PhDResearch Progress Report

TITLE: Enhancing climate resilience in banana-coffee cropping systems, using stable isotope techniques

Name of Student: Mathilde Vantyghem

Supervisor: Prof. Roel Merckx, Prof. Rebecca Hood-Nowotny, PhD Gerd Dercon, Prof. Steven Bouillon

Timeline of study:2019-2022

University: KU Leuven, Belgium / International Atomic Energy Agency (IAEA), Austria

Research Problem and Objectives

Climate change is expected to have a major impact on agriculture in Africa. In Tanzania, temperatures are expected to rise 2 to 4°C (Adhikari, Nejadhashemi, & Woznicki, 2015). Drought stress is predicted to become an issue for both coffee and banana. It is yet to be seen how these crops react to low water availability and understanding of their physiology in terms of water management is limited. Stable isotope techniques are a useful tool to investigate that. Several researchers have already made use of these techniques, yet samples are always pooled over different leaves or even entire plants. However, isotopic content can already vary within a single leaf.

A detailed study on variability in isotope ratios is still missing. For one to draw conclusions on a plants' water status based on a leaf signal, one should first understand the complexity of the leaf signal. There is a need for assessing the variability within a leaf, within a plant and within a field and trying to explain this variability by gathering information on plant characteristics (leaf age, position, angle, chlorophyll content, temperature, genes, …) and the environment (air temperature, humidity, soil characteristics, solar radiation, …). Such research could help us to understand banana, coffee and their response to water availability and drafting management recommendations, while at the same time improving cutting-edge isotopic techniques.

The objectives of the research are the following:

1) To gain an understanding of variability in $\Delta^{13}C$ in coffee and banana, initially at leaf, plant and field level and later at landscape level
2) To improve stable isotope techniques for the purpose of evaluating WUE in coffee and banana and to develop a protocol, based on the understanding of variability in isotope signals
3) To develop and assess proxies, like leaf temperature, for water stress in coffee and banana
4) To assess the WUE of coffee and banana in an intercropping setting
5) To formulate recommendations for coffee and banana growing under a climate change scenario

Achievements

- First exploration in the field in July-August 2019 on banana: sampling for $\Delta^{13}C$ analysis and leaf temperature measurement
- Followed 3 courses at BOKU University, Vienna, Austria: Introduction to statistical learning with R, Stable isotopes (C, N, S, O, H) in Soil and environmental Sciences, Bio-Resources and Technology
- Presented early results at the Docday Conference 2019 in Tuln, Austria
- 9 months evaluation presentation in KU Leuven, Belgium

Research context

Agriculture is of utmost importance in Sub-Sahara Africa and the major economic sector in the region. Crops are largely rainfed and therefore, production is highly weather dependent. As such, millions of people are directly influenced by the changing weather conditions, expected under climate change scenarios. In particular in Africa, a rise in temperature is predicted, more pronounced than the global average. In Tanzania, a rise of 2-4°C is predicted (Adhikari et al., 2015). More specifically, in the Kilimanjaro region, retreat of its glaciers indicates that climate change is already happening right now (Kaser, Hardy, Mölg, Bradley, &Hyera, 2004; Mölg, Hardy, &Kaser, 2003). The rising temperatures, associated with climate change result in drought stress for plants. This will also be the case for coffee and banana. Drought is already considered a major limiting factor for banana production in the Great Lakes Region and increasing temperatures and erratic rain are predicted to affect banana productivity even more (Adhikari et al., 2015; Ramirez et al., 2011). Moreover, harvest numbers of banana are found to be strongly correlated with cumulative rainfall (Van Asten, Fermont, &Taulya, 2010). Coffee yields as well are expected to decline in Tanzania, mostly due to rising night temperatures and especially at lower altitudes, although predictions are sometimes contradictive (Craparo et al., 2015; Rahn, Vaast, et al., 2018).

In order to improve a crops' resilience towards climate change, its water balance should be well-understood. When evaluating plant-water relations, water-use efficiency (WUE) is a useful parameter. It is expressed as the amount of biomass or carbon produced per unit of water used (Briggs & Shantz, 1913). This parameter changes under varying environmental conditions, indicating the productivity of plants under those conditions. Plants with a high WUE under different conditions are desirable. Evaluating the WUE of coffee and banana at reduced water availability could help us understand how climate change will affect coffee and banana production.

WUE is however difficult to measure directly, especially in the field. Rather, proxies are used. The most direct estimation of WUE in leaves is the natural ratio between stable carbon isotopes 13C and 12C in the plant tissue (Kissel, Van Asten, Swennen, Lorenzen, &Carpentier, 2015). During photosynthesis, fractionation takes place whereby carbon dioxide (CO_2) containing 12C is preferentially built in. The extent of fractionation (expressed as delta (Δ), a ratio between 13C and 12C) depends on the amount of gas exchange, which is on its term depending on the gradient in CO_2 concentration (inside to outside the plant) and on the resistance to gas exchange. During water stress, plants tend to close their stomata, not to lose water. They use water in a more efficient way. Consequently, CO_2 exchange is impeded as well. Under these CO_2-limited conditions, the plant will build in any carbon available and no longer fractionate 12C and 13C to the same extent. Δ is thus different and this is the reason it can be used as a proxy for WUE. This linear relationship was defined mathematically by Farquhar, O'Leary, & Berry (1982). WUE can be expressed in terms of Δ, carbon assimilation (A), stomatal conductance (gs), CO_2

concentration in the air (ca) and two constants a and b, expressing fractionation rates within the plant.

$$WUE = \frac{A}{g_s} = \frac{c_a}{1.6}(\frac{b-\Delta}{b-a})$$

However, in reality, we see that this relationship between Δ and WUE does not always hold. Many parameters affect both factors in a different way and thus alter their relationship, some of the most important ones being stomatal and mesophyll conductance and carbon consumption rate (Seibt, Rajabi, Griffiths, & Berry, 2008). These factors depend to a certain extent on genetics but are also influenced by the environment. It is therefore crucial to understand which factors differ from leave to leave, plant to plant and field to field in order to understand the differences in Δ and to distinguish WUE from other effects.

To this purpose, we will initially measure Δ13C values in different leaves and plant parts and even within leaves to see the extent of variation in natural abundance and try to link this to differences in micro-climate. In addition, this will allow us to determine which plant (-parts) are suitable for sampling and give correct estimations of WUE. Furthermore, in-between plant variation will be looked at. This will help us understand how plant characteristics affect Δ values. Finally, a comparison will be made between fields under different treatments: monoculture versus intercropping and full irrigation versus deficit irrigation. All relevant environmental parameters will be measured simultaneously and parameters other than stable isotopes (like leaf temperature) will be evaluated as potential proxies for drought stress. Eventually, this will provide with an improved understanding of the water balance in coffee and banana, the physiology behind it and methods to measure it.

Way forward

- Feb-March 2020, Tanzania: continue temperature measurements, set-up new field trial, isotope sampling after onset dry season
- April - May 2020, Vienna: EGU conference, further lab analysis
- June-July 2020, Belgium: data-analysis, guide MSc student
- Aug 2020, Tanzania: Measurements in second trial during dry season
- Sept-Dec 2020, Belgium: Data-analysis, start first paper, follow-up MSc student, courses
- Jan- Ap 2021, Vienna: Set-up experiment in greenhouse, further data-analysis

- June-July 2021, Tanzania: repeat measurements in onset of dry season
- Aug-Dec 2021, Vienna: Measurements in greenhouse experiment, data-analysis, prepare last field measurements
- Jan- Feb 2022, Tanzania: Measurements on-farm
- March-Dec 2022, Vienna: Sample analysis, data analysis, publish, finalize PhD

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