 2006).

In fact, in this context of climate change, where nitrogen plays a decisive role due to the pollution it brings, numerous technologies and time-proven practices are available for producers to employ that will result in improved crop N-use efficiency (NUE). The NUE of a cropping system is the proportion of all the nitrogen inputs contained in the harvest in the cultivated biomass, contained in recycled crop residues and incorporated into organic soil nitrogen inorganic matter and pool. Nitrogen not recovered in these sinks are lost in the soil and therefore contribute to the reactive load nitrogen (Nr), passing through the external environments to the agroecosystem (Cassman et al., 2002).

The strategies to improve NUE are explained below:

- Rotations with cover crops: one strategy is to insert cover crops into the field. After the summer crops have been cut, the autumn crops can capture the residual nitrogen in the field; the cover crops have the necessary energy to develop with the initial in the spring period that also stimulates nitrogen mineralization from crop residue and SOM. Then the cover crop is cut and the principal summer crop can, thus benefit from the residual nitrogen from the previous crop. Some cover crops are more advantageous than others, this is an example of leguminous, because of its N<sub>2</sub> fixation. The associated benefits of cover cropping also includes building SOM and some of these have lower nitrogen needs and they are more efficient at seeking nitrogen from soil than others.
- Better Prediction of Crop Nitrogen and Water Requirements: in this case there are many approaches that can be adopted to measure the needs of the crops. The yield-goal approach indicates the amount of fertilizer to be applied based on the maximum

yield of the test crop multiplied by a yield factor N. This approach is improved by soil tests prior to fertilization. Another approach used is the site-specific nitrogen rate at which the value from increased grain yield only matches the cost of added nitrogen. Any additional nitrogen cannot be economically justified in the absence of higher prices of grain or less expensive fertilizers. By definition, the economically optimum nitrogen rate will be lower than the fertilizer rate at which yields are maximized.

- The right time and place to fertilize: using the right fertilizer product at the right time and the right place is a basic principle to improve the NUE. Simple measures such as fractional applications of forms of nitrogen fertilizers can significantly limit nitrogen losses. Today there are technologies that can minimize and control the impact of nitrogen in the environment. Among these techniques we find precision fertilization, with technologies that allow the timely and accurate measurement of the spatial variability of the crops and the availability of nitrogen in the soil. Farm technologies and practices to improve the NUE in agricultural production systems are becoming available to help producers make better nitrogen management decisions and to facilitate their capability to implement such changes (Follett R.F. et al., 2001). These tools are essentially aimed at:

- ✚ 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.

These tools allow "precision" farming, with variable fertilizer application rates within a field. Depending on the tools, they can be used by hand by the farmers, mounted on tractors or with the involvement of aerial or satellite views.

Commonly, best practice requires two applications to cultivate crops, like corn, with a start-up rate ( $\sim 30 \text{ kg N ha}^{-1}$ , for example) applied to sowing and a secondary clothing rate (the remaining nitrogen must be applied) several weeks later (Philip Robertson et al., 2009).

#### 4.5. Conclusion

The perturbations of the climate and of the N cycle will bring more stress factors for the functioning of the ecosystem and for life that could be additive or synergistic. In this context it is important to activate mitigation policies for inefficiency in the use of nitrogen: this is the first step to help avoiding a strong change in the future.

## **5. Impact of the environment on uptake of micronutrients**

### 5.1. Introduction

Feeding the world's growing population in the present era of climate change is a serious challenge. Food insecurity is mostly concentrated in developing countries where mostly drought and low soil quality contribute to low food production. Many crops in developing countries are supported by weathered soils in which nutrients deficiencies and ion toxicities are common. Many factors decline soil fertility such as ongoing soil degradation, inadequate use of fertility input and intense resource use by populations. Climate models predict that warmer temperatures and increases in the frequency and duration of drought during 21<sup>st</sup> century will have net negative effect on agricultural productivity. Scientific publications on the isolated effects of elevated CO<sub>2</sub> 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 (Tubiello et al., 2007). In addition to crop growth and yield, crop quality is expected to be affected by global climatic changes. Crop quality is thought to be multi-faceted and complex subject involving growth, assimilate partitioning and storage and pre- and post-harvest, including nutritional, technological and environmental facets (Hay and Porter, 2006). Elemental composition in plant tissue is expected to change in future high CO<sub>2</sub> world (Taub et al., 2008). The efforts to understand the impact of elevated CO<sub>2</sub>, temperature and other ongoing climatic changes on food crops are crucial to estimate food production in the future. The potential 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.

### 5.2. Micronutrients in plants

Micronutrients are elements that are essential for plant growth but required in much smaller amounts than those of the primary nutrients such as N, P, K and S. Plants show different needs for certain micronutrients, but generally accepted elements for all higher plants are: boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni) and zinc (Zn). Short overview of basic functions of micronutrients in plant metabolism is given below.

#### Boron

B in plants is involved in many important processes, including protein synthesis, transport of sugar, respiration, RNA and carbohydrate metabolism and the metabolism of plant hormones.

Moreover, functions of boron are related to cell wall synthesis, lignification and cell wall structure by cross-linking of cell-wall polysaccharides as well as the structural integrity of biomembranes. Most of these functions are fundamental to meristematic tissues, due to what boron deficiency is generally damaging actively growing organs such as shoot and root tips, so that the whole plant may be stunned.

### Chlorine

Chlorine exists in more than 130 organic compounds in plants. Most soils contain sufficient levels of chlorine. However, Cl deficiencies have been described in sandy soils in high rainfall areas (Broyer et al., 1954). Because of mobility of Cl in plants, most of its functions are related to electrical charge balance. In chloroplasts, chloride is structural constituent of photosystem II in the oxygen evolving complex as one of the 3 important cofactors. Proton pumping ATPase at the tonoplast is specifically stimulated by chloride (Churchill and Sze, 1984). Opening and closing of the guard cells is mediated by the flux of potassium and anions such as malate and chloride. Reduction of leaf surface area, wilting of the plant and restricted highly branched root system are main chlorine-deficiency symptoms.

### Copper

Copper is essential for photosynthesis and mitochondrial respiration, for carbon and nitrogen metabolism, for oxidative stress protection and it is required for cell wall synthesis. Copper exists in two oxidation states  $\text{Cu}^+$  and  $\text{Cu}^{2+}$  and can change between these two forms. This allows copper to function as a reducing or oxidizing agent in biochemical reactions. Copper has high affinity to dioxygen molecules which explains why copper is the catalytic metal in many oxidases (cytochrome C oxidase). Cu is also found in electron carrier proteins (plastocyanine). Cu deficiency is first visible in young leaves and reproductive organs and later consequences are stunted growth of the whole plant and pale green leaves.

### Iron

As redox-active metal, Fe is involved in photosynthesis, mitochondrial respiration, nitrogen assimilation, hormonal biosynthesis, production and scavenging of reactive oxygen species, osmoprotection and pathogen defense. Depending on the type of iron ligand, 3 groups of iron-containing proteins can be defined: 1) proteins with iron-sulfur clusters 2) heme-containing proteins and 3) other iron proteins.

1) Fe-S proteins: function in electron transfer, they constitute part of substrate binding sites in enzymes, they form iron storage moieties, they are involved in transcriptional and translational regulation, they control protein structure and they are involved in disulfide reduction and sulfur donation.

2) Heme proteins: Photosynthetic and respiratory cytochromes involved in electron transfer and globins which bind oxygen. Other examples are oxidative enzymes catalase, peroxidase, oxidase involved in production and scavenging of free radicals and the very large group of cytochrome P450 enzymes.

3) Other iron proteins: These proteins are sometimes grouped as non-heme proteins and they bind iron ions directly. Ferritins are the most prominent among them. They are plastidic iron storage proteins and control the interaction between iron homeostasis and oxidative stress (Ravet et al., 2009).

### Manganese

Mn is essential for plant metabolism and development and occurs in oxidation states II, III and IV in approximately 35 enzymes of a plant cell (Hebberner et al., 2009). Mn may serve as catalytically active metal and it may exert an activating role on enzymes. Manganese activation was seen in enzymes of nitrogen metabolism, gibberic acid biosynthesis, RNA polymerase activation and fatty acid biosynthesis.

### Molybdenum

Handful plant proteins are known to contain molybdenum. These proteins are very important because of their involvement in nitrogen assimilation, sulfur metabolism. For example, nitrate reductase is a key enzyme for nitrate assimilation and nitrogenase is found in nitrogen fixing bacteria inside nodules of symbiotically grown species. Last part of abscisic acid biosynthesis is catalysed by the molybdenum enzyme aldehyde oxidase. In all organisms molybdenum has to be complexed by a pterin compound thereby forming the molybdenum cofactor in order to gain biological activity (Hille, 1996).

### Nickel

Among plants, nickel occurs in oxidation states I, II and III. Nickel holds a special place among heavy metals. Ni is a constituent of urease and small quantities of Ni are essential for some plant species. Deficiency symptom in plants is accumulation of toxic urea (Eskew, 1983) which can be explained with the complete loss of urease activity within the cell.

### Zinc

Zinc is important as a component of enzymes for protein synthesis and energy production and maintains the structural integrity of biomembranes. More than 1200 proteins are predicted to contain, bind or transport  $Zn^{2+}$ , including a large number of zinc-finger containing proteins and transcription factors, oxidoreductases and hydrolytic enzymes such as metalloproteases (Kramer et al., 2005). Zinc plays an important role in seed development and zinc-deficient plants show a delayed maturity. Most of the zinc enzymes are involved in regulation of DNA-

transcription, RNA processing and translation. Chloroplasts, mitochondria, cytoplasm, lysosom and apoplasic space are compartments with zinc-dependent hydrolytic activities (Lin et al., 2005).

### 5.3. Climate change consequences and their effects on crop nutrient status

#### 5.3.1. Drought effects 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 (Mackay and Barter, 1985). Roots extend their growth, increase surface area and alter their architecture to capture less mobile nutrients. Reduction of root growth and impairment of root function under drought thus reduces micronutrient acquisition capacity of root system (Marchner, 1995). The moisture of the soil can affect Fe content and availability. 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 than  $Fe^{3+}$  (Sardans et al., 2008). The effects of water stress on chloride content in plants are not well studied. 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 (Larcher, 2006). Cu is available for plant uptake only when it appears as the free divalent ion  $Cu^{2+}$ . Its 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) boron deficiency is mainly seen in soils with high pH and under drought conditions. In plants, B is considered as non-mobile element and a constant supply from the soil is necessary in order to avoid its deficiency (Taiz and Zeiger, 2006). Low soil moisture can induce Mn deficiency. The conversion of Mn to its reduced and more soluble forms is increased in moist soil conditions (Hu and Schmidhalter, 2005). The lower diffusion of Zn in dry soil restricts uptake of Zn and may exacerbate Zn deficiency. The accessibility of Ni usually declines at higher pH values of the soil solution due to the formation of low soluble complexes (Singel and Singel, 1986). Higher Ni mobility was also

reported in the soils with lower humus content, lighter granulometric composition and higher moisture content (Merkusheva et al., 2001).

### 5.3.2. Effects of intense precipitation on micronutrient acquisition

Excessive precipitation can reduce crop yields. Intense rainfall events can be a major cause of erosion in sloped cropping systems and where soil instability results from farming practices that have degraded soil structure and integrity. Surface erosion during intense precipitation events is a significant source of soil nutrients loss in developing countries (Tang et al., 2008). 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 synthesized through the oxygen dependent mitochondrial electron transport chain (Drew, 1988).

### 5.3.3. Effects of high temperature on micronutrient acquisition

Soil warming can increase nutrient uptake from 100–300% by enlarging the root surface area and increasing rates of nutrient diffusion and water influx. Since warmer temperatures increase rates of transpiration, plants tend to acquire water soluble nutrients more readily as temperature increases. Temperature increases in the rhizosphere can also stimulate nutrient acquisition by increasing nutrient uptake via faster ion diffusion rates and increased root metabolism. However, any positive effects of warmer temperature on micronutrient capture are dependent on adequate soil moisture. If under dry conditions higher temperatures result in extreme vapor pressure deficits that trigger stomatal closure (reducing the water diffusion pathway in leaves) (Abbate et al., 2004), 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. Emerging evidence suggests that warmer temperatures have the potential to significantly affect nutrient status by altering plant phenology (Nord and Lynch 2009). The duration of plant developmental stages is extremely sensitive to climate conditions and is particularly responsive to temperature. Warmer temperatures can increase or decrease crop productivity and yield depending on crop type and agricultural zone. In the tropical and subtropical



climates of most developing countries a 2–3°C increase in temperature is expected to diminish crop productivity (Easterling and Apps 2005).

#### 5.3.4. Effects of elevated CO<sub>2</sub> concentration on micronutrient acquisition

Carbon emissions related to climatic changes have been significantly contributing to the elevation of atmospheric CO<sub>2</sub> and temperature. More recently, carbon emissions have greatly accelerated, thus much stronger effects on crops are expected. Over the past 800,000 years, atmospheric CO<sub>2</sub> changed. Projections to the end of this century suggest that atmospheric CO<sub>2</sub> will top 700 ppm or more, whereas global temperature will increase by 1.8–4.0 °C, depending on the greenhouse emission scenario (IPCC, 2007). There is growing evidence suggesting that many crops, notably C<sub>3</sub> crops, may respond positively to increased atmospheric CO<sub>2</sub> in the absence of other stressful conditions (Long et al., 2004), but the beneficial direct impact of elevated CO<sub>2</sub> can be offset by other effects of climate change, such as elevated temperatures, higher tropospheric ozone concentrations and altered patterns of precipitation. Crops sense and respond directly to rising CO<sub>2</sub> through photosynthesis and stomatal conductance. Manderscheid et al. (1995) studied two wheat and two barley cultivars grown in pots under ambient and two elevated CO<sub>2</sub> levels. They found overall decreases for most micronutrients under high CO<sub>2</sub>, with nutrient concentrations more affected in straw than in grains, although the responses to elevated CO<sub>2</sub> were species- and cultivar-dependent. Idso and Idso (2001), in a qualitative narrative of several papers, suggested that more often than not high CO<sub>2</sub> caused decreases in leaf concentrations of essential mineral elements. Loladze (2002) performed a analysis based on 25 studies covering 19 herbaceous and 11 woody species and concluded that leaf concentrations of micronutrients such as Fe, Zn, Mn and Cu all decreased under elevated CO<sub>2</sub> as compared to controls grown at ambient CO<sub>2</sub>. Intriguingly, relatively more data concerning mineral composition exist on non staple crops than on crop species, particularly in their foliar content. For the two major staple crops, rice and wheat, most studies suggest that, overall, decreased concentrations of nutrients, with the exception of a few minerals will be the norm in a high-CO<sub>2</sub> world. In rice, Seneweera and Conroy (1997) found lower concentrations Fe (17%) and Zn (28%) under elevated CO<sub>2</sub>. In wheat, Loladze analyzed five published studies and noted slight decreases (ranging from ca. 3% to 10%, though significant) in Zn, and decreases superior to 10% in the concentrations of Fe, and Zn. More recently, Högy and Fangmeier (2008) compiled existing data for mineral composition of wheat grains obtained with different CO<sub>2</sub> enrichment technologies and rooting volumes. They noted high- CO<sub>2</sub>-induced decreases in the concentrations of all micronutrients by 3.7–18.3%

over a range of CO<sub>2</sub> enrichment technologies, with the exception of Fe, which increased by 1.2% in closed field chambers. From the above, although detailed information regarding mineral composition of major crops is scanty, the preponderance of evidence suggests that decreases in essential microelements in grains of major crops such as wheat and rice are to be expected, which, ultimately, will aggravate the already acute malnutrition in the world, putting millions at risk of the “hidden hunger” of micronutrient malnutrition (Stafford, 2008). Idso and Idso (2001) suggested that plant mineral deficiencies associated with CO<sub>2</sub> enrichment might be relieved by larger fertilizer inputs in intensive agricultural settings. This statement must be cautiously envisaged, however, especially because high inputs of micronutrients beyond a certain critical level (that is too narrow for most micronutrients) can easily lead to toxicity and losses in both quality and quantity of grain yield, as shown for zinc (Rengel et al., 1999). In addition, high-micronutrient applications have been associated with nutrient disorders and environmental pollution.

#### 5.4. Conclusion

Although the interactions of global climate change and crop nutrition are not well understood, it is probable that the net effects of these changes 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 may reduce soil fertility by increasing soil organic matter decomposition, and may have profound effects on crop nutrition by altering plant phenology. Since soil fertility is already a primary constraint to food security in many developing regions, and crop production is already marginal, these stresses may be disastrous. Social adaptation to changing conditions is possible, although most of the technical options face serious obstacles in application. An urgent effort is required to improve crop nutrition and soil fertility management in poor nations, integrating agro-ecological and socio-cultural aspects of the problem, to avert worsening of a situation that is already desperate.

#### **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? There are now great concerns about the decline in soil fertility and crop production governed by the

increase in temperature, elevated CO<sub>2</sub> level and changed patterns of rainfall. It is evident that over time, more nutrients have been removed from the soil as a consequence of intensive exploitation of soils in plant production concomitantly with climate change. 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. Overall, N is a critical element that primarily controls plant metabolism and composition. Stabilizing N levels within an appropriate range in terrestrial ecosystems by mitigation pathways for N management is the priority of future management practices. Xylem hydraulic traits are important means which plant species employ to survive altered environmental conditions. Therefore, 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 use of vegetation indices has already been successfully applied to research on temporal and spatial trends and variations in vegetation distribution, dynamics and productivity to monitor effects of climate change on agriculture. The encouraging 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.

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