INSTITUTE OF
APPLIED PLANT NUTRITION

ANNUAL REPORT 2022

RESEARCH ON SUSTAINABLE PLANT NUTRITION

Imprint

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November 2023

IAPN – Institute of Applied Plant Nutrition

at Georg-August-Universität Göttingen

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Preface

Dear readers,

with 2022, we look back on a year that was marked by the end of the Covid pandemic and the still ongoing transition phase to reorganize the junior professorship in Applied Plant Nutrition at IAPN. The agricultural and scientific environment in 2022, similar to everyday life, was dominated by the Russian aggression against Ukraine, so that we were confronted with skyrocketing prices for nearly all goods, particularly fertilizers. In research, this again led to numerous enquiries about options for improving nutrient-use efficiencies. Therefore, together with the ongoing need for efficient use of other resources like water, the research subjects at IAPN cover some of today's most urgent problems in agriculture.

On the following pages you will find introductions into our research topics and reports on IAPN's scientific achievements. I hope that you will enjoy reading the contributions, mostly written by young, enthusiastic junior researchers who are delighted to be able to conduct research on the problems of practical plant nutrition while working on the inspiring academic campus of the University of Göttingen.

With best wishes

Professor Dr. Klaus Dittert
Scientific director of IAPN

At IAPN, researchers work on their projects together with technical assistants and with students in an international atmosphere. The team uses advanced research methods and benefits from each other's knowledge and experience. (Photo: K+S)

IAPN at a Glance

Structure and development of the Institute of Applied Plant Nutrition – public-private partnership at the University of Göttingen

The Institute of Applied Plant Nutrition (IAPN) was initiated by Georg-August-Universität Göttingen and K+S Minerals and Agriculture GmbH following both institutions' impetus to strengthen the exchange in academic research and formation activities between the public academic institution and the private company sector. There is much common interest in questions related to sustainable nutrition of plants as well as in environmentally sound strategies for advancing agricultural systems of 21st century. Both partners have vital interest in promoting the formation of young scientists who, based on broad and solid knowledge, are capable of initiating, critically reflecting and developing new ideas and new research methods. IAPN is an Associated Institute and, as such, it is closely linked to the University of Göttingen and contributes to the University's core responsibilities, academic teaching and research. For both, the University and the Associated Institutes, the common rules of good scientific practice apply.

IAPN became active in 2012. Since then, IAPN's scientific and technical personnel were built up and a large number of methods and techniques were established. Researchers work on their projects together with Bachelor's and Master's students, who thereby get closely involved in IAPN's research activities. Moreover, many links to divisions of the Department of Crop Sciences and other University institutes have been established.

IAPN's objectives

Increasing demands for agricultural production and global changes necessitate progress in optimized crop nutrition, which can only be achieved with targeted research efforts. IAPN is committed to research and teaching on the role of resource-efficient use of nutrients in the plants' physiology. As an interface between research, teaching and practice we are involved in interdisciplinary knowledge exchange in a global network.

Our activities complement each other and mainly include:

- **Research**
  Focal point of our research is to improve our understanding of how the plant nutrients magnesium (Mg), potassium (K), and nitrogen (N) affect the self-protective mechanisms and performance of plants in situations of stress and deficiency. IAPN's research projects concentrate on water-use efficiency (WUE), photoprotection, photosynthesis, drought-stress tolerance and salt tolerance. Additionally, we explore remote sensing methods for early detection of nutrient deficiencies in plants as well as interactions of plant nutrients and the environment.

- **Teaching**
  The IAPN team is very active in offering classical lectures to students, as well as laboratory and greenhouse courses and insights into practical research. The institute also offers opportunities for students to do their Bachelor's, Master's or PhD thesis or internship.

- **Knowledge exchange**
  IAPN cooperates with experts and research institutions in various countries. On a worldwide basis, we strive to maintain a fruitful interdisciplinary knowledge exchange during conferences and on research visits of IAPN scientists in foreign countries. Also, visiting scientists and students as well as agricultural advisors and extensionists from abroad spend time at IAPN regularly. This way, we are creating synergies for successful research and practical implementation of research results.

The IAPN team

In 2022, the team of IAPN consisted of up to seven members in scientific staff, administration, and technical as well as laboratory assistance. The institute's scientific director is Professor Dr. Klaus Dittert. Heading the institute is part of his duties as director of the Division of Plant Nutrition and Crop Physiology in the Department of Crop Sciences at the University of Göttingen, to which the IAPN is closely associated. All administrative matters at IAPN are managed by Martina Renneberg. The technical and laboratory assistance is provided by Kirsten Fladung and Ulrike Kierbaum.

Dr. Paulo Cabrita continued his research on the application of digital and remote sensing methods in plant nutrition as well as in other projects that focus on the WUE and nutrient status of crop plants. In his latest publication, on using the non-invasive leaf patch clamp pressure (LPCP) probe, Paulo Cabrita showed how this method, so far used to monitor plant water status continuously, can also be used to study changes in the air pressure inside plant leaves. Paulo Cabrita's article "Non-invasive assessment of the physiological role of leaf aerenchyma in *Hippeastrum* Herb. and its relation to plant water status" was published in June 2022 in *Planta*. In 2022, he focuses on the plant-water relations of crassulacean acid metabolism (CAM) plants and the water exchange mechanisms between the hydrenchyma and the photosynthetic tissue (the chlorenchyma) in their leaves.

Tingting Liu, in the second year of her PhD project, investigated the development of apoplastic barriers under K deficiency, and their effect on K transport. She presented the latest results of her research at the 5th International Symposium on Plant Apoplastic Diffusion Barriers in Scotland in September 2022 and at the 54th Annual Conference of the German Society of Plant Nutrition one month later.

Since September 2022, Dr. Renata Callegari Ferrari from São Paulo, Brazil works as a guest scientist at IAPN and the Division of Plant Nutrition and Crop Physiology at the University of Göttingen. After completing her PhD in 2021, her thesis in the field of plant physiology was selected for the Highlight Recognition award by the University of São Paulo. Now, her research focuses on assessing photosynthesis in barley grown with different K availability under drought stress. For her research stay, she was awarded a Georg Forster Fellowship from the Alexander von Humboldt Foundation for two years.

Throughout the year, the IAPN team was supported by numerous graduate and undergraduate student assistants who helped in plant cultivation, measurements and the preparations of plant, soil, gas, biochemical and molecular samples. We are very grateful for their contributions.

The IAPN team: Dr. Renata Callegari Ferrari, Kirsten Fladung, Tingting Liu MSc., Ulrike Kierbaum, Martina Renneberg, Dr. Paulo Cabrita, Professor Dr. Klaus Dittert. (Photo: IAPN)

A young pineapple plant; cultivated in an IAPN experiment. (Photo: Cabrita)

Research

Linking plant nutrition and plant physiology

The growing world population, changing dietary habits and climate change place great demands on agricultural research. Increasingly, the focus in agriculture and agricultural sciences is on questions pertaining to the efficient use of arable land, pasture, water and plant nutrients. IAPN addresses these issues.

Our research projects concentrate on understanding the connection between plant physiology, plant nutrients and climatic as well as environmental impacts on plant production. Since the founding of IAPN, the institute's scientists contribute to the international advancements of research especially on the plant nutrients Mg, K and N, and their relation to WUE, drought stress tolerance, photosynthesis, photoprotection, and salt stress tolerance.

For early detection of nutrient deficiencies in plants, we are also exploring remote sensing methods.

The research at IAPN provides contributions to a number of scientific problems and solutions:

- Relevance of nutrients for stress tolerance in plants under changing climate conditions.
- Connection between mineral nutrition, fertilizers and water-use efficiency in the soil/plant system.
- Understanding alterations in the plants' physiology in response to fertilization.
- New strategies for improving fertilizer recommendations and management.

In 2022, IAPN's research activities were affected by the still present impacts of the Corona pandemic and the fact that it hasn't been possible to identify a new structure for the junior professor position at IAPN. However, some major results were published in 2022 and the current research topics and projects will be introduced on the following pages.

Growing big out of little: plant-water relations and water exchange mechanisms in leaves with crassulacean acid metabolism

Research project conducted by Dr. Paulo Cabrita

In order to adapt to unfavorable environments, often with severe limitations in the availability of water, in which most plants would live poorly or not even survive, plants have evolved different strategies to cope with such conditions. Among those strategies, the crassulacean acid metabolism (CAM) stands out as one of the most ingenious ways developed by plants to strive under a very limited water budget.

CAM is a carbon fixation physiological pathway that allows CAM plants to photosynthesize with a higher water-use efficiency compared to other plants. To fix the same amount of carbon and thus produce their biomass, CAM plants use less water than non-CAM plants under the same conditions, performing the so-called C_3 photosynthesis that is observed in most species of higher plants. However, CAM photosynthesis is not only observed in plants living in semiarid environments, but also in epiphytic plants and some aquatic plants. In the last case, the driving factor for performing CAM photosynthesis is not the limitations on water supply, rather the very high, hence unfavorable, competition for the acquisition of CO_2. In fact, it is now believed that the determining factor in the evolution of CAM photosynthesis was the limited availability of CO_2 that drove plants to develop strategies to improve their CO_2 fixation and photosynthesis, in the same way as other species under limiting CO_2 conditions developed the C_4 photosynthetic pathway. Consequently, by performing CAM photosynthesis, terrestrial plants conquered a niche in semi-arid environments by outperforming their competitors that were incapable to photosynthesize in the same way.

Today, CAM photosynthesis is observed in about 7% of all known plant species, belonging to 37 plant families, including some of important economic value, e.g., pineapple, agave, opuntia, and vanilla. Common to all of them, the CAM photosynthetic pathway is highly distinguished by the nocturnal fixation of CO_2, its subsequent storage in the form of organic acids in the cell vacuoles, their diurnal decarboxylation resulting in the release of CO_2 that is then used in the light period similarly to C_3 plants. Therefore, by opening the stomata mostly at night, when the air humidity is higher than during the day, in order to acquire CO_2, CAM plants lose less

Leaf patch clamp pressure probe on an Aloe vera plant leaf at IAPN: For assessing the plant water status a small patch of a leaf is clamped between two magnets. The force exerted by the magnets applies a constant pressure on the leaf patch. A sensor chip is embedded in one of the magnets and detects the pressure transmitted throughout the leaf patch – that is the attenuated pressure, P_p, of the original pressure exerted by the magnets. The data thus obtained, P_p values, are continuously recorded at specific time intervals that can be as small as 1 min. P_p is ultimately related to the leaf patch water status, from which one can infer about the overall plant water status. (Photo: Cabrita)

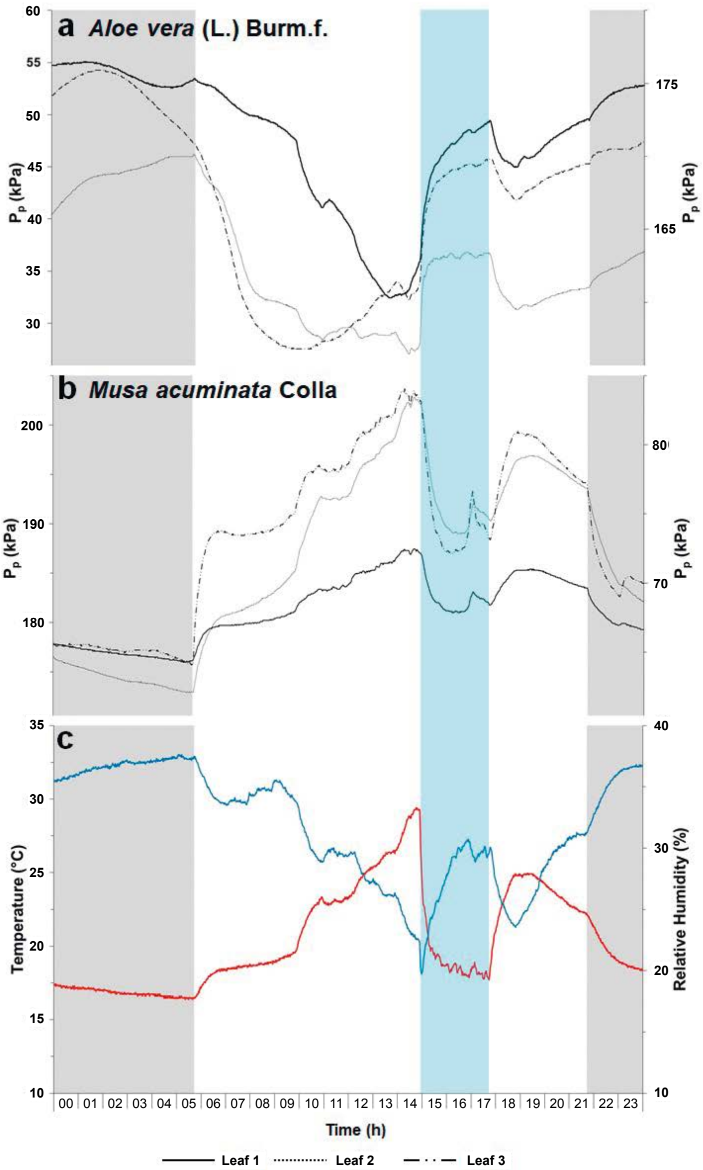

Figure 1: The changes in the LPCP output pressure, P_p, in *Aloe vera* (a) and banana (b) under a transient decrease (blue shaded area) in air temperature (red line) and corresponding increase in the relative humidity (blue line) (c). Dark period indicated by gray shaded areas. Leaf 3 referred to right-hand side axis. (Source: Cabrita)

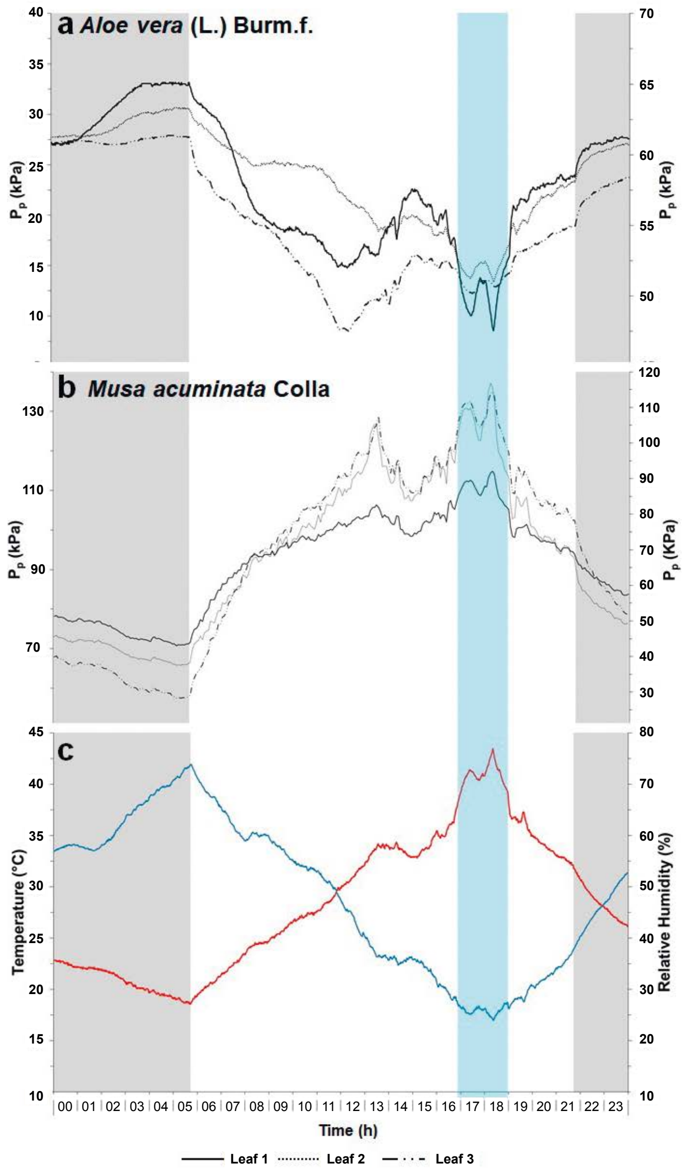

Figure 2: The changes in the LPCP output pressure, P_p, in *Aloe vera* (a) and banana (b) under a transient increase (blue shaded area) in air temperature (red line) and corresponding increase in the relative humidity (blue line) (c). Dark period indicated by gray shaded areas. Leaf 3 referred to right-hand side axis. (Source: Cabrita)

water compared to other plants that do not perform a similar photosynthetic pathway. CAM plants need thus less water than most plants to fix the same amount of CO_2 and ultimately grow and develop. Considering climate change and the related limitations on the availability of water in many regions of the world, the increasing interest in CAM plants is therefore not surprising. Additionally, the physiological machinery of CAM photosynthesis is quite versatile and many CAM plants can also perform C_3 photosynthesis depending on whether there are environmental stressors or not.

CAM photosynthesis is accompanied by specific anatomical adaptions that evolved to cope with limited water availability. These are mostly observed on the photosynthetic tissues and associated regions of the plant body. Among those adaptions, in some species, there is the development of a highly differentiated parenchyma tissue specialized in storing water, called the hydrenchyma.

Using non-invasive methods, this project focuses on the plant-water relations of CAM plants and the water exchange mechanisms between the hydrenchyma and the photosynthetic tissue (the chlorenchyma) in their leaves. To that end, leaf gas exchange measurements were combined with leaf patch clamp pressure (LPCP) probe measurements applied on pineapple (*Ananas comosus* (L.) Merr.) and *Aloe vera* (L.)

Burm f. plants, both CAM species, and compared with those of banana (*Musa acuminata* Colla [AAA group] 'Dwarf Cavendish'), a C_3 plant. The methods are non-invasive and allow continuous monitoring of photosynthesis and the plant water status, including long-term measurements. Plants were grown in 6 l pots in the greenhouse, watered and fertilized regularly, under a 16/8 h light-dark regime with a photon flux density that varied between 150 and 1400 μmol.m^{-2}.s^{-1} at 1 m above ground during the light period. Simultaneously, air temperature, relative humidity, and pressure in the greenhouse were also recorded continuously. Water deficit was imposed by withholding watering, while temperature treatments were done by opening and closing the greenhouse windows for specific periods of time.

The diel pattern of the leaf patch clamp pressure, P_p, of both pineapple and Aloe vera plants is reverse to that of banana. However, in these species, P_p is inversely related to the leaf patch turgor pressure, P_c, which relates to the tissue water content ultimately. This means that the higher the P_p values, the lower the leaf turgor, i.e., the lower the leaf water content. Hence, by following the changes in the values of the LPCP output pressure, P_p, one can follow the plant water status and evaluate its needs. Comparing both these species, one observes that there are differences at the time at which higher and lower leaf turgor pressure values are observed. However, although different, the P_p patterns observed on both species follow their respective diel photosynthetic activity and associated internal water dynamics.

The main difference observed in these measurements is due to the different leaf structure in these species. That is, while in banana, the LPCP output pressure, P_p, followed the changes in the leaf patch turgor pressure caused by transpiration during photosynthesis, in Aloe vera, P_p followed the changes in the hydrenchyma turgor pressure. In this species, the hydrenchyma composes more than 70% of the leaf volume, thus contributing far more for the LPCP output pressure value than that of the narrower chlorenchyma. Further evidence of such interpretation of LPCP data is given by the response of both plant species to rapid changes in temperature, as shown in Figure 1. In banana, the changes in photosynthesis caused by a sudden decrease in temperature, namely, the decrease in transpiration as the air humidity rose with the decreasing temperature, causing the leaf patch turgor pressure, P_c, to increase and concomitantly the P_p to decrease (Figure 1). In *Aloe vera*, as the stomata are closed, changes in the surrounding air humidity are irrelevant. But, the decrease in temperature slows down the photosynthetic activity, hence the utilization of the organic acids that have been stored in the previous night. Consequently, the decreased decarboxylation of those stored organics acids leads to an increase in the chlorenchyma water potential, thus, drawing more water from the nearby hydrenchyma decreasing its turgor pressure. Concomitantly, the LPCP output pressure, P_p, in *Aloe vera* will increase as temperature rapidly decreases. A new physiological equilibrium is reached once the lower temperature is stabilized. However, as soon as the temperature rises again, everything returns almost completely to its previous state (Figure 1). The reverse of these scenarios happens in both species if a sudden increase in temperature is caused instead (Figure 2).

This work presents not only a novel interpretation of the LPCP probe measurements, but also a new approach to monitor and study CAM photosynthesis and the water exchange processes associated with it. The LPCP probe allows us to observe non-invasively and continuously the hydrenchyma dehydration/rehydration dynamics and the internal redistribution of water within CAM plants leaves in response to treatments or changes in the surrounding environment.

K availability and photosynthetic modulations in barley

Research project conducted by Dr. Renata Callegari Ferrari
Scientific collaboration with Dr. Tino Kreszies

Renata Callegari Ferrari is investigating the role of K nutrition in photosynthesis during drought stress using barley (*Hordeum vulgare* L.) as a model species.

Throughout her stay, Renata Callegari Ferrari has been standardizing the experimental conditions using barley cultivars "Lexy" and "Avalon", both being on the list of recommended cultivars for the state of Lower Saxony. She has been pre-assessing whether her experiments would be conducted in soil and/or in hydroponic systems, hence performing multiple consecutive trials to compare the plants' development, nutrient deficiency phenotypes, and meaningful experimental drought duration. The first experiments performed at IAPN used a low-K soil from a long-term fertilization experiment conducted by the University of Göttingen. Then, she performed experiments in the hydroponic plant grow system at IAPN to develop a suitable combination of K deficiency and polyethylene glycol (PEG) treatment to simulate reduced water availability even in hydroponic systems. It was also important to assess the best barley developmental phase for conducting photosynthesis measurements and, concomitantly, to assess all other parameters, including the generation of a transcriptomic profile to match the physiological and anatomical analyses.

Overall, these first experiments were tested for K quantification in nutrient solution, soil, and leaves. Moreover, the relative water content in leaves was assessed to determine the water status of the plants, leaf anatomy, and photosynthetic pigments. The gas assimilation using the LI-6800 photosynthesis system (an infra-red gas analyzer) was used to characterize the photosynthetic attributes. In the next step, Renata Callegari Ferrari plans to start modelling the photosynthesis under the varying K concentrations, by analyzing chlorophyll *a* fluorescence and running A/C_i and light curves, both in normal and non-photorespiratory conditions (e.g., less than 2% O_2). All these physiological parameters will be correlated to the transcriptomic sequencing of barley leaves; an integrative approach that will provide an in-depth characterization of photosynthesis under drought stress and K nutrition combined.

The project is conducted in cooperation with the Division of Plant Nutrition and Crop Physiology in the Department of Crop Sciences at the University of Göttingen. For her research stay at the University of Göttingen, Renata Callegari Ferrari was awarded a Georg Forster Fellowship from the Alexander von Humboldt Foundation for two years. Additional funding for the project is provided by K+S Minerals and Agriculture GmbH.

Renata Callegari Ferrari and some of her experimental barley plants that were cultivated under various K concentrations and drought stress. (Photo: IAPN)

Effects of K deficiency on apoplastic barriers in soil-grown maize root

PhD research project of Tingting Liu
Supervisors: Dr. Tino Kreszies and Professor Dr. Klaus Dittert

In the year of 2022, Tingting Liu continued her PhD project "The effects of plant macronutrients on apoplastic barriers in soil-grown maize roots". She started her study with the nutrient element K.

Plant roots play a crucial role in the uptake and transport of nutrients in plants. According to the composite transport model there are three parallel pathways how water and nutrients are transported from the soil to the root central cylinder: (i) the apoplastic pathway, (ii) the symplastic pathway, and (iii) the coupled trans-cellular pathway. However, as the root matures, it forms apoplastic barriers such as suberin lamellae and Casparian bands, which are deposited in the endodermal and exodermal cell walls. These barriers are thought to be hydrophobic and may hinder the transport of water and nutrients.

In the root, the exodermis is the layer of cells located below the epidermis that serves as the first barrier for the transport of water and nutrients. Conversely, the endodermis, the innermost layer of cortex cells, separates the cortex from the central vascular system and controls the movement of water and nutrients into the stele. In addition to regulating the influx of nutrients and water, the endodermis also prevents the backflow of nutrient ions. As a result, the presence of apoplastic barriers in these cell layers can significantly affect the uptake and transport of nutrients and water. Interestingly, not all plant species have both exodermis and endodermis in their roots. For instance, Arabidopsis and barley only have an endodermis and do not form an exodermis. On the other hand, maize and rice have both exodermis and endodermis. Additionally, the formation of apoplastic barriers varies depending on the plant's environment, further complicating the study of the physiological and genetic regulation of these barriers.

K is an essential nutrient for the growth and development of crops, but little is known about the development of apoplastic barriers under K deficiency in maize. In this study, Tingting Liu focused on understanding how apoplastic barriers develop under low K conditions and their impact on K transport. To investigate this, she conducted an experiment in which she grew maize plants under two conditions: normal K concentration (control) and low K concentration (K deficiency). After harvesting the plants, she compared the development of apoplastic barriers and K content in the roots and analyzed the concentration of suberin via fluorescence microscopy and gas chromatography. As expected, Tingting Liu found that K deficiency resulted in reduced growth of maize plants. Interestingly, she also observed that the low K concentration induced the early development of suberization in the maize roots. The composition of the suberin polymer in maize roots included five substance classes including alcohols, fatty acids, diacids, ω-hydroxyacids, and 2-hydroxyacid, with a carbon chain length ranging from C16 to C28. In the next phase of the study, Liu plans to conduct transcriptomic analysis to better understand the genetic regulations of the apoplastic barriers.

The PhD project with a scheduled duration of three years is funded by the Chinese Scholarship Council and K+S Minerals and Agriculture GmbH.

The photograph displays the root-to-shoot junction of a young maize plant. The long seminal roots exhibit numerous slender lateral branches, whereas the recently developed brace roots are notably thicker, serving to stabilize the maize plants shoot. (Photo: Kreszies)

Tingting Liu examines freshly harvested maize roots for subsequent sampling, such as mineral nutrient analysis or determination of suberin concentrations. (Photo: Kreszies)

Teaching

Teaching at the University of Göttingen

An important objective of IAPN is to provide students with knowledge on nutrition and physiology of plants. For this, alongside classical lectures, practical parts and lab training units are included in the teaching activities. So, students get insight into the importance of plant nutrition and the different functions of single plant nutrients. Of course, students have options of doing a thesis at IAPN, at undergraduate, Master's and PhD level.

As the professorship for "Applied Plant Nutrition" at IAPN was vacant in 2022, the university educational programs of the professorship of Klaus Dittert including plant nutrition teaching modules in one Bachelor and three Master programs were continued. In contrast, the IAPN-specific lectures and courses were halted. However, in 2022, six Master's students completed their theses at IAPN which in all cases included experimental studies with plants and the respective laboratory analysis. The topics of these theses are listed in the following.

Completed student theses supervised by IAPN scientists in 2022

Tahar Ashfaq, MSc Thesis (2022): Comparison of wild and cultivated potato genotypes with regard to their phosphorus utilization efficiency

Fynn Claassen-Helmers, MSc Thesis (2022): Effects of N-fertilizer intensity and DMPSA on N_2O emissions in a potato field

Jonas Eckei, MSc Thesis (2022): Effects of growing plants and Nitrogen uptake on denitrification and denitrification product stoichiometry on the field scale

Dorothea Heil, MSc Thesis (2022): Einfluss von Stickstoff-Düngungsintensität und -form auf die Emission klimarelevanter Gase bei Kartoffeln

Shiwei Li, MSc Thesis (2022): Benzoic acid as candidate for soil nitrification inhibition – effects on soil microbial communities and gas emissions as influenced by soil moisture

Beatrice Thumb von Neuburg, MSc Thesis (2022): Effect of wood vinegar on germination and juvenile development of *Zea mays* L.

Knowledge Exchange

Interdisciplinary discourse with scientists and practitioners

IAPN strives to expand its international and national cooperation with professionally complementary institutions and researchers. In addition, IAPN consciously turns to practice-oriented research. The institute aims to transfer the already available scientific knowledge into practice more intensively, but also to formulate open research questions jointly with national and local practitioners and scientists.

IAPN at the 5th International Symposium on Plant Apoplastic Diffusion Barriers and the 54th Annual Conference of the German Society of Plant Nutrition

In 2022, Tingting Liu presented a poster about her latest research projects at two conferences. Her poster was entitled "The effect of potassium deficiency on apoplastic barriers development in soil-grown maize roots", with Klaus Dittert and Tino Kreszies as co-authors.

The 5th International Symposium on Plant Apoplastic Diffusion Barriers was held from September 13th to 15th 2022 in Dundee, Scotland with invited speakers from Europe, Asia, and North America.

From October 4th to 5th 2022, the Annual Conference of the German Society of Plant Nutrition (Deutsche Gesellschaft für Pflanzenernährung e.V., DGP) took place at the Academic Centre Raitenhaslach of the Technical University of Munich. The conference was organized by the Division of Crop Physiology of TUM, and it was held under the topic "From Molecules to Traits – How Plants Feed the Future". Invited speakers came from Japan, Denmark, England, and Germany.

The effect of K deficiency on apoplastic barriers development in soil-grown maize roots

Tingting Liu[1], Klaus Dittert[1,2], Tino Kreszies[2]
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Introduction

1. Potassium (K) plays a vital role in a plethora of physiological processes including water and nutrient uptake.
2. In plant roots, the formation of suberin and Casparian bands in the endo- and exodermis can limit the apoplastic transport of water and mineral nutrients. Maize develops both endodermis and exodermis.
3. There is little knowledge about how suberin and Casparian bands in endo- and exodermis develop under K deficiency in maize.

Purpose

To elucidate the relationship between K nutrition and apoplastic barriers, we grew maize in soil with different K concentrations and analyzed the development of suberin and Casparian bands in roots.

Experimental design

-control: 100 mg K per kg soil

-K-deficiency: 24 mg K per kg soil

Results

1. K deficiency reduces plant growth

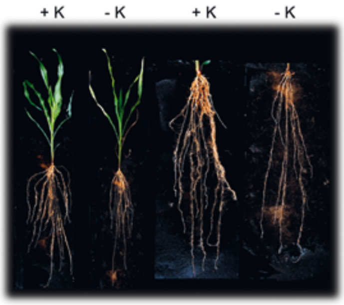


Fig. 1 Maize plants under K deficiency.

2. K content in maize primary root and seminal roots

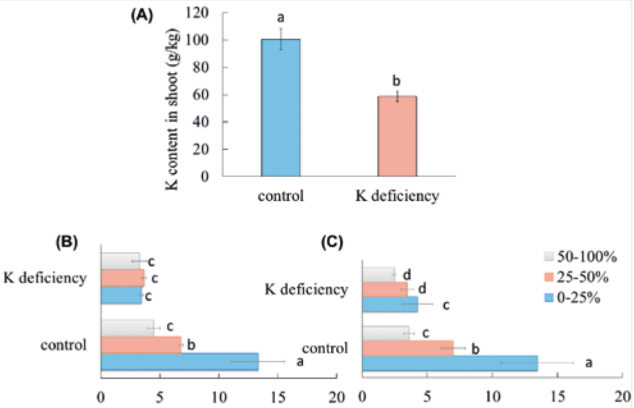


Fig. 2 K content in maize shoot (A) and primary root (B) and seminal root (C). (The root is divided into three zones: 0-25%, 25-50% and 50-100 of the total root length calculated from root tip).

3. K deficiency leads to early formation of suberin and Casparian bands

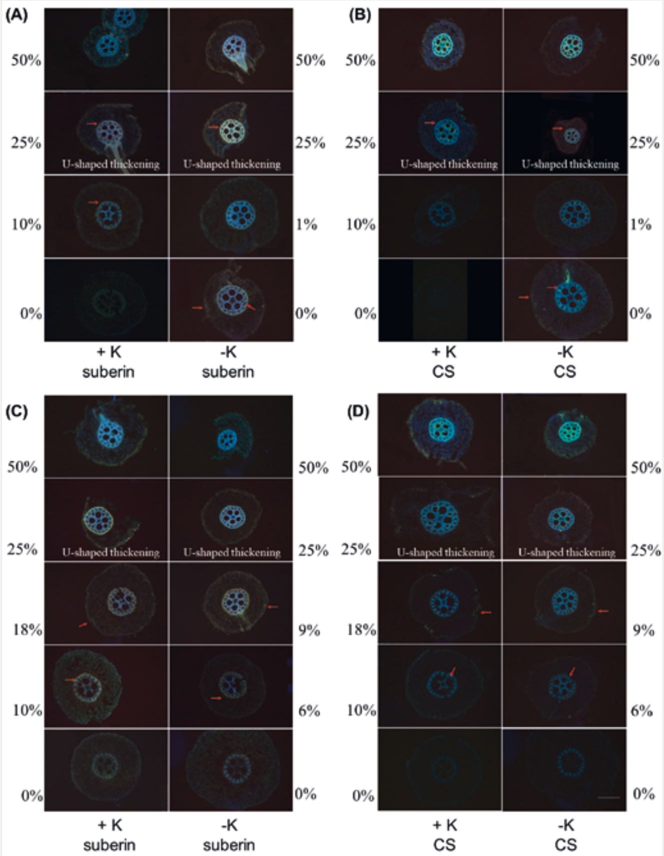


Fig. 3 Suberin and Casparian bands (CS) development at different position in maize primary root (A, B) and seminal root (C, D). Bars, 8 µm.

Conclusions and prospects

1. K deficiency significantly reduces plant shoot and root growth.
2. K deficiency leads to earlier formation of suberin and Casparian bands along the maize primary and seminal roots compared to the control plants.

The poster presented by Tingting Liu at the 5th International Symposium on Plant Apoplastic Diffusion Barriers in Dundee, Scotland, and at the 54th Annual Conference of the German Society of Plant Nutrition in Munich, Germany. (Source: IAPN)

Guests and visitors at IAPN

Knowledge exchange and establishing international networks are always important aims of IAPN. Visits of scientists and students are often funded by public institutions like the German Academic Exchange Service DAAD, non-governmental organizations or the private sector. During their stay, some visitors bring in their own research ideas and in one way or another, all of them get involved with IAPN's research projects and methods. In 2022, apart from Renata Callegari Ferrari, whose research has been introduced in previous pages, two other guests visited IAPN in 2022 to conduct their research with our team.

Professor Dr. Abdullah Ulas conducting research at IAPN

From June to September 2022, Professor Dr. Abdullah Ulas investigated several nutritional aspects of grafted tomatoes at IAPN and the Division of Plant Nutrition and Crop Physiology in the Department of Crop Sciences at the University of Göttingen. His stay is part of joint research activities between IAPN and the Department of Soil Science and Plant Nutrition of Erciyes University in Kayseri, Turkey, where he is assistant professor since 2011. To intensify the scientific exchange and to seek for fostering the cooperation between Erciyes University and IAPN, several common research interests had been identified.

One of the joint research activities is the project "Improving Nitrogen Use Efficiency (NUE) and Drought Tolerance in some Pre-Selected Tomato Varieties by Grafting", initiated and managed by Abdullah Ulas. Following the focus of this project, he conducted a hydroponic experiment on NUE and drought tolerance in grafted tomato cultivars under controlled growth chamber conditions. Although grafted fruit and vegetable plants are widely grown in many countries, i.e., two different genotypes grow with each other in one plant, questions about their nutritional physiology are still virtually unresolved.

At Erciyes University, Abdullah Ulas is head of the Division of Plant Nutrition at the Department of Soil Science and Plant Nutrition and director of the Agricultural Research and Applied Center. He supervises many national and international Master's and PhD theses, which are part of various research projects funded mainly by the Turkish Scientific and Technological Research Council (TÜBITAK). He published numerous scientific papers in national and international scientific journals. Furthermore, he attended many national and international symposiums with oral and poster presentations in Turkey, Germany, Italy, Croatia, Poland, Kyrgyzstan, and Portugal. Before taking up his professorship at Erciyes University in Kayseri, Turkey, Abdullah Ulas had obtained his Master's and doctoral degrees at the Institute of Plant Nutrition at Leibniz University Hannover under the supervision of Professor Dr. Walter Horst.

Professor Dr. Abdullah Ulas. (Photo: Ulas)

Abdullah Ulas measuring the Nitrogen Nutrition Index of grafted tomato plants using a DUALEX hand-held multispectral photometer. (Photo: Ulas)

Kamilla Himinec visiting IAPN based on a European Erasmus+ internship

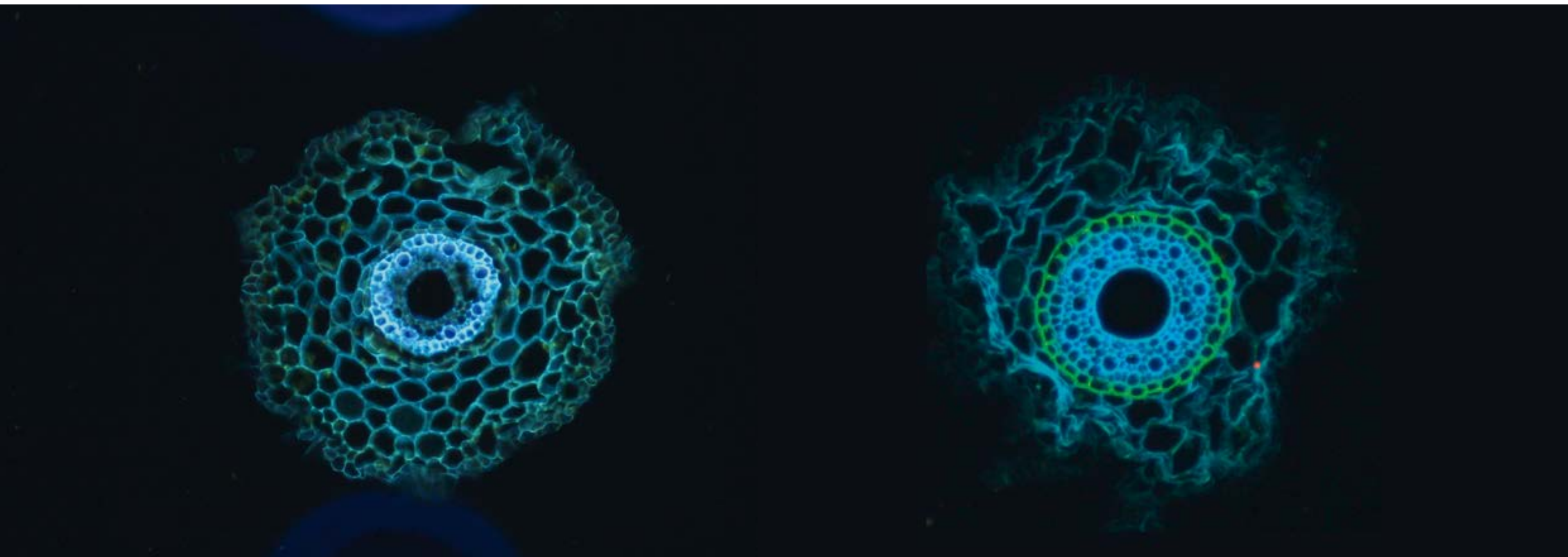
Kamilla Himinec, Erasmus+ student from Ukraine, joined IAPN for a three-month's voluntary internship following the completion of her Bachelor studies at the University of Debrecen, Hungary. She holds a degree in Horticultural Engineering and came to broaden her scientific skills by engaging in various ongoing research projects. Earlier in 2022, she also completed an internship at the University of Aarhus in Denmark.

During her time in Göttingen, she worked under the supervision of postdoctoral researchers Renata Callegari Ferrari and Tino Kreszies, and she contributed to routine analysis conducted by research technicians at the University of Göttingen and IAPN. She was mainly involved in Renata Callegari Ferrari's project which focuses on the role of K in photosynthesis during drought stress, utilizing barley (*Hordeum vulgare* L.) as a model plant. Here, Kamilla Himinec helped to standardize experimental conditions for upcoming trials. Hence, she acquired experience in plant cultivation both in soil and hydroponic systems. She gained knowledge in inducing different levels of K supply and subjecting plants to drought stress. Her primary responsibilities included assembling hydroponic experiments and monitoring K availability while the plants grew.

Furthermore, she observed the different growth phases of barley and learned about the associated K deficiency symptoms and effects of drought (osmotic stress) simulated with PEG8000. This particular experiment required performing K quantification assays in nutrient solution and leaves, measuring the relative water content of leaves in response to drought exposure. Here she familiarized herself with the LI-6800 portable photosynthesis system, an infra-red gas analyzer to measure CO_2 assimilation.

The typical visual Mg deficiency symptoms – interveinal chlorosis. (Photo: Himinec)

While working with Tino Kreszies, Kamilla Himinec conducted an experiment in a hydroponic system with barley to monitor Mg deficiency symptoms in order to analyze the deposition of suberin in roots. She was also in charge of sampling the plant material for a comprehensive barley root characterization and in addition, she utilized the cryostat microtome and fluorescence microscopy for histological analyses of nutritional effects on suberinisation at different developmental phases of barley roots.



Comparison of cross sections of barley seminal roots stained with Fluorol Yellow 088 grown under Mg deficiency (left) or control conditions (right). The yellow fluorescence shows the suberized cells in the endodermis in roots grown under moderate Mg supply (right). It was observed that under Mg deficiency the suberin deposition was delayed (left). (Photos: Himinec and Kreszies)

Publications

Work published in peer-reviewed journals and proceedings (including non-IAPN publications of IAPN employees, e.g., reports on previous research activities)

Cabrita, P. (2022) Non-invasive assessment of the physiological role of leaf aerenchyma in *Hippeastrum* Herb. and its relation to plant water status. Planta 256, 19. https://doi.org/10.1007/s00425-022-03930-2

Dittert, K. and Buerkert, A. (2022) Special problems of plant nutrition - tropical and subtropical climates (in German). In M. Wachendorf, A. Buerkert, & R. Graß (Eds.), Organic agriculture (Ökologische Landwirtschaft) (2 ed., pp. 299-310). Stuttgart, Germany: Eugen Ulmer

Füllgrabe, H.; Claassen, N.; Hilmer, R.; Koch, H.J.; Dittert, K. and Kreszies, T. (2022) Potassium deficiency reduces sugar yield in sugar beet through decreased growth of young plants. J PLANT NUTR SOIL SC 185:545-553. https://doi.org/10.1002/jpln.202200064

Koebke, S.; He, H.; Boeldt, M.; Wang, H.T.; Senbayram, M. and Dittert, K. (2022) Climate overrides effects of fertilizer and straw management as controls of nitrous oxide emissions after oilseed rape harvest. FRONT ENV SCI-SWITZ 9: 625. https://doi.org/10.3389/fenvs.2021.773901

Piepel, M.F.; Dittert, K. and Olfs, H.W. (2022) Evaluation of physicochemical on-farm quick tests for estimating nutrient concentrations in pig slurry and development of an application for mobile devices. AGRONOMY 12: 1-2. https://doi.org/10.3390/agronomy12112809

Suriyagoda, L.; Tränkner, M. and Dittert, K. (2022) Growth and nutrition of rice seedlings when phosphorus or silicon was applied to a soil heavily contaminated with both arsenic and cadmium. J PLANT NUTR 45: 1849-1865. https://doi.org/10.1080/01904167.2022.2027977

Tavakol, E.; Jákli, B.; Cakmak, I.; Dittert, K. and Senbayram, M. (2022) Optimization of potassium supply under osmotic stress mitigates oxidative damage in barley. Plants, 11,55. https://doi.org/10.3390/plants11010055

Wang, H.T.; Oertelt, L. and Dittert, K. (2022) The addition of magnesium sulfate and borax to urea reduced soil NH_3 emissions but increased N_2O emissions from soil with grass. SCI TOTAL ENVIRON 803. https://doi.org/10.1016/j.scitotenv.2021.149902

Conference talks – papers – posters

Geries, S.; Röder, C. and Dittert, K. (2022): Reduction of diffuse phosphorus inputs by new VDLUFA guideline values based on a eutrophic lake in northern Lower Saxony (in German). 133rd Annual Conference of the Association of German Agricultural Inspection and Research Institutes VDLUFA, September 13th-16th, Halle/Saale, Germany.

Liu, T.; Dittert, K. and Kreszies, T. (2022): The effect of K deficiency on apoplastic barriers development in soil-grown maize roots. Annual Conference of the German Society of Plant Nutrition (DGP). October 4th-5th, Munich, Germany.

Liu, T.; Dittert, K. and Kreszies, T. (2022): The effect of K deficiency on apoplastic barriers development in soil-grown maize roots. Plant Apoplastic Diffusion Barrier 2022, September 13th-15th, Dundee, Scotland.

Cooperation in Science

Partner	Location
Al-Quds Open University	Jerusalem, Palestine
Bodengesundheitsdienst	Ochsenfurt, Germany
Chamber of Agriculture	Hannover and Oldenburg, Germany
China Agricultural University	Beijing, China
Erciyes University, Department of Soil Science and Plant Nutrition	Kayseri, Turkey
Institute of Sugar Beet Research (IfZ)	Göttingen, Germany
International Magnesium Institute (IMI)	Fuzhou, China
Julius Kühn-Institut, Institute for Crop and Soil Science	Braunschweig, Germany
K+S Analytik- und Forschungszentrum (AFZ)	Unterbreizbach, Germany
K+S Minerals and Agriculture GmbH	Kassel, Germany
LUFA Nord-West, Institut für Düngemittel und Saatgut	Hameln, Germany
Sabanci University, Biological Sciences and Bioengineering Program	Istanbul, Turkey
SKW Stickstoffwerke Piesteritz GmbH	Lutherstadt Wittenberg, Germany
Thünen-Institute – Institute of Climate-Smart Agriculture	Braunschweig, Germany
University of Göttingen	Göttingen, Germany
Plant Pathology and Crop Protection	
Division of Quality and Sensory of Plant Products	
Functional Agrobiodiversity	
University of Halle, Institute of Plant Nutrition	Halle, Germany
University of Kassel, Organic Plant Production and Agroecosystems Research	Witzenhausen, Germany
University of Peradeniya	Peradeniya, Sri Lanka
University of São Paulo	São Paulo, Brazil

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