REPORT PAPER ON A6:

Transport Systems: Links and Fluxes of Energy and Matter between Atmosphere, Pedosphere and Biosphere, GCE A6

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GLOBAL CHANGE ECOLOGY

1. INTRODUCTION

Water is the single most precious chemical element for all living organisms, yet plants use more water for transpiration than for processes that directly contribute to their growth and development. Examples of such growth processes are cell expansion, fruits, leaves and stem growth. The amount of water demanded by the atmosphere is usually larger than the amount of water taken up from the soil by plant roots. However, root uptake of soil water must also satisfy atmospheric demand for water and when this is insufficient, plant water deficit develops. (Gallardo et al. 2005). The water status of plants is the sum of the interaction of various atmospheric, plant, and soil factors. The availability of soil water, the atmospheric demand (determined by radiation, humidity, temperature, and wind), the capacities of the root system to absorb water and of the plant to transport absorbed water to transpiring leaves, and stomata responses for regulating transpiration, can all appreciably influence plant water status. Various parameters are used to measure plant water status, the most common being water potential. Water potential theoretically represents the work involved in moving one mole of water from a selected point within the plant (or soil) to a reference point of pure water at the same temperature and at atmospheric pressure. Total water potential has four components: the osmotic potential, pressure potential, matric potential and gravitational potential. In most situations, total plant water potential is considered to be the sum of the pressure potential and osmotic potential since both are dependent on tissue water content. While in soils, the main components are matric potential and gravitational potential. Water moves along a gradient from high to low water potentials.

In the course of a fieldwork exercise in a maize plot located at the agricultural school of Bayreuth, data on leaf water potential, soil water potential and stomata conductance were measured and collected. The goal of this study and the reasons for choosing to measure these variables is to study the transport of water across the soil-plant-air continuum. However, we intend to make rational conclusions from our acquired datasets while providing answers to important questions. Therefore, this report aims at summarizing all measurements collected during the field exercise, describe relationships observed among variables and their temporal evolutions.

2. RESEARCH QUESTIONS

Following the fieldwork exercise performed at the agricultural schools of Bayreuth, the purpose of this study is to provide answers to the following questions based on the data collected from this site.

- What is the reaction of maize plant stomatal conductance and transpiration to variations in its leaf water potential?
- How is transpiration and stomatal conductance influenced by atmospheric demand for water (vapour pressure deficit).
- How is the variation in soil matric potential along the soil gradient and what does this mean for plant water uptake?

3. MATERIALS & METHODS

This document is an account of the fieldwork which took place from 4th July 2019 to 11th July 2019. The aim of the field exercise and lectures on soil physics and micrometeorology was to understand the principles of water transport or flow across interfacial boundaries, therefore daily data measurements on relevant parameters, such as soil water potential, leaf water potential and stomata conductance were collected. The field measurements began with the installation of equipments on 3rd July 2019 and ended with deinstallations on the 10th July 2019. The following variables were important focus of both the lectures and the fieldwork: leaf-water potential, soil water potential, potential evapotranspiration, vapour pressure deficit, stomatal conductance, shortwave radiation (Wm^{-2}), longwave radiation (Wm^{-2}), wet and dry bulb temperature, and so on. Daily measurements of these parameters were taken at pre-dawn (4:00), mid-day (11:00), afternoon (16:00) and evening (21:00). The entire fieldwork took place at the maize field of the Landwirtschaftliche Lehranstalthen, Bayreuth and it involved the participation of students from the Global Change Ecology and Geoecology study programs. The fieldwork was conducted and coordinated by Prof. Andrea Carminati (who handled the lecture part on soil physics), Dr. Babel Wolfgang (who handled the micrometeorology part) and Dr. Mutez Ahmed.


After the fieldwork, the collected data were compiled and analyzed. In this section, this paper describes the methods and instruments used for data collection in the course of the fieldwork.

3.1 Micrometeorological measurements

To understand the rate of atmospheric demand of water and its influence on the quantity of water available to plants, we took measurements on atmospheric variables using the following instruments attached to a meteorological tower. Measurements were automatically taken daily by the instruments and these were monitored everyday to ensure that the instruments were running smoothly. The meteorological tower was powered by an electrical source close to the field site.

3.1.1 Windvane: used to measure wind direction.

3.1.2 Cup anemometer: A cup anemometer also attached to a meteorological tower was used to measure wind speed, by the speed of rotation of 3 or 4 hemispherical or conical cups, each fixed to the end of a horizontal arm projecting from a vertical axis.

3.1.3 Psychrometer plastic bottle: A psychrometer was also used to measure the water vapour content of the air. The psychrometer is a type of hygrometer that consists of the welt-bulb and dry-bulb temperature. We used the assmann psychrometer in which the thermometric elements were well shielded from radiation.

3.1.4 Aspirators and Multiplexer relays: an aspirator (a suction fan) was installed on the meteorological tower to provide ventilation for our meteorological instruments. A multiplexer is a device that combines several separate communications signals into one and outputs them on a single file.

3.1.5 CR3000 data logger: The data logger is used for calculating, viewing and plotting variables measured by the different meteorological instruments attached to the meteorological tower. For example, the data logger can be used to compute certain psychrometric data such as the dew point, relative humidity, and vapour pressure from known values of dry-bulb and wet-bulb temperature. Other variables that could be plotted are short and long wave upwelling and downwelling radiation, atmospheric pressure, temperature, etc. We used the CR3000 micro logger which has a built-in keyboard and display. The micro logger and the whole meteorological tower were powered by an electrical source close to the field site. A card reader was also connected to the micro logger to ensure data retrieval after field measurements. With the CR3000 logger, we could generate plots of measured variables while on site. However, it is important to note that the timezone of the weather data generated by the datalogger is in Central European Time (CET) rather than Central European Summer Time (CEST).

3.2 Licor 6400: A licor device (version 6400) is an instrument that measures the quantities of photosynthesis and transpiration based on the differences in CO_2 and H_2O. The main parts of the device includes the CO_2 cartridge header and regulator, chemical tubes, chamber, cable assembly and the console. Measurements were taken through the chamber which is connected to a sensor head. Both the chamber and the sensor head are connected via cables to the console which contains the screen and buttons for controlling the device. Batteries were inserted into the device to power it and were also connected to the console. In order to take measurements, the chamber was fixed directly on the plant leaves so that the leaf is enclosed within the chamber. The chamber has a PAR sensor that takes readings from the leaves. The licor device can record measurements not only on photosynthesis and transpiration but on other variables such as relative humidity, vapour pressure deficit, dew point temperature, atmospheric pressure, stomatal conductance, and so on. Measurements on transpiration and conductivity were taken from 4 maize plants from different plant rows and were taken twice a day, at 11:00 and 16:00.

3.3 LAI-2000: We measured leaf area index of our maize field using the LAI-2000 which computes foliage density or LAI from measurements of how quickly radiation is attenuated by leaves as it passes through the canopy.

3.4 Scholander bomb: We used the scholander bomb to measure leaf water potential. Here, the leaf water potential equals the pressure needed to bring water out of the xylem at atmospheric pressure. The major parts of the scholander bomb includes a rubber seal, pressure bomb, and an air pressure gauge. A leaf and its stalk were placed firmly (with the use of a rubber seal) into the pressure bomb with a small part of the stalk left shooting out. Pressurized gas was then slowly added to the bomb with the use of a bicycle pump/air pressure gauge connected to it. As the pressure increases at some point the water contents of the leaves is forced out of the xylem and is visible at the cut end of the leaf stem or petiole. The leaf water potential was then recorded as the amount of pressure read from the air pressure gauge. Measurements of leaf water potential were taken at all time slots; 4:00, 11:00, 16:00 and 21:00.

3.5 Tensiometers: We used tensiometers buried at different depths (20, 40, 60 and 80 cm) to determine the matric potential of the soil. Basically, we installed four tensiometers of different depths in four rows of maize plants. And measurements were taken only at midday (11:00). The tensiometer consists of a glass tube with a porous ceramic cup which is filled with water. The top of the tube has a rubber cap used with a hypodermic needle which is punctured into the cap to measure the pressure inside the tensiometer. The difference in pressure between water and the gas phase in the soil is equal to the matric potential of the soil. A vacuum formed at the upper part of the tube increases as water is being pulled out of the soil by plants and evaporation. The matric potential of the soil is determined from a portable puncture instrument which generates a specific value after its needle is being punctured into the rubber cap.

4. RESULTS AND DISCUSSIONS

4.1 COMPARISON BETWEEN MEASURED AND MODELLED PENMAN-MONTEITH EVAPOTRANSPIRATION

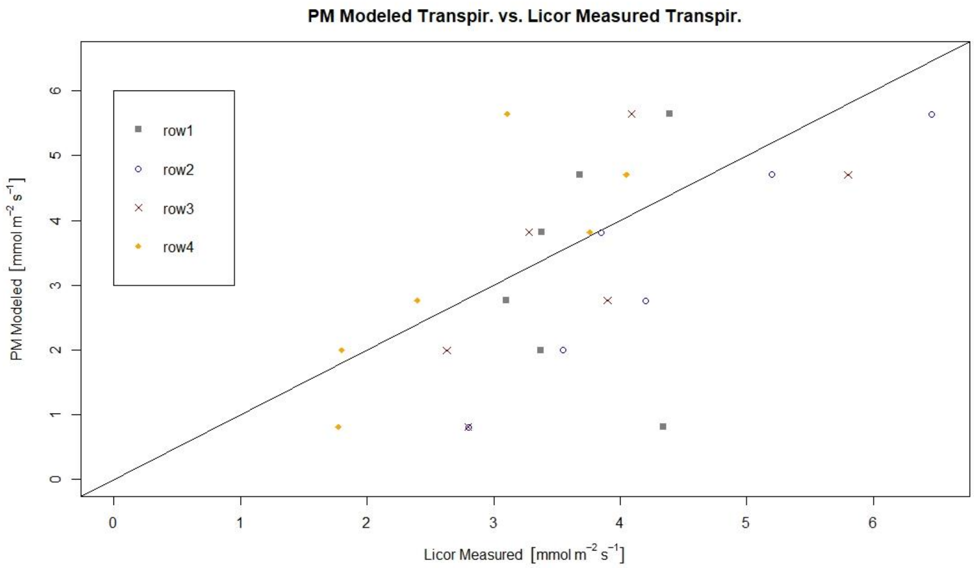

Figure 1: Comparison between measured and modelled evapotranspiration

Figure 1 shows the relationship between the measured values of actual evapotranspiration from the LICOR device and a modelled value of evapotranspiration derived from the calculation of actual evapotranspiration from the Penman-Monteith equation. This value gives us an impression of how changing atmospheric and physiological factors change evaporation and the leaf energy balance.

We computed values of Penman-Monteith (PM) evapotranspiration for each day using measurements collected by the devices installed on the meteorological tower. We then plotted this value against daily values of measured transpiration in each plant rows. From Figure 1, we can observe an overall widespread of the points from left to right. The plot is divided diagonally by a 1:1 line. The interpretation is that when the points are entirely above the 1:1 line, this means that the modelled transpiration (PM) is higher than the measured transpiration meanwhile the modelled transpiration is lower than the measured transpiration when the points are entirely below the 1:1 line. Here, we have more points below than above. If we had the values perfectly plotted on the line, this means that measured transpiration values are good representatives of the PM modelled values.

4.2 THE INFLUENCE OF LEAF WATER POTENTIAL ON STOMATAL CONDUCTANCE AND TRANSPIRATION

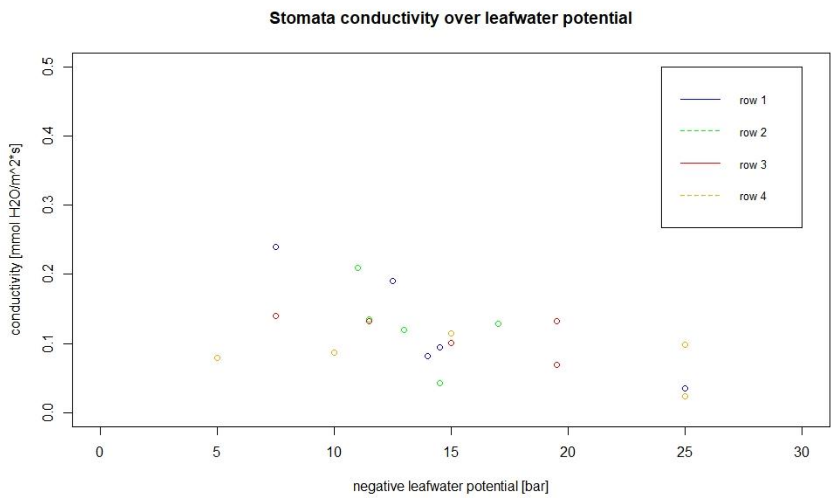

Figure 2: Relationship between stomatal conductance and leafwater potential

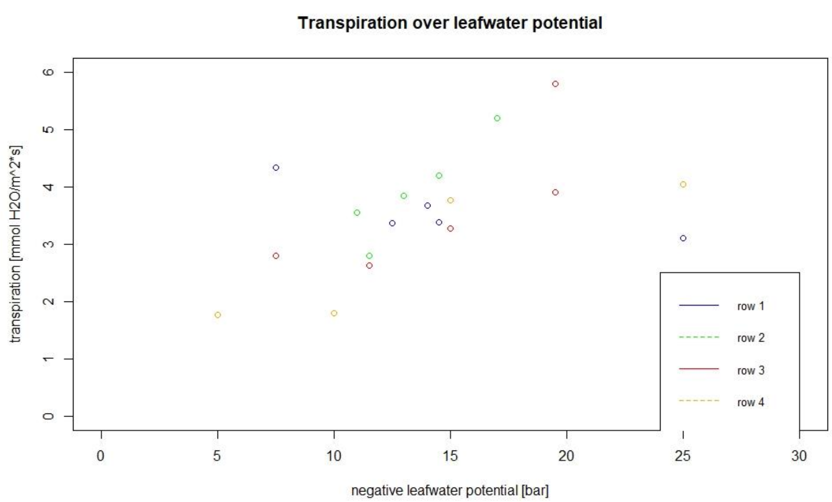

Figure 3: Relationship between transpiration and leafwater potential

Figure 2 shows the relationship between leaf water potential and stomatal conductance. Theoretically there is no linear relationship between these two variables but overall, the points show leaf water potential becoming more negative with decreasing stomatal conductance. One could say that stomatal conductance is limited due to plant stomata regulation and that's why there are few data points at the upper right of the graph (Figure 2). The more negative the leaf water potential, the more chance to have plants close their stomata. Plants also try as much as possible to avoid cavitation as leaf water potential becomes more negative. This is a typical characteristic of maize plants being an isohydric plant.

Figure 3 shows the relationship between transpiration and leafwater potential. An overall increasing trend of transpiration can be observed as leafwater potential becomes more negative. Transpiration is more driven by differences in vapour pressure between leaves and atmosphere rather than differences in water potential. Despite stomata being closed, there is still an increasing trend of transpiration which is as a result of high atmospheric demand of water (vapour pressure deficit).

Furthermore, transpiration is driving the leaf water potential more negative. The higher the water flowing in plant leaves, the stronger it is for the plant to respire.

4.3 THE INFLUENCE OF VAPOUR PRESSURE DEFICIT ON TRANSPIRATION AND STOMATAL CONDUCTANCE

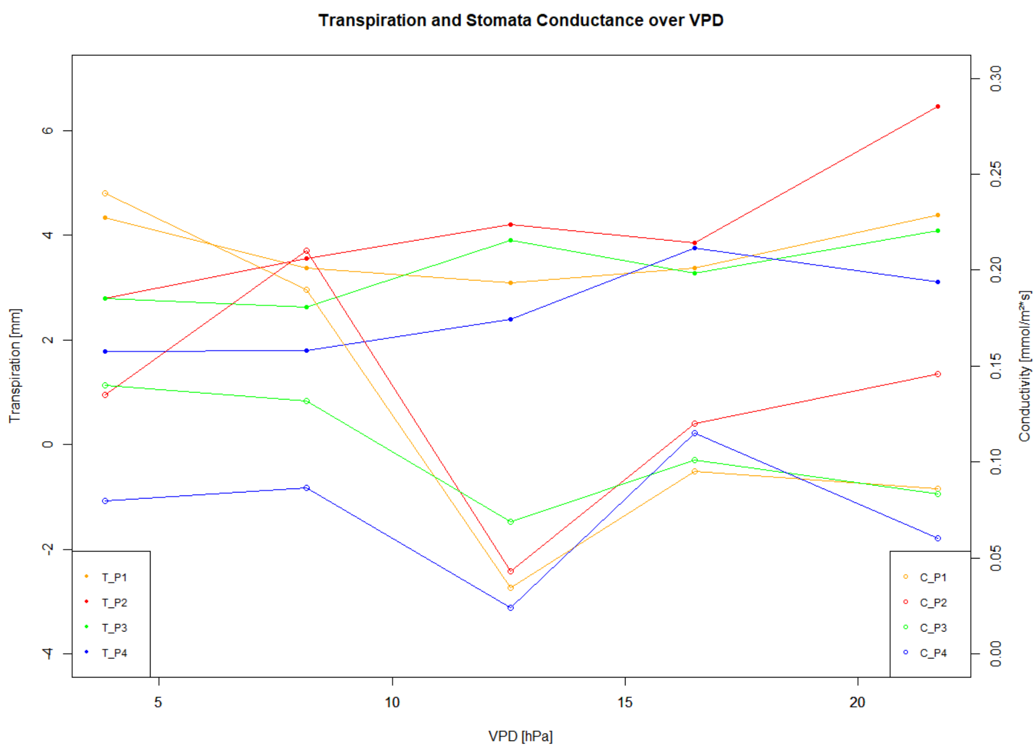

Figure 4: Transpiration and stomatal conductance as influenced by vapour pressure deficit (VPD)

Figure 4 shows the relationship between transpiration, stomatal conductance and VPD. Here we can observe that in all the plants observed, transpiration is higher than stomatal conductance. When we have a low VPD, stomata opens up and transpiration is not so high. Meanwhile when there is a high VPD, stomata closes but there is still high transpiration. This is similar to our discussion in Figure 3.

4.2 DAILY VARIATIONS IN MATRIC POTENTIAL AT VARIOUS SOIL DEPTHS

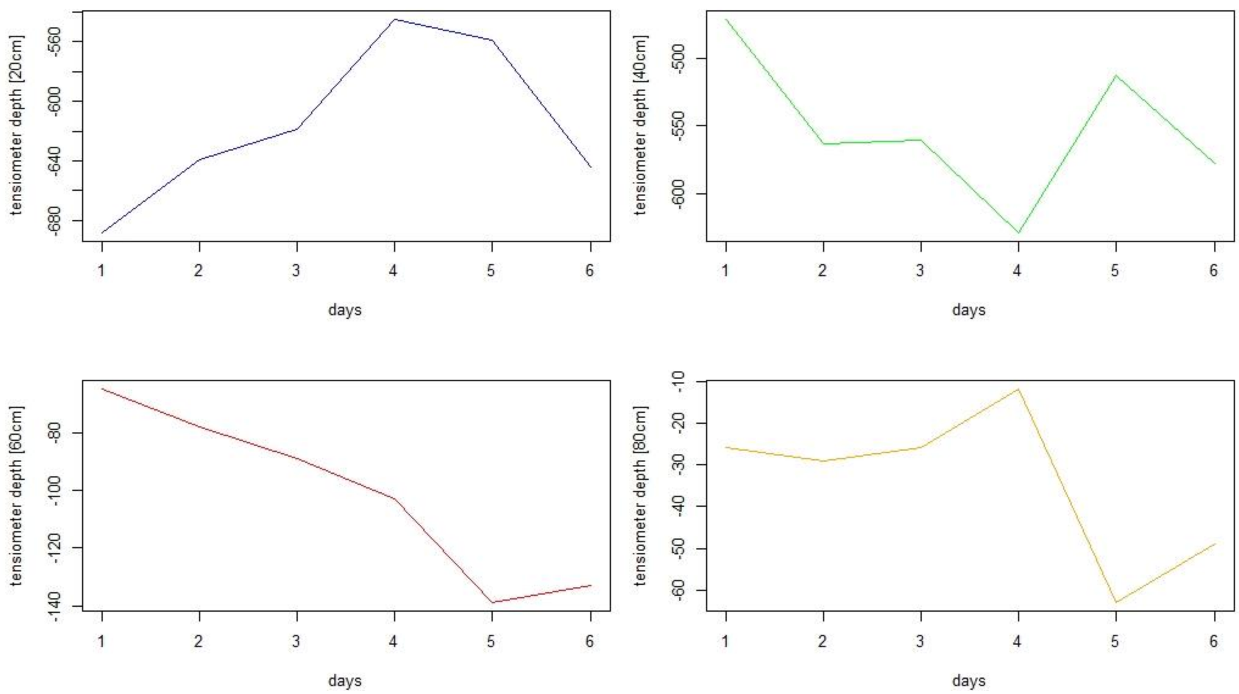

Figure 5: Daily variations of matric potential at various soil depths

Figure 5 shows the daily variations of matric potential for tensiometers installed at different depths, i.e. 20, 40, 60, and 80cm. Looking at the Y-axis of the graphs, we can observe that matric potential increases or becomes less negative with increasing depths from 20cm to 80cm.

At 20cm, we can see that matric potential gradually becomes less negative towards the 4th day when it rained. Thereafter, matric potential began to increase and became more negative towards the 6th day. The more negative the value of matric potential is, the lower the volume of water available. Lower or less negative matric potential on the 4th day tells us relatively that enough water was available to plant roots on this day than other days.

At 40cm, we have a sharp decrease in soil water availability from the 1st to 4th day and an increase and decrease on the 5th day and 6th day respectively.

At 60cm, the soil is more saturated as we have less negative matric potential values. Here, we have a gradual decrease of saturation from the 1st day to 4th day and a sharp decrease towards the 5th day where matric potential is the most negative. However, it began to increase again after this day.

At 80cm, we have even more matric potential values close to 0, meaning that the soil pores are more saturated with water at this depth. Perhaps this depth is very close to the water table. Here, matric potential becomes more negative after the first day and gradually increases towards the

4th day when it rained. A sharp decrease is observed towards the 5th day and an increase on the 6th day.
The soil probably contains a high quantity of sandy particles as a very high rate of percolation can be observed. Since water flows along a gradient from high to low matric potentials.

4.3 GRADIENT OF MATRIC POTENTIAL

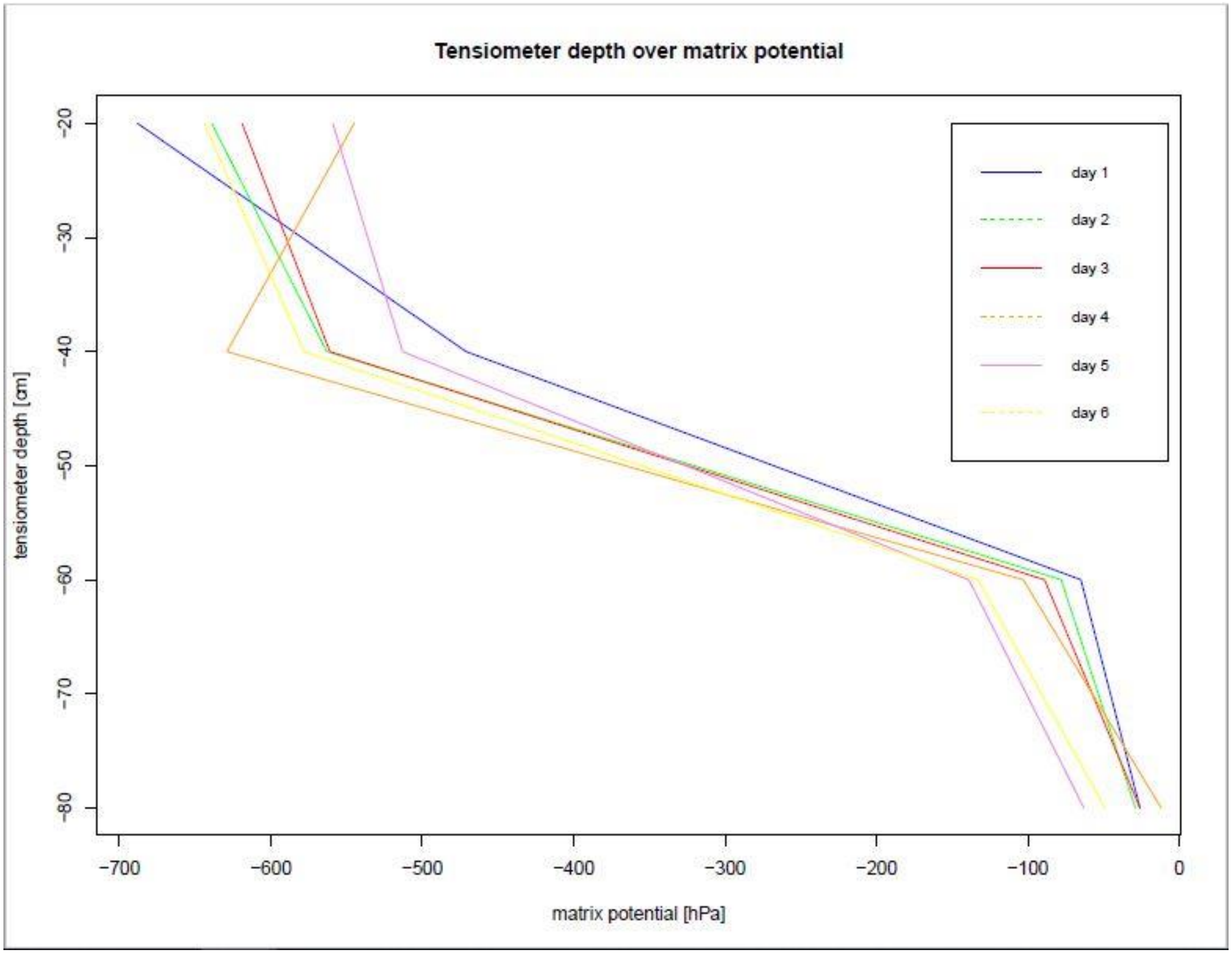

Figure 6: Variation of matric potential along the soil gradient

Figure 6 was plotted to answer the third question of how the variation in soil matric potential is along the soil gradient and how this influences water uptake by plant roots. The gradient of matric potential is such that water flows from high water potential to low water potential.
From Figure 6, we can observe an overall increase of water potential from low depth (20cm) to high depth (80cm) in all the days of measurements. In other words, water potential becomes less negative or moves close to 0 along the soil gradient. Relating this to water availability, this means that water becomes more available in the soil pores as we move from top to bottom. The soil probably contains more clay below than above, that could be the reason why it is wetter below than above.

Most of the water uptake by plant roots is between 0 and 40cm. We observe a huge gradient of matric potential between 40cm and 60cm depths. This probably represents a transition to less roots and less water uptake by plants.
Again, we can see that at 20cm depth water potential is higher on the 4th day (when it rained) than the other days. On this day, water potential becomes more negative up to 40cm and gradually increases thereafter.

5. CONCLUSIONS

This study is a report of the fieldwork exercise performed in a maize plot close to the agricultural schools of Bayreuth. The study focussed on the movement of water across the soil-plant-air continuum of a maize plantation by examining the relationship between parameters depicting water availability in the soil, plant and atmospheric interfaces. We found out that leafwater potential influences both stomatal conductance and transpiration of the maize plants, exhibiting an isohydric behaviour. Atmospheric demand for water (represented by vapour pressure deficit) has more influence on transpiration of maize plants than their stomatal conductance. However, it is a surprise to see that transpiration rate may not be affected by stomata opening or closing as plants may lose water despite stomata being closed. This usually happens when there is a very high demand of water by the atmosphere. We also found out that soil water potential increases or becomes less negative along the soil gradient, connoting that the soil becomes wetter with increasing soil depths. Although most of the soil water uptake by plant roots is between 0 and 40cm depth.

REFERENCES

Gallardo M, Gimnez C, Thompson RB (2005) Plant water relations. In Hillel D, ed. *Encyclopedia of Soils in the Environment*, pp. 231 – 238. Oxford: Elsevier.