IAPN
INSTITUTE OF
APPLIED PLANT NUTRITION

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RESEARCH ON SUSTAINABLE PLANT NUTRITION

Imprint

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IAPN – Institute of Applied Plant Nutrition

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Preface

Dear reader,

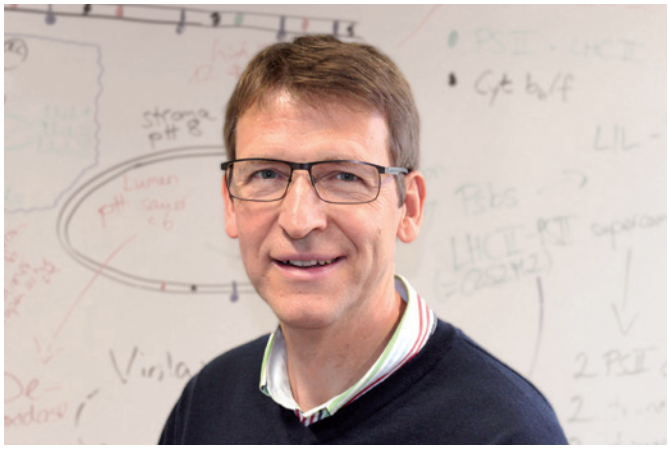
with 2019, the second year in a line of very dry years for the farming community in Germany and large parts of Europe, we look back at a period in which water-use efficiency and drought tolerance of crop plants, the key subjects of research and teaching at IAPN, received great attention. 2019 was a year of important results in our research, for instance in setting the first knowledge base for remote sensing of crop responses to magnesium (Mg) fertilization. IAPN provided a systematic review and meta-analysis of critical plant leaf Mg thresholds for photosynthesis, plant growth and photo-oxidative defense. In another research topic, we outlined the importance of potassium (K) for quinoa (*Chenopodium quinoa* Willd.) which is an important crop cultivated under moderately saline soil conditions. In these and several other areas, the research of IAPN scientists addressed subjects of high scientific and societal impact. Several awards have been received, for example the "Förderpreis" for the Bachelor's thesis of Henriette Quehl issued by the German "Association for the Promotion for the Potato Industry" or the poster prize for the contribution of Setareh Jamali at the annual conference of the German Society of Plant Nutrition. These were great acknowledgements of the excellent scientific level of the young researchers studying and working at the University of Göttingen and at IAPN.

An important step in advancing the impact of our research has been the successive improvement of plant analytical facilities in the field of stress physiology by the junior research team of Professor Dr. Merle Tränkner in recent years. Given the greater capacity and flexibility of such structures, they will play an increasingly important role in IAPN's capabilities to provide new knowledge in relevant future research subjects.

Beyond our research and the university teaching with classical formats like lectures, practical courses and seminars, IAPN contributed to public outreach by joining the University of Göttingen's "Night of Knowledge" and by providing another webinar on K and drought stress.

I hope this report will provide interesting new views. For an up-to-date look at our ongoing activities, I recommend visiting IAPN's webpages at www.iapn.de. Whether online or on paper – I am looking forward to your comments and suggestions: info@iapn.de.

Professor Dr. Klaus Dittert
Scientific director of IAPN



As an Associated Institute, IAPN is closely linked to the University of Göttingen's Department of Crop Sciences at the Faculty of Agricultural Sciences. IAPN's scientific director Professor Dr. Klaus Dittert (left) is heading the Department's Division of Plant Nutrition and Crop Physiology. Professor Dr. Merle Tränkner (right), who is head of IAPN's junior research group, is leading the Department's Division of Applied Plant Nutrition. (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 according to Lower Saxony's tertiary education legislation. Consequently, 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, 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 were established and cooperations were brought on their way.

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 Mg, 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, photoprotection, photosynthesis, drought-stress tolerance and salt tolerance. Additionally, we explore remote sensing methods for early detection of nutrient deficiencies in plants.

- **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.

Research, teaching and knowledge exchange: IAPN scientists, assistants and students are working together in an international atmosphere, using advanced research methods, and benefitting from each other's experience. (Photos: K+S)

The IAPN team

In 2019, the team of IAPN consisted of up to ten members in scientific staff, administration, and technical as well as laboratory assistance. The institute's scientific director is Professor Dr. Klaus Dittert. Professor Dr. Merle Tränkner holds the junior professorship. All administrative matters are managed by Martina Renneberg.

In January 2019, Dr. Ariel Turcios joined the team as a postdoctoral scientist. He supports the teaching in the field of applied plant nutrition. On the research side, he focusses on investigating the importance of K in quinoa cultivated under saline conditions, and on Mg distribution in plants.

Annika Lingner and Dr. Melanie Hauer-Jákli both left IAPN in April 2019 and took on new professional challenges. During the previous months, after her successful doctorate, Annika Lingner had worked as a postdoc within the IMPAC^3 project at IAPN. She also taught within the scope of Bachelor's modules, at the Department of Crop Sciences of the University of Göttingen. Melanie Hauer-Jákli had successfully completed her work on IAPN's meta-analysis of "Critical leaf nutrient concentrations for plant growth and photosynthesis". It was jointly published with Merle Tränkner in *Frontiers in Plant Science* in June 2019.

Dr. Paulo Cabrita continued his research on "The application of digital and sensing methods in plant nutrition" as well as in other projects that focused on the water-use efficiency and nutrient status of crop plants. Setareh Jamali Jaghdani, in the second year of her PhD studies, conducted trials on the impact of Mg deficiency on the photosystem functionality and photosynthetic efficiency. Together with her supervisor Merle Tränkner, she published the previous year's research results in the article "Minimum magnesium concentrations for photosynthetic efficiency in wheat and sunflower seedlings" (*Journal of Plant Physiology and Biochemistry*).

In August 2019, our technical and laboratory assistance received support: the team of Kirsten Fladung and Ulrike Kierbaum was complemented by Wael Alyoussef. He supports the project "The application of digital and sensing methods in plant nutrition".

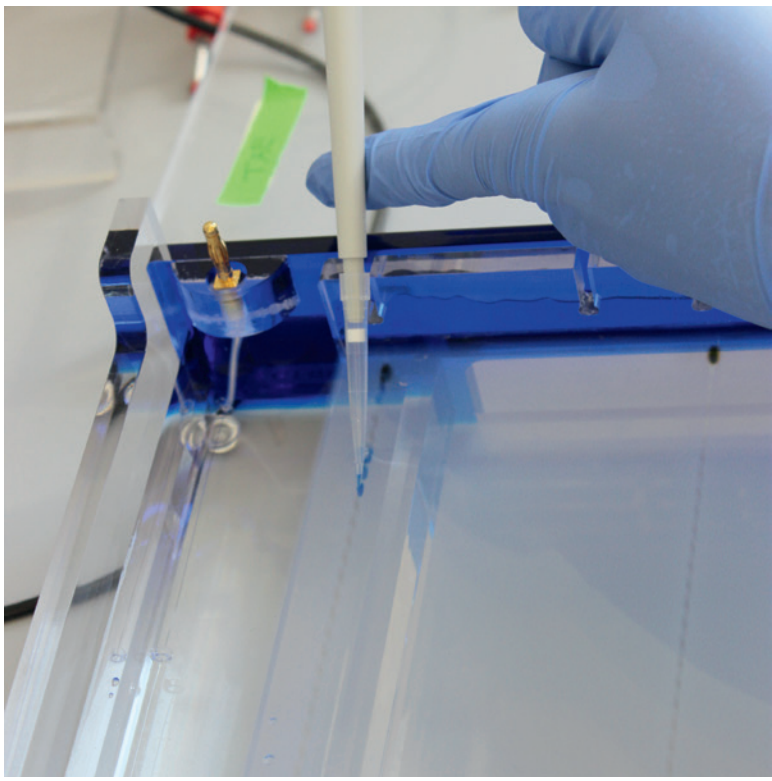
Throughout the year, the IAPN team was intensively supported by many graduate and undergraduate student assistants who helped in plant cultivation, measurements and preparations of numerous plant, soil, gas, biochemical and molecular samples. Their contribution is greatly acknowledged.

The IAPN team: Martina Renneberg, Wael Alyoussef, Setareh Jamali Jaghdani MSc., Dr. Paulo Cabrita, Dr. Ariel Turcios, Kirsten Fladung, Ulrike Kierbaum, Professor Dr. Klaus Dittert and Junior Professor Dr. Merle Tränkner (from left). (Photo: Urstadt)

Wael Alyoussef and Rizal Andi Syabana, student assistant at IAPN, harvesting wheat samples of an experiment which was developed in cooperation with the start-up company Spacenus for the project "Digital assessment of crop nutrient status". (Photo: Tränkner)

Mg deficiency in a spinach grown in an experiment of IAPN's PhD student Setareh Jamali Jaghdani. (Photo: Tränkner)

Soybean plants grown under aluminum (Al) toxicity and nutrient deficiency. (Photo: Tränkner)



Pipetting of DNA samples for gel electrophoresis to visualize amplification products obtained by polymerase chain reaction (PCR). (Photo: Tränkner)

Measurement of chlorophyll fluorescence on a soybean leaf. (Photo: K+S)

Research

IAPN topics

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 water-use efficiency, drought stress tolerance, photosynthesis, photoprotection and salt stress tolerance. For early detection of nutrient deficiencies in plants, we are also exploring remote sensing methods.

IAPN scientists focus on a range of concrete problems and their 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.

The following pages will introduce you to IAPN's junior research group and the research activities in 2019.

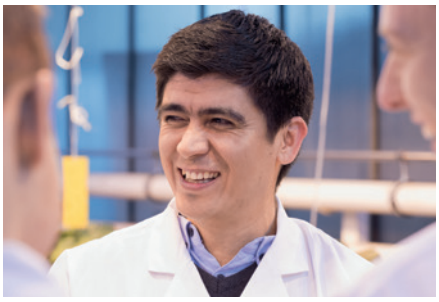
IAPN's junior research group

Merle Tränkner is junior professor for "Applied Plant Nutrition" at IAPN and at the Department of Crop Sciences of the University of Göttingen since 2017. In addition to research and teaching, her professorship includes heading the scientific working group at IAPN. Focal points of her research are Mg nutrition, photoprotection and water-use efficiency.

Junior research group

Before joining IAPN in 2018, **Paulo Cabrita** worked on the application and development of remote sensing methods to monitor and determine morphological and physiological parameters both on test trials as well as at field level in forests and crops. He obtained his PhD in plant physiology in 2011 at the Justus Liebig University Giessen.

Ariel Turcios completed his PhD in biology at the Leibniz University Hannover in 2016 focussing on the use of halophytes as biofilters to decrease organic and inorganic contaminants in water. He holds a Master's degree in water resources management, and a Bachelor's degree in agricultural engineering.



Setareh Jamali Jaghdani finished her Master's studies at the Faculty of Agricultural Sciences in the Division of Plant Pathology and Crop Protection at the University of Göttingen in 2017. In 2013, she did her Bachelor's degree in agricultural engineering – horticulture at the University of Tehran.

Quantification of plant responses to Mg fertilization using remote sensing

Research project conducted by Paulo Cabrita in cooperation with Dr. Stefan Erasmi from the Cartography, GIS and Remote Sensing Section from the Institute of Geography, University of Göttingen. Part of the planned field work was carried out by Christian Elm, Master's student at the Faculty of Agricultural Sciences, and Jana Lorenzl, Bachelor's student at the Faculty of Geoscience and Geography, as part of their theses.

The project's main goal is to understand the plant response to Mg fertilization, namely on plant growth and development, using remote sensing combined with field measurements. A field with inherently low soil Mg status was selected for studying the development of winter wheat (*Triticum aestivum* L.). Growth and properties were monitored and surveyed at specific times until harvest. Field data collection and satellite imagery (WorldView-3 Satellite) were scheduled at specific dates, complemented with weather and phenological data. Field work involved gas exchange measurements, leaf reflectance measurements (field spectrometry), leaf sampling for subsequent analysis on pigments (chlorophyll, carotenoids, and anthocyanins) and Mg content.

The increase in the amount of leaf pigments observed shortly after Mg fertilization is mostly due to increases in biomass and leaf area index, agreeing with what is called Mg-induced N uptake. Leaf pigments, specially at early developmental stages, do not seem to be good indicators of Mg content in plant leaves, most probably due to their diverse physiological role. The application of high-resolution satellite images proved to be a very useful method to monitor not only plant development, but also physiological and morphological responses to Mg fertilization, which can be used in precision farming. First results were presented as poster contribution at the conference of the German Society of Plant Nutrition "Plant Nutrition meets social expectations of sustainable plant production", in Berlin, September 2019.

Remote sensing trial with winter wheat on a field in Ahlten, close to Hannover, that had a naturally low Mg status. The trial was conducted in order to analyze the effects of Mg deficiency on photosynthesis as well as water-use efficiency and the consequent hindrance on plant growth and development. (Photo: Tränkner)

Digital assessment of crop nutrient status

Research project conducted by Paulo Cabrita

At the end of 2019, K+S Minerals and Agriculture GmbH and Spacenus GmbH, a start-up based in Darmstadt, announced a cooperation on developing the digital product Agricultural Nutrient Assistant (ANA). This technology aims to support farmers in the area of precision farming. As part of the cooperation a trial using spring wheat, subjected to different levels of nutrient deficiencies, was established to provide data for training and testing artificial intelligence (AI) models.

Plant hydraulic mechanisms in response to drought stress

Research project conducted by Paulo Cabrita

The leaf patch clamp pressure probe (LPCP) was used to investigate the hydraulic mechanisms involved in the dynamics of plant water relations, namely plant responses to drought stress. Compared to other methods that measure plant water status, the LPCP offers advantages as it monitors plant water status continuously. The patch clamp pressure output, P_p, resulting from two small magnets applied on a leaf or a suitable plant part is inversely related to the leaf patch turgor pressure, P_c, which relates to the tissue water content. Hence, the ability to observe the changes in P_c non-invasively and continuously makes it possible to follow the dehydration/rehydration kinetics, i.e. the internal redistribution of water, over diel scales in response to treatments.

Different plant species were submitted to varying water supply under different environmental conditions. Experiments were carried out in a growth chamber under controlled conditions and in a greenhouse with monitored temperature and relative humidity. Drought stress on the plants in hydroponics was simulated by using polyethylene glycol 6000 in the nutrient solution. First results indicate that under varying water supply regimes plants redistribute water within their tissues, prioritizing different water needs between older and younger tissues. Well hydrated plants show a hysteretic relationship between P_p and temperature (Figure). As the day advances, temperature rises and P_p increases up to a maximum reflecting the decrease in turgor due to transpiration. As temperature decreases after noon so does transpiration, which causes P_p to decrease resuming to levels similar to those observed previously at dawn. The shape and area defined by the hysteresis loop relate to the kinetics and hydration state of the plant, thus water stress level. The continuous monitoring of the patch clamp pressure output, P_p, proves to be an efficient way of assessing plant water status as well as assisting on irrigation and water management.

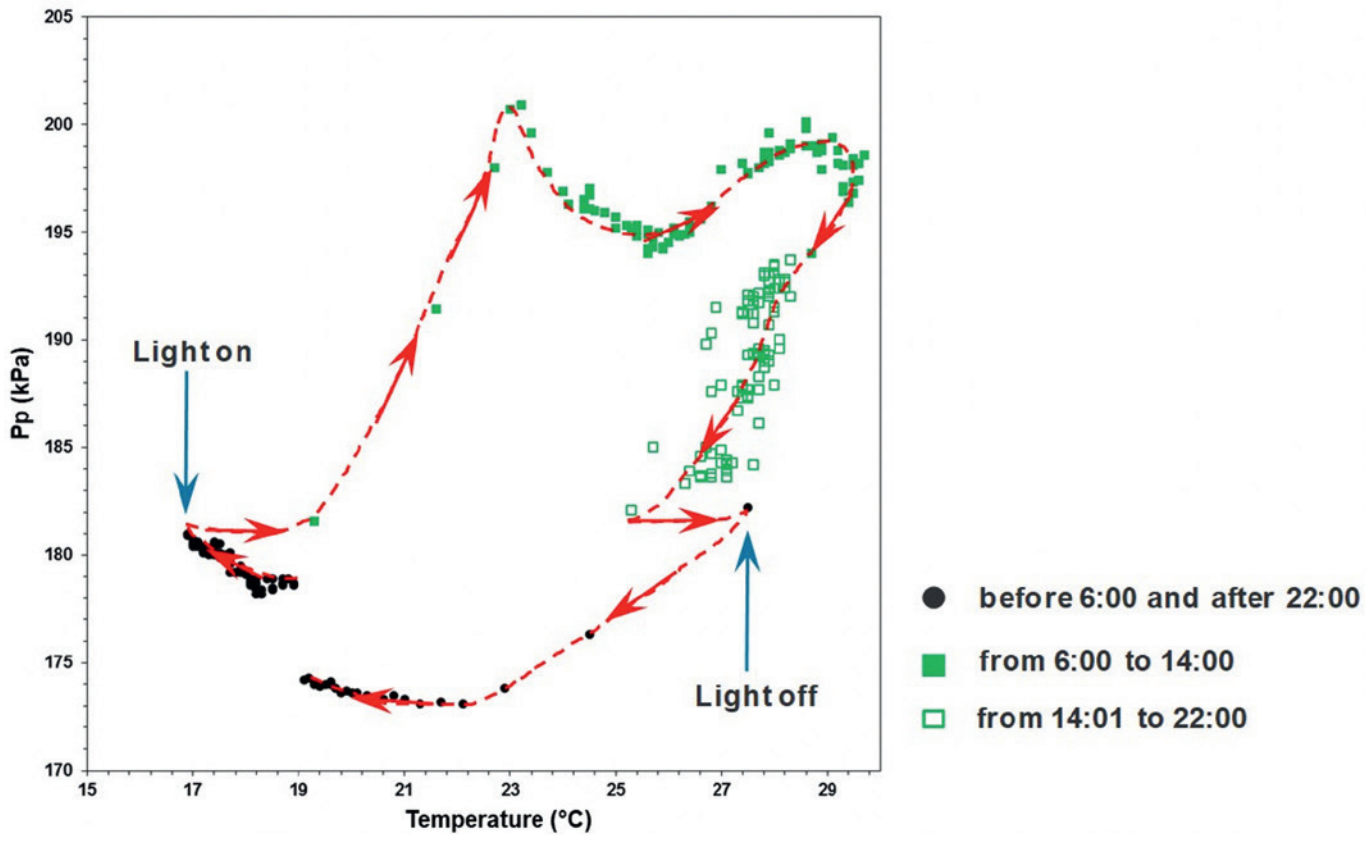


Figure: Hysteresis between the patch clamp pressure, P_p, and temperature observed on a leaf of soybean (*Glycine max* (L.) Merr.) under a 16/8 light-dark cycle in greenhouse. Indicated by red arrows is the progression of measurements following the local time. (Source: Cabrita)

Importance of K in *Chenopodium quinoa* cultivated under saline stress

Research project conducted by Ariel Turcios

It is estimated that about 15 % of the total land area of the world has been degraded by soil erosion and physical and chemical degradation, including soil salinization. Currently, salt-affected soils are naturally present in more than 100 countries of the world, where many regions are also affected by irrigation-induced salinization. Based on this, halophytes play an important role as they are salt-tolerant plants. The facultative salt-tolerant species *Chenopodium quinoa* (Figure 1) is a very important crop due to its edible seeds and its ability to grow in highly saline environments. It has been selected by the Food and Agriculture Organization of the United Nations (FAO) as one of the crops destined to offer food security in future.

Sodium chloride (NaCl), the most prevalent salt in soils, adversely affects the acquisition of essential nutrients because sodium (Na^+) competitively inhibits the uptake of K^+, calcium ($Ca2^+$) and other cations, whilst chloride (Cl^-) restricts anion uptake, affecting ion homeostasis within the plant. Furthermore, salinity may create specific ion toxicity as unbalanced presence of Na^+ and Cl^- in cellular and intracellular compartments inhibits many enzymatic activities, altering a wide range of important physiological processes for plant growth.

Figure 1: *Chenopodium quinoa* cultivated under saline conditions. (Photo: Turcios)

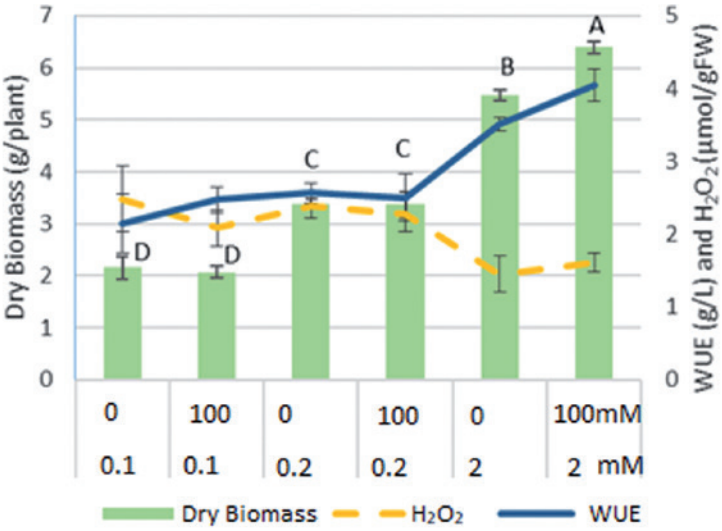


Figure 2: Dry biomass, water-use efficiency (WUE) and H_2O_2 concentration in quinoa plants supplied with different K concentrations (0.1, 0.2, and 2 mM K supplied as KSO_4) under non-saline (0 mM NaCl) and saline conditions (100 mM NaCl). FW = fresh weight. (Source: Turcios)

Plants have different mechanisms to counteract salt stress and this depends on each species. For example, *Chenopodium quinoa* has specialized trichomes known as salt glands or bladders. Sequestration of absorbed salt into these structures appears to be an efficient strategy contributing to salinity resistance in some drought and salt tolerant species. In addition, under salt stress, quinoa tends to take up and accumulate K^+. Thus, the regulation of K^+ homeostasis is an important aspect of salt tolerance, and the ability to retain an optimal Na^+/K^+ ratio is believed to be crucial for tolerance or adaptation to salt stress. As first results, it was observed that K is very important in quinoa to increase its biomass and the water-use efficiency (WUE) (Figure 2).

The aim of this research is to quantify the role of inorganic ions, mainly K^+, for osmotic adjustment in quinoa, and investigate the accumulation of K^+ and Na^+ in the roots, and their transport to the shoot under saline conditions. For this purpose, several morphological and physiological parameters (e.g. stomatal density, biomass production, Na^+/K^+ ratio, chlorophyll content, photosynthesis rate, WUE, leaf area) are determined.

Mg distribution and re-translocation within the plant

Research project conducted by Ariel Turcios

Mg is essential for the synthesis of chlorophyll, and it is known that when there is a Mg deficiency, the chlorophyll concentration in plants decreases. The activity of the enzyme responsible for the insertion of Mg into the chlorophyll molecule, Mg chelatase, depends on the concentration of the available Mg. Hence, chlorophyll synthesis is decreased in case of Mg deficiency. However, depending on the Mg uptake and status of the plant, young growing leaves show no decrease in chlorophyll concentrations, while old leaves show symptomatic chlorosis and reduced chlorophyll concentrations. This effect can be attributed to the remobilization of Mg and its translocation from old leaves to young leaves, causing a decrease in Mg concentration in old leaves first. Degradation of chlorophyll is believed to be a strategy to release Mg when the concentration of Mg in the plant is insufficient.

Assessment of the chlorophyll concentration of a leaf that shows symptoms of Mg deficiency, using a chlorophyll meter (SPAD-502 by Konica-Minolta, Japan). The small handheld device allows a non-invasive, thus non-destructive measurement. (Photo: D. Jákli)

In order to understand in more detail how translocation processes affect the chlorophyll synthesis and degradation in different leaves, an experiment was carried out to investigate whether reduced chlorophyll concentrations in old leaves are a result of degradation (Mg recycling) or impaired biosynthesis (insufficient Mg concentrations) of chlorophyll. For this purpose, the chlorophyll biosynthesis and its degradation products in young and old leaves are investigated. Analyses will continue in 2020.

PhD student Setareh Jamali Jaghdani (right) demonstrates results of gas exchange measurements to her supervisor Merle Tränkner. (Photo: K+S)

Capacity and efficiency of photosynthesis and photoprotective mechanisms under Mg deficiency in crop plants

PhD research project of Setareh Jamali Jaghdani

Setareh Jamali Jaghdani started her PhD in January 2018. The title of her project is "Capacity and efficiency of photosynthesis and photoprotective mechanisms under magnesium deficiency in crop plants – linking plant physiology with plant genomic and proteomic reactions", hence her studies within this project focus on Mg nutrition. It is funded by K+S Minerals and Agriculture GmbH.

Mg is often called the "forgotten element" since it is neglected in plant nutrition in many regions. It plays various important roles in plants during their growth and development. Being the center atom of chlorophyll molecule, Mg deficiency induces chlorophyll degradation. It acts as a cofactor modulator for the most important enzyme in photosynthesis, ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco). It has been found that under Mg deficiency the activity of Rubisco is reduced. Since Mg is an important element in photosynthetic apparatus, its deficiency affects carbon dioxide (CO_2) assimilation and thereby stomatal conductance.

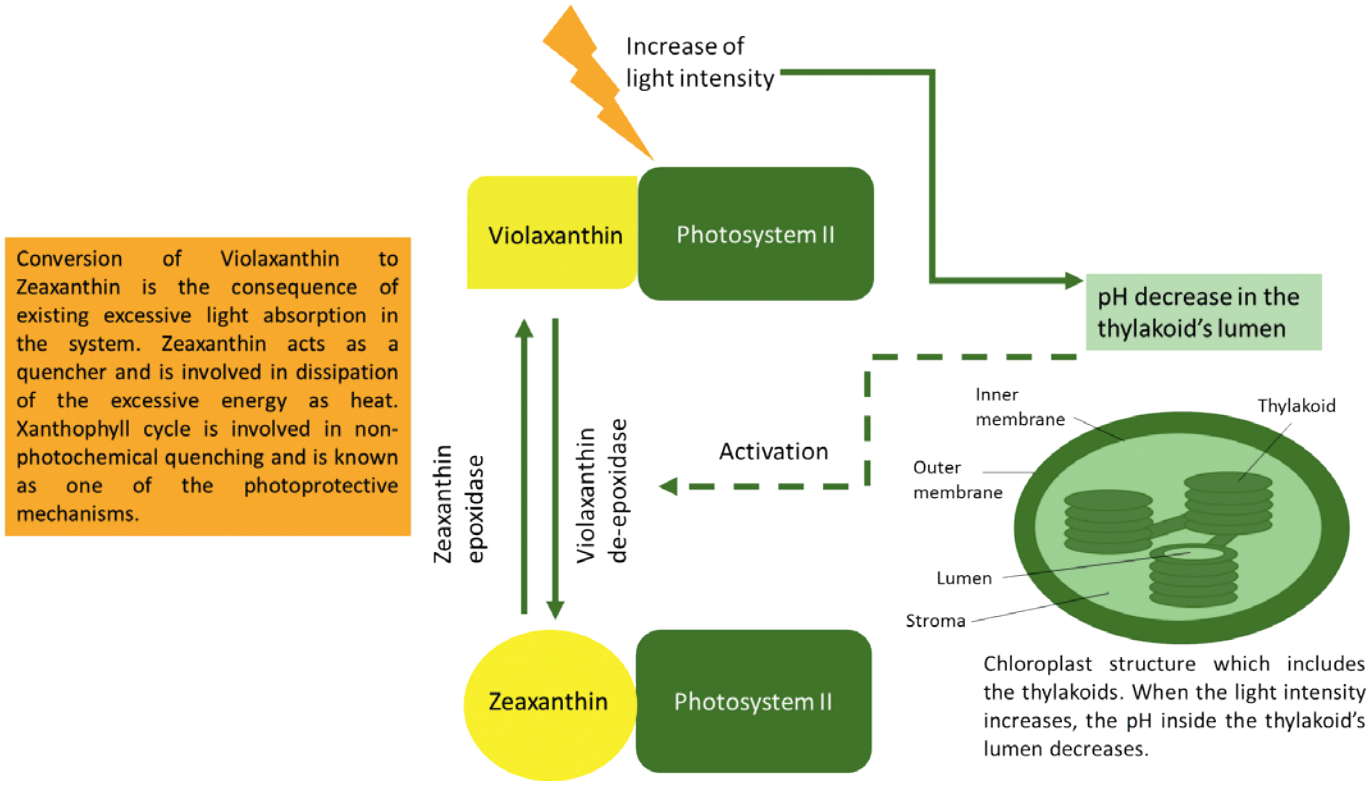


Figure: Schematic illustration of the xanthophyll cycle during the photosynthesis. (Source: Jamali-Jaghdani)

Under Mg deficiency, light energy becomes excessive and is beyond the utilization capacity of the photosynthetic apparatus. In this situation, production of reactive oxygen species (ROS) is increased. ROS are toxic, damage the photosynthetic system and cause cell death. Plants have developed mechanisms to cope with this excessive energy, which are called "photoprotective" mechanisms. One of the mechanisms is detoxification of ROS via different enzymes. Another mechanism is dissipation of excessive energy as heat, called non-photochemical quenching (NPQ), involving the "xanthophyll cycle". When within the photosynthetic machinery the absorption of light increases, the pH inside the thylakoid's lumen (matrix inside the lumen) decreases and activates an enzyme called "violaxanthin de-epoxidase". This enzyme converts the pigment violaxanthin to zeaxanthin and thereby initiates the NPQ mechanism. As the light absorption reduces, pH will be increased, and zeaxanthin will be converted back to violaxanthin (see figure).

The mechanism of NPQ is not yet completely resolved and the impact of Mg nutrition on the functioning of NPQ is studied only scarcely. Thus, the PhD project of Setareh Jamali Jaghdani aims at understanding the changes in photoprotection and photosynthetic processes under various Mg supplies.

During the first year of her PhD, she conducted experiments with different Mg concentrations in different crops such as wheat, sunflower and barley in order to identify the minimum Mg supply, which has a direct effect on photosynthesis rate and photosynthetic efficiency. The results were published in autumn 2019 (Traenkner M. and Jamali Jaghdani S. (2019), Minimum magnesium concentrations for photosynthetic efficiency in wheat and sunflower seedlings, *Plant Physiology and Biochemistry,* 144: 234-243, https://doi.org/10.1016/j.plaphy.2019.09.040).

In the second year, she continued with experiments in barley plants which were grown under various Mg treatments. The aim was to assess the photosynthetic efficiency and CO_2 assimilation and investigate the level of oxidative stress by analyzing the expression of genes related to enzymes responsible for detoxification of ROS, such as superoxide dismutase (SOD), ascorbate peroxidase (APX) and glutathione reductase (GR) and catalase (CAT). For complementing the measurements of NPQ, she extracted the pigments involved in xanthophyll cycle including violaxanthin and zeaxanthin for their quantification. It is planned to publish the results in 2020.

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 traditional 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 the single plant nutrient. Of course, students have options of doing a dissertation at IAPN, at undergraduate, Master's and PhD level.

Experiencing plant nutrition and plant physiology

Teaching at IAPN is interactive, promoting discussions and sustainability of learning. Lectures provide theoretical knowledge on photosynthetic leaf gas exchange, water-use efficiency and plant physiology under conditions of stress, such as nutrient deficiency. In practical exercises students conduct measurements and biochemical analyses of plant material and learn to depict and interpret the data gained.

The current Bachelor's course at IAPN is entitled "Plant Nutrition meets Plant Physiology – Experimental Work at the Intersection of these Disciplines". The module targets at students of agricultural sciences with focus on "Crop Sciences". It provides expert knowledge on the roles of nutrients in plant physiology and on the symptomatology of various nutrient deficiencies. The course is held by Merle Tränkner and Ariel Turcios.

Bachelor's students listening to explanations of a measurement by Merle Tränkner. Here, she demonstrates how to identify a suitable leaf for photosynthesis measurements. (Photo: D. Jákli)

Hands-on research: quinoa – a salt-tolerant "Superfood-Crop"

In this unit, students investigate the influence of salt stress, comparing the reactions of salt-tolerant and of salt-sensitive plants. Quinoa plants are used as an example of salt-tolerance. In Guatemala, Ariel Turcios' country of origin, this is a crop with considerable economic relevance. But not only in Guatemala: the United Nations General Assembly declared 2013 the "International Year of Quinoa". Worldwide, this so-called "Superfood" has been receiving increasing attention. "We did not initially tell students which plants they were looking at in the greenhouse. When they found out they were looking at quinoa, they were very excited. In general, people are familiar with the seeds, but not with quinoa plants", says Merle Tränkner. And Ariel Turcios adds: "I particularly enjoy introducing students to crops from abroad and how these are cultivated, and to then identify similarities and differences in the worldwide production systems."

From lecture hall to greenhouse

By attending expert lectures students acquire knowledge on the functions of nutrients in plants. The focus is on the processes of photosynthesis and transpiration. This is followed by the various parameters of water-use efficiency and their determination. The latter is based on measuring the sugars, which are produced during photosynthesis and are required for plant growth, and the amount of water the plant used for transpiration. Transpiration is influenced by abiotic factors such as drought or soil salinity. Soil salinity is induced by a higher concentration of salts in soil, resulting in decreased availability of water to plants.

Experimentation is used to link the theory on plant-physiological reactions conveyed in lectures to applied research. For these experiments, conducted in parallel to the lectures, students raise plants and induce nutrient deficiency, salt stress, drought stress or a combination of these stress factors. In weekly practice sessions, students then learn how to conduct measurements on plants, focusing on photosynthetic leaf gas exchange and water-use efficiency.

Learning, measuring, analyzing: students apply modern practical research methods and become acquainted with state-of-the-art expert knowledge on the roles of nutrients in plant physiology and nutrient deficiency symptoms – in addition to theory mediated in lectures. (Photos: D. Jákli)

Field trip on plant nutrition research and sustainable use of fertilizers

On June 12th and 13th 2019, Klaus Dittert offered a field trip on plant nutrition research and sustainable use of fertilizers. About 30 Bachelor's students of Göttingen University took part. The excursion started with a visit of the research station Hanninghof of the fertilizer company Yara in Dülmen, where the participants were introduced to different research projects. The focus of these projects is the development of innovative fertilization systems with special regard to the improvement of water- and N-use efficiency while simultaneously protecting the environment through sustainable nutrient management.

On June 13th, the first station was the Field Day in Hamerstorf, near Uelzen, organized by the Chamber of Agriculture of Lower Saxony. Here, students saw and discussed ground water protection-oriented crop rotations, fertilizer schemes and research methods.

Soil scientists of the Chamber of Agriculture of Lower Saxony discuss the special properties of the widespread sandy soils in this region based on a c. 1.5 m depth soil profile. Also, concepts of water-saving irrigation systems and their interaction with plant nutrient efficiency are reflected. (Photo: Dittert)

In the field, Master's student Christian Elm demonstrates how photosynthetic gas exchange on a leaf and of the entire plant canopy is measured. (Photo: Dittert)

IAPN field trial in Ahlten

Afterwards, the group visited the IAPN field trial in Ahlten, close to Hannover, where Merle Tränkner and Paulo Cabrita joined to explain their research. The trial focused on wheat that received different Mg fertilizer treatments to study changes in the photosynthetic capacity, pigment composition and water-use efficiency in response to varying Mg supply. Here the students got insights into several novel methods for analyzing plant physiological performance in the field and they saw new approaches for non-destructive assessment of the Mg nutritional status of crop plants in the field.

Before measurements were shown in the field, Merle Tränkner and Paulo Cabrita explained the background of the experiment and the related plant physiological processes.

"It was a very successful excursion and the students were pleased with the wealth of interesting subjects and methods", says Klaus Dittert. And Merle Tränkner adds: "I enjoyed to demonstrate to the students how science can be conducted in the field."

IAPN scientist Paulo Cabrita explains which pigments are present in plants such as the red poppy in his hand. Also, he presents results obtained from satellite images of the field which show different vegetation indices such as Chlorophyll Index. He introduces how the technology of remote sensing including satellites can contribute to evaluate plant stresses in the field. (Photo: Tränkner)

Writing a thesis: development award for Bachelor's thesis by Henriette Elisabeth Quehl

For her Bachelor's thesis Henriette Elisabeth Quehl received the development award of the Förderungsgemeinschaft der Kartoffelwirtschaft e.V., association for the promotion of the potato industry in Germany. Her thesis was entitled "Influence of Potassium and Drought Stress on Leaf Gas Exchange, Assimilate Formation and the Content of Chlorophyll and Free Amino Acids in *Solanum tuberosum* L.". It was written as part of a joint project between the Division of Quality of Plant Products and IAPN. Both of them are institutions of the Department of Crop Sciences at the University of Göttingen.

For her experimental research project Henriette Quehl cultivated potato plants in a hydroponic system, in which the plants' roots were immersed in a nutrient solution. In her study, she supplied the plants with various K concentrations, and some treatments included drought stress. Measurements of leaf gas exchange provided information on the photosynthetic performance and the transpiration rate of the differently treated plants. These measurements were complemented by analyses of the concentrations of the leaf pigment chlorophyll, free amino acids and sugars glucose and fructose.

"We consider the work done by Ms. Quehl an excellent example for the integration of potatoes in topical research", is how Helge Johannes explains the awarding decision. He is chairman of the Förderungsgemeinschaft der Kartoffelwirtschaft e. V. Identifying strategies to cope with drought stress is one of the most relevant issues in today's crop production. The award was endowed with 250 euro and also included publication of the research results in the agricultural magazine *Kartoffelbau*, in the beginning of 2019.

The thesis was supervised by Dr. Marcel Naumann from the Division of Quality of Plant Products and by Merle Tränkner from IAPN acting as co-supervisor. Assistance in plant cultivation and lab analyses was provided by the staff of both divisions.

Henriette Quehl conducts research in the exterior greenhouse facility of the Division of Quality of Plant Products and IAPN. Among other issues, her research addresses the influence of K and drought stress on leaf gas exchange in potato plants. (Photo: IAPN)

Completed theses supervised by IAPN scientists in 2019

Caroline Benecke, MSc Thesis (2019):
Der Einfluss von Kaliumversorgung und Trockenstress auf Photosynthese und Metaboliten am Beispiel der Kartoffelsorte Agria

Anna-Lena Doehring, BSc Thesis (2019):
Stickstoffnachlieferung aus zwei Böden mit verschiedenen Nachlieferungseigenschaften nach Einarbeitung unterschiedlich gedüngter Zwischenfrucht

Christian Elm, MSc Thesis (2019):
Wassernutzungseffizienz und Ertragsbildung von Winterweizen bei unterschiedlicher Magnesiumversorgung aus Boden und Düngung im Feldversuch

Finn Esche, BSc Thesis (2019):
Steuerungsoptionen für die effiziente Pflanzenproduktion in Vertical Farming Systemen

Henrik Füllgrabe, BSc Thesis (2019):
Kaliumverfügbarkeit im Boden: Einfluss auf Wachstum, Ertrag und Qualität von Zuckerrüben

Torben Gruß, MSc Thesis (2019):
Mineralstoffverteilung, Photosynthese- und Metabolitenanalyse in der Kartoffel (*Solanum tuberosum L.*) bei unterschiedlicher Kaliumversorgung und Trockenstress

Jana Lorenzl, BSc Thesis (2019):
Monitoring der Bestandsvariabilität in Winterweizen mit in situ Spektroskopie

Frank Morgenroth, MSc Thesis (2019):
Löslichkeit verschiedener schwefelhaltiger Mineraldünger in einem Freilandgefäßversuch mit Sommerweizen (*Triticum aestivum*) und einem Perkolationsversuch

Justus Palisaar, BSc Thesis (2019):
Analyse von unterschiedlichen photoprotektiven Mechanismen unter verschiedenen Magnesiumversorgungsbedingungen in Gerste (*Hordeum vulgare*) mithilfe molekularer Methoden

Olivia Luisa Peiß, BSc Thesis (2019):
Einfluss der Korngröße von Düngemitteln auf die P-Verfügbarkeit in Gefäßversuchen

I Made Arisudana Putra, MSc Thesis (2019):
Influence of magnesium deficiency on photosynthetic parameters and carbon flux of wheat and sunflower

Marco Rohleder, MSc Thesis (2019):
Stickstoffbilanzierung im Kontext der novellierten Düngeverordnung – Auswertung exemplarischer Beispielbetriebe

Daniel Schickhoff, MSc Thesis (2019):
Effects of N-fertilizer form and application method on N_2O emissions of potatoes

Gesa Schulz, BSc Thesis (2019):
Auswirkungen des Klimawandels auf die Pflanzenproduktion

Nico Willich, BSc Thesis (2019):
Das Potential zur Klärschlammvererdung für die Phosphatrückgewinnung in Deutschland

Master's students of IAPN's molecular lab course "Modern Plant Nutrition" discussing the harvest procedure to obtain leaf samples for RNA extraction. (Photo: Tränkner)

The wheat experiment is run with the help of student assistants who provide support in plant cultivation. The experiment was developed in cooperation with the start-up company Spacenus and is supervised by Paulo Cabrita. (Photo: Tränkner)

IAPN's intern John Kumi during sampling of barley leaves. (Photo: Tränkner)

Knowledge Exchange

Interdisciplinary discourse with scientists and practitioners

Global environmental, economic and demographic change call for an interdisciplinary knowledge exchange to successfully answer the numerous needs for agricultural research. IAPN strives to expand its cooperation with professionally complementary institutions and researchers, nationally as well as internationally. And, 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.

Guests at IAPN

Visiting scientists and visiting students are very welcome at the institute. Typically based on funding by public institutions such as the German Academic Exchange Service DAAD, non-governmental organizations or the private sector, IAPN offers internships of up to three months. The interns are integrated into the ongoing work and projects at IAPN. Some even bring their own research ideas, which are then implemented in their own projects. Internships offer a great opportunity for an intensive exchange of knowledge, from which both sides can benefit: the young multipliers can pass on their knowledge in their home countries, while IAPN benefits from the knowledge they have taken into IAPN from their countries of origin.

In 2019, **Master's student John Kumi from Ghana** joined the IAPN team as an intern for two months. He worked on a project focusing on options for reducing aluminum (Al) toxicity. Using a hydroponic system, he conducted an experiment with different supply levels of the plant nutrients Mg and boron (B) and examined the effects on Al toxicity in the plant. Afterwards, he measured a range of parameters regarding growth and plant physiology. John Kumi ran these tests in close cooperation with Ariel Turcios. The internship was part of the Master's program "Agrobiotechnology", which John Kumi took at the Justus Liebig University Giessen.

In 2014, John Kumi already spent an internship at IAPN. At that time, he was still enrolled in the Bachelor's program at Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. His 2014 stay at IAPN was sponsored by the student internship program "International Association for the Exchange of Students for Technical Experience" (IAESTE).

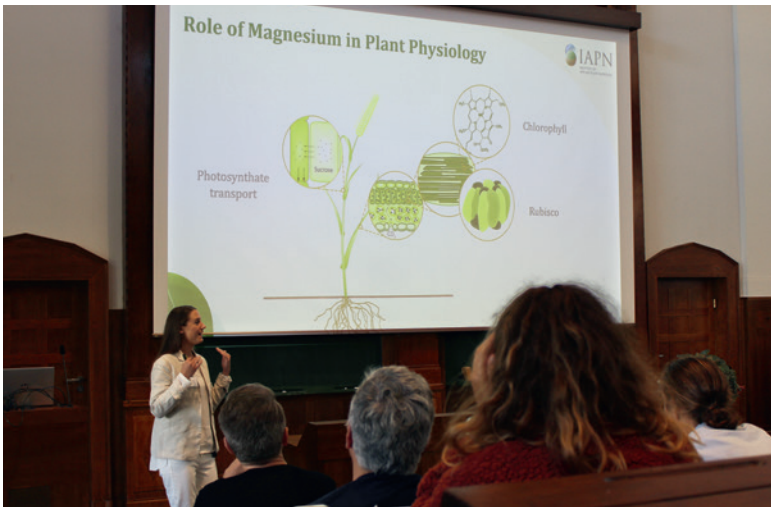
Master's student John Kumi (second from left) working together with Wael Alyoussef, Ariel Turcios, and Master's student Anupa Alice Mathew in the greenhouse (from left to right). (Photo: K+S)

The annual conference of the German Society of Plant Nutrition

The annual conference of the German Society of Plant Nutrition, Deutsche Gesellschaft für Pflanzenernährung (DGP), was held from September 25th to 27th 2019 in Berlin. The main theme was "Plant Nutrition meets social expectations of sustainable plant production". This year, more than 100 participants attended the conference with a wide range of contributions covering the diversity of plant nutrition research. All scientists of the IAPN team participated.

Merle Tränkner presented the meta-analysis on 70 years of Mg studies

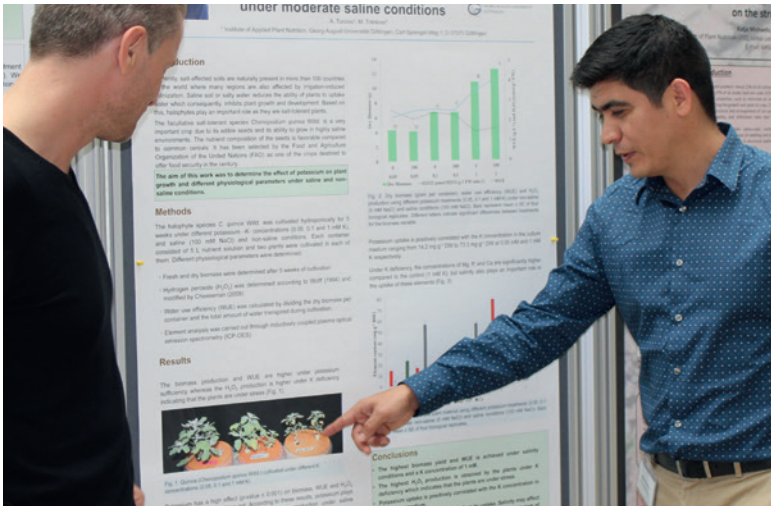
Merle Tränkner gave a talk entitled "Critical Leaf Magnesium Thresholds for Plant Growth" within the session about environmentally friendly plant nutrition. She presented results of a systematic review and meta-analysis that was performed on Mg studies published over the last 70 years. She showed that critical Mg concentrations for biomass formation fall within the range of 0.1 to 0.2 % for numerous crop species such as wheat, potato, rice, maize, sorghum and barley, but critical Mg concentrations are mostly higher for net CO_2 assimilation than for biomass formation.



Merle Tränkner introduces results of a meta-analysis on scientific Mg studies from 1950 to 2018. (Photo: Jamali)

Poster of Ariel Turcios addressed the effect of K in quinoa plants

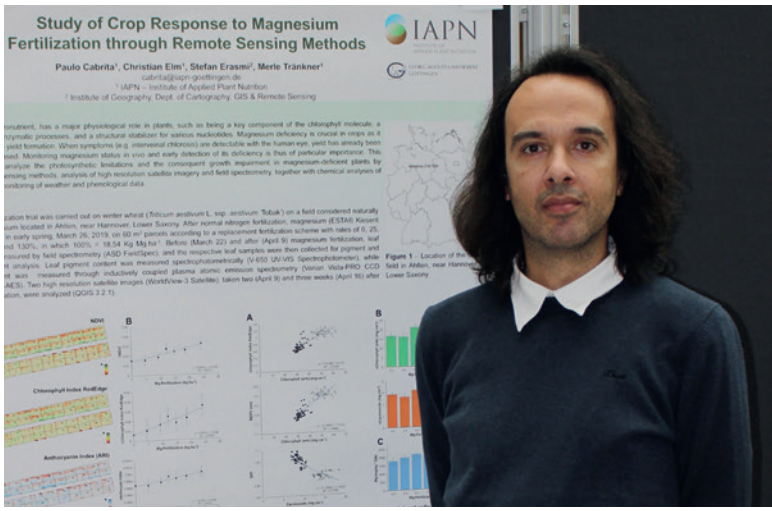
Both postdoctoral researchers Ariel Turcios and Paulo Cabrita presented posters. Ariel Turcios' poster was entitled "Importance of potassium for quinoa (*Chenopodium quinoa* Willd.) cultivated under moderate saline conditions". It highlighted the effect of K on plant growth and plant physiology for quinoa plants grown under saline and non-saline conditions. The study demonstrated that K is a very important nutrient to increase the productivity of the facultative halophyte *Chenopodium quinoa* Willd. His study showed that salinity may negatively affect K uptake even when the K supply is considered adequate due to the antagonism of the two cations Na and K.



Knowledge exchange at the DGP conference 2019: Ariel Turcios explains how K affects the growth and physiology of the facultative halophyte *Chenopodium quinoa* Willd. (Photo: Tränkner)

Remote sensing in a field trial on Mg: research results of Paulo Cabrita

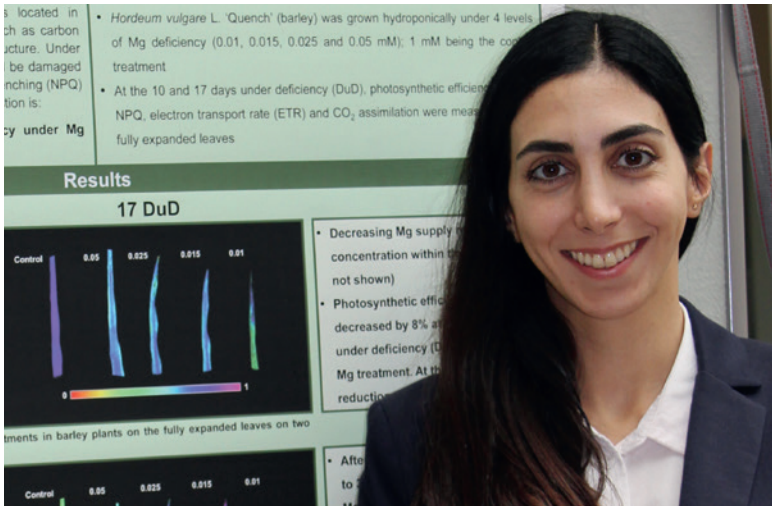
Paulo Cabrita presented results of a field trial on Mg fertilization in a poster entitled "Study of Crop Response to Magnesium Fertilization through Remote Sensing Methods". In the field trial, an analysis of high-resolution satellite imagery and field spectrometry together with chemical analyses of field samples was conducted. In his study, Paulo Cabrita showed that there was an increase in biomass, leaf size, and amount of pigment with increasing Mg fertilizer rates, indicated by changes in a number of optical indices (NDVI, MSAVI, Chlorophyll Index RedEdge, ARI). He also demonstrated that remote sensing, namely the application of high-resolution satellite images, presents a very promising method to monitor not only plant growth and development, but also crop physiological and morphological responses to Mg fertilization.



IAPN postdoctoral scientist Paulo Cabrita introduces research results on digital and sensing methods in plant nutrition. (Photo: Tränkner)

Photoprotection under Mg deficiency: poster of Setareh Jamali Jaghdani awarded by DGP

IAPN's PhD student Setareh Jamali Jaghdani introduced results of her recent research. On her poster "Influence of magnesium on photosynthesis and photoprotection in barley" she addressed the question whether the photoprotective mechanism of NPQ can prevent a reduction in photosynthetic efficiency under Mg deficiency. Her results showed that CO_2 assimilation rates decreased under conditions of moderately deficient Mg supply and, under severe Mg deficiency, a decline in NPQ as a photoprotective mechanism was recognized. For her poster, Setareh Jamali Jaghdani was awarded a DGP poster prize.



Exploring the impact of Mg deficiency on the photosystem functionality and photosynthetic efficiency: IAPN's PhD student Setareh Jamali Jaghdani. (Photo: Tränkner)

The German Society of Plant Nutrition was founded in 1968. It is a scientific forum of plant nutritionists that brings together the disciplines of nutritional physiology, nutrient cycling in soils and fertilization. Each year, the annual conference of the DGP is held at another location.

IAPN in Dialogue: Dr. Beate Deuker, Dr. Rolf Härdter, Professor emeritus Dr. Norbert Claassen, Professor Dr. Klaus Dittert, Professor Dr. Merle Tränkner, Professor Dr. Mónica Barbazán and Professor emeritus Dr. Walter Horst (from left). (Photo: Rethmeyer)

IAPN in Dialogue: K management in Uruguay

Since 2013, IAPN runs the event series called "IAPN in Dialogue". Within this series, researchers and practitioners from around the world report about topics that are closely related to the work of IAPN. On December 4th 2019, Professor Dr. Mónica Barbazán from the Universidad de la República in Uruguay was speaker. She is one of the leading researchers on K in the South American country and provided very interesting insights into the challenges and breakthroughs of K research in Uruguay. Merle Tränkner moderated the event and the vivid discussion.

Agriculture is one of the most important sectors of Uruguay's economy. About 75 % of the country's total exportations are agricultural products with cellulose, beef, dairy products and soybean being the main exported commodities. In 2017, soybean, wheat, rice, barley and maize were the Top Five Crops in agricultural production. In numerous crops, symptoms of K deficiency are observed more frequently in recent years.

Reports of K deficiency require research

Beginning with the year 2000, the agricultural systems in Uruguay started to change, due to higher grain prices and a growing production of soybean: "The annual cropped area increased from 700 thousand in 2002 to above 2 million ha in 2014. Soybean and wheat were sown on 67 % and 20 % of the area in 2014, respectively", Mónica Barbazán explains. "Cropping systems have been intensified, shifting the production systems from crop-pasture rotations to continuous annual cropping under no-till systems showing a current index of 1.5 crops per year." The focus shifted from winter to summer crops. Land prices increased, and farmers started to rent fields, mainly with short-term contracts over two to three years.

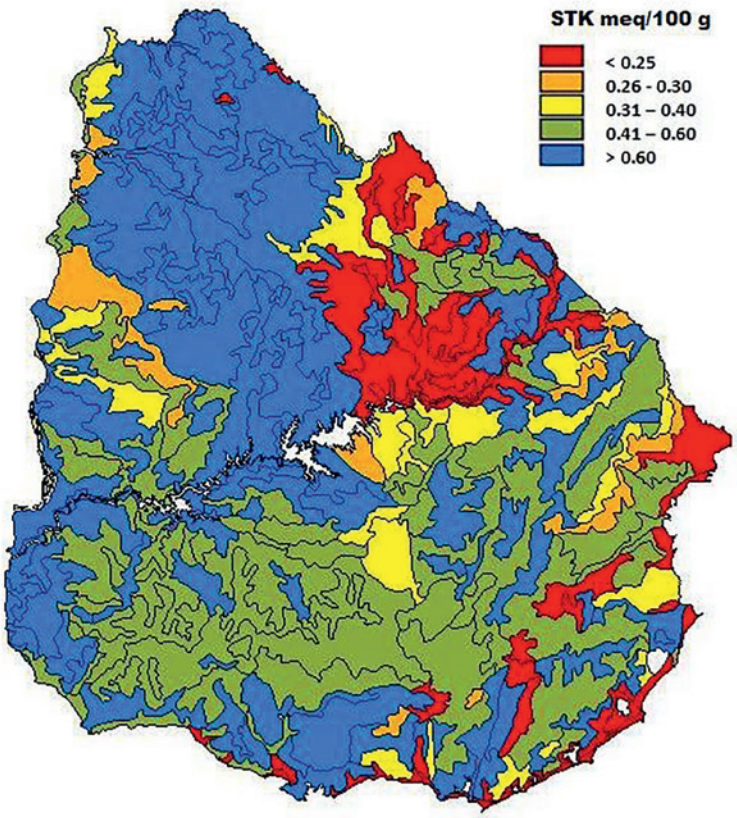
Soy plants on a field in Uruguay, showing symptoms of K deficiency. (Photo: Barbazán)

Because there was almost no K fertilization in Uruguay, more K was removed from the soil than returned. The K balance became even more negative when the production of soybean – that requires large amounts of K – increased and agriculture spread into regions with marginal soils that have low rates of exchangeable K. In the late nineties and early 2000s, field research reported K deficiency symptoms in soils with low exchangeable K in several crops, and recently, visual deficiency symptoms appeared increasingly frequent.

Finding the critical level for K application

Further surveys were conducted that explored and demonstrated crop responses to K. "We summarized data from 50 trials on K response in barley, wheat, corn, soybeans, sorghum, and sunflower", says Mónica Barbazán. "These trials were conducted by different working groups between 2004 and 2010, in soils with different texture and soil test K (STK, exchangeable K) levels. K fertilizer increased crop yields in 15 of 50 sites ($p<0.10$). Across all sites and crops, the critical level of exchangeable K was 0.3-0.40 cmol kg^{-1} (120-160 ppm; 0-20 cm depth). This study represented a breakthrough in K research in Uruguay. Its results have demonstrated the great need for further studies of K dynamics in soils of Uruguay." Afterwards, the number of trials was increased. Among other questions, the relationship between response probability and STK as well as between relative yield for all crops and STK were studied.

Due to the variability in the prediction of K responses it was necessary to consider other factors that could affect the response to K. Examples are the sampling time, soil texture, and soil mineralogy. Uruguayan soils present a wide range of clay types. Hence, the knowledge of this could help to improve the index of soil testing for K. For example, soils with more Kaolinite clay could have a lower critical level than soils with more Illite.



Based on the results of soil tests and on information of agronomists, a map was developed showing the soil test K (STK; 0-20 cm) according to the soil recognition guide of Uruguay. Scale: 1:1,000,000. (Source: Califra and Barbazán, unpublished)

IAPN at the 4th Night of Knowledge

More than 25,000 visitors attended the 4th Night of Knowledge ("Nacht des Wissens") on January 26th 2019, on Göttingen University's Central Campus. A total of 370 events put on by 75 participating institutions offered impressive and entertaining options to find out about the latest developments in science and research. IAPN joined in and gave exciting insights into plant nutrition and the institute's scientific work.

IAPN's event motto was: what do plants need to grow? Visitors of all ages were fascinated by the institute's nutrient quiz. It involved six different sunflower plants. Only one of the plants showed balanced nutrition, while five plants showed different deficiency symptoms. The challenge was to find out which mineral is missing. After successfully completing the nutrient quiz, visitors got a chance to try out virtual fertilization: the VR-game "Nutriball", provided by K+S Minerals and Agriculture GmbH, attracted lots of younger visitors. To explain IAPN's scientific work, members of the institute demonstrated research methods like thermal imaging, LPCP probes, and gas exchange measurements.

The IAPN team (left to right): Kirsten Fladung, Ulrike Kierbaum, Setareh Jamali Jaghdani, Klaus Dittert, Merle Tränkner, Ariel Turcios, Annika Lingner and Martina Renneberg; missing: Paulo Cabrita. (Photo: IAPN)

In order to solve IAPN's nutrient quiz, visitors compare actual sunflower leaves, which are showing deficiency symptoms, with the descriptions provided in the reference book "Illustrated pocket guide to nutrient deficiency in major arable crops". Kirsten Fladung (third from left), technical assistant at IAPN, gives some hints. (Photo: IAPN)

At the 4th Night of Knowledge, visitors at the IAPN booth can find out which nutrients plants need to thrive. (Photo: IAPN)

Visitors at the IAPN booth are enthralled by the thermal imaging camera. Klaus Dittert explains how the colors in the infrared images relate to nutrient deficiencies in plants. (Photo: IAPN)

KALI Akademie webinar on drought stress

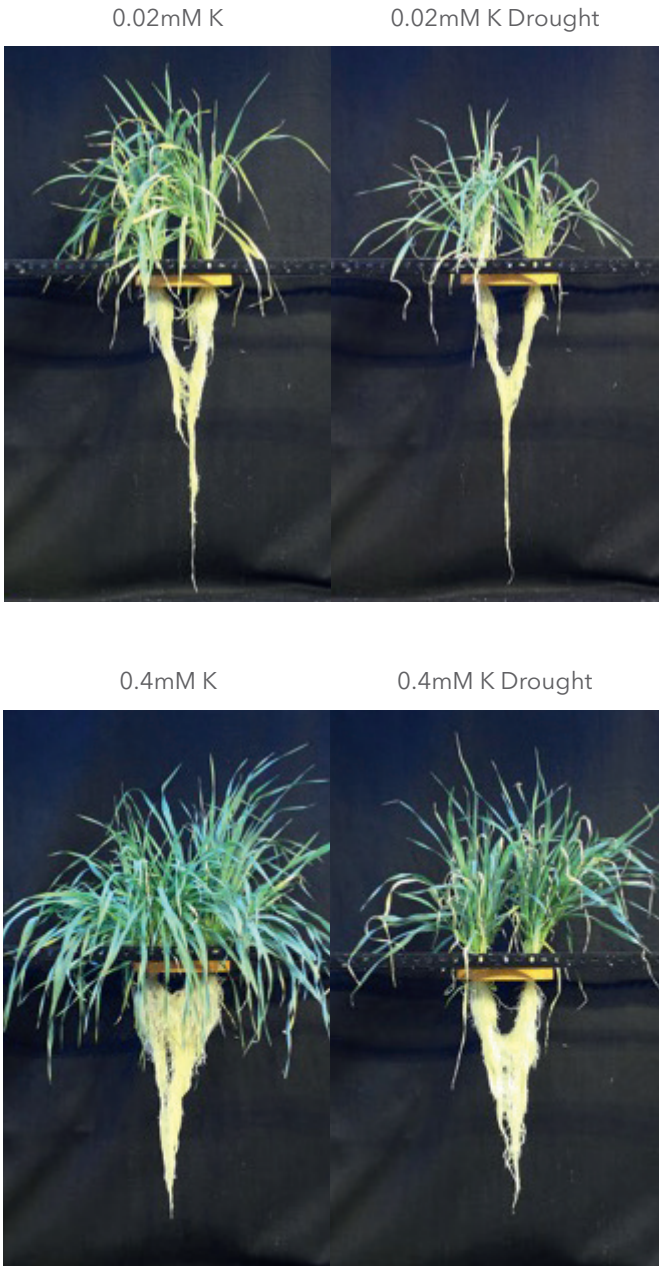
In many countries of the world, increasing and persistent droughts create major challenges to farming. The issue is no longer abstract, even in Germany, where for 10 consecutive months in 2018, the warmest and sunniest year ever was recorded with a precipitation that was much less than normal. This resulted in massive harvest shortfalls.

One of IAPN's primary research foci is the question as to how optimization of the plant's nutrient supply can raise its water-use efficiency and ensure satisfactory yields even when water is scarce. In a webinar held on January 22nd 2019 on KALI Akademie, the knowledge platform of K+S Minerals and Agriculture GmbH dedicated to plant nutrition, Klaus Dittert provided insight into the current IAPN's research. The online seminar was entitled "Drought stress: Efficient water usage for enhancing crop yields – a look at research".

K and Mg: important for drought-stress tolerance and water-use efficiency

After a brief report on the precipitation levels and soil humidity in Germany in 2018 and a subsequent outline of worldwide regions threatened by drought, Klaus Dittert introduced the results of various fertilization trials. He then explained relevant, topical scientific IAPN findings.

The institute's research results show that K and Mg are extremely important for drought stress tolerance and water-use efficiency, even though the physiological functions are not immediately discernible. A study by Tavakol et al. (2018) showed that transpiration and therefore water usage increased with K concentration in barley plants. A study by Jákli et al. (2017) focusing on wheat however showed that on the other hand the plants' photosynthesis performance was even more stimulated, so that finally as a result of the enhanced K supply the water-use efficiency was markedly improved. Other studies showed that assimilate transport, which is extremely important for example for root growth, also depends on optimum K supply, as this mineral is essential for loading of assimilates into the plant's vascular system for transport. In addition to K, Mg is also vital for relocating carbohydrates to the roots, thereby ensuring growth and excellent root penetration of soils.



Spring barley treated with low K (0.02 mM K) and adequate K supply (0.4 mM K) under well-watered and drought conditions. (Photos: Tavakol, IAPN)

Concluding his webinar presentation, Klaus Dittert briefly explained the drone-based multispectral technology used at IAPN, and he introduced the project IMPAC³ as an example of how new cropping methods are also tested as a possibility of enhancing water-use efficiency.

Publications

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

Abbadi, J.; Dittert, K.; Steingrobe, B. and Claassen, N. (2019) Mechanisms of potassium uptake efficiency and dynamics in the rhizosphere of safflower and sunflower in different soils. Journal of Plant Nutrition. 42, 2459-2483: doi:10.1080/01904167.2019.1655035

Cabrita, P. (2019) – A model for resin flow. In: Ramawat, K.; Ekiert, H. and Goyal, S. (eds) Plant Cell and Tissue Differentiation and Secondary Metabolites, Reference Series in Phytochemistry, Springer, Cham, Switzerland (in print), https://link.springer.com/referenceworkentry/10.1007/978-3-030-11253-0_5-1

Grahmann, K.; Dittert, K.; Verhulst, N.; Govaerts, B. and Buerkert, A. (2019) ^{15}N Fertilizer recovery in different tillage-straw systems on a Vertisol in north-west Mexico. Soil Use and Management 35: 482-491

Hauer-Jákli, M. and Tränkner, M. (2019) Critical leaf magnesium thresholds and the impact of magnesium on plant growth and photo-oxidative defense: A systematic review and meta-analysis from 70 years of research. Frontiers in Plant Science, doi: 10.3389/fpls.2019.00766

Hornbacher, J.; Rumlow, R.; Pallmann, P.; Turcios, A.E.; Riemenschneider, A. and Papenbrock J. (2019) The levels of sulfur-containing metabolites in *Brassica napus* are not influenced by the circadian clock but diurnally. Journal of Plant Biology 62, 359-373, doi: 10.1007/s12374-019-0143-x

Hou, W.; Tränkner, M.; Lu, J.; Yan, J.; Huang, S.; Ren, T.; Cong, R. and Li, X. (2019) Interactive effects of nitrogen and potassium on photosynthesis and photosynthetic nitrogen allocation of rice leaves. BMC Plant Biology, doi: 10.1186/S12870-019-1894-8

Khanal, G.; Wachendorf, C.; Dittert, K.; Willich, M.; Dietz, H.; Buerkert, A. and Ingold, M. (2019) Nitrogen turnover in a repeatedly manured arid subtropical soil: Incubation studies with ^{15}N isotopes. Journal of Plant Nutrition and Soil Science. 182, 836-845. doi:10.1002/jpln.201800340

Reginato, M.; Turcios, A.E.; Luna, V. and Papenbrock, J. (2019) Photosynthesis, metabolism and mineral composition in the halophyte *Prosopis strombulifera* growing under NaCl and Na_2SO_4 salinization. Plant Physiology and Biochemistry, 141, 306-314, doi: 10.1016/j.plaphy.2019.05.027

Tränkner, M. and Jamali Jaghdani, S. (2019) Minimum magnesium concentrations for photosynthetic efficiency in wheat and sunflower seedlings. Plant Physiology and Biochemistry 144, 234-243, doi: 10.1016/j.plaphy.2019.09.040

Turcios, A.E. and Papenbrock, J. (2019) Enzymatic degradation of the antibiotic sulfamethazine by using crude extracts of different halophytic plants. International Journal of Phytoremediation, 21(11), 1104-1111, doi: 10.1080/15226514.2019.1606782

Conference talks – papers – posters

Cabrita, P.; Elm, C.; Erasmi, S. and Tränkner, M. (2019) Study of Crop Response to Magnesium Fertilization through Remote Sensing Methods. Annual Meeting of the German Society of Plant Nutrition (DGP), September 25th – 27th 2019, Berlin, Germany

Jamali Jaghdani, S. and Tränkner, M. (2019) Magnesium and photosynthetic activities in *Triticum aestivum* and *Helianthus annuus*. International CEPLAS Summer School 2019, Transatlantic Summer School - Frontiers in Plant Sciences, May 27th – 31st 2019, Maria in der Aue, Wermelskirchen, Germany

Jamali Jaghdani, S. and Tränkner, M. (2019) Influence of Magnesium on photosynthesis and photoprotection in *Hordeum vulgare* L. Annual Meeting of the German Society of Plant Nutrition (DGP), September 25th – 27th 2019, Berlin, Germany

Tränkner, M. (2019) Critical Leaf Magnesium Thresholds for Plant Growth: A systematic review and meta-analysis from 70 years of research. Annual Meeting of the German Society of Plant Nutrition (DGP), September 25th – 27th 2019, Berlin, Germany

Turcios, A. and Tränkner, M. (2019) Importance of potassium for quinoa (*Chenopodium quinoa* Willd.) cultivated under moderate saline conditions. Annual Meeting of the German Society of Plant Nutrition (DGP), September 25th – 27th 2019, Berlin, Germany

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
CIP International Potato Center, Central Africa Branch	Nairobi/Kenya, Germany
Deutsche Landwirtschafts-Gesellschaft (DLG)	Frankfurt/Bernburg, Germany
Deutscher Wetterdienst	Leipzig, Germany
EuroChem Agro GmbH	Mannheim, Germany
Forschungszentrum Jülich, Institute of Bio- und Geosciences Agrosphere (IBG-3)	Jülich, Germany
Hanninghof Research Station – Yara Int. ASA	Dülmen, Germany
Huazhong Agricultural University	Wuhan, China
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
Spacenus GmbH	Darmstadt, Germany
Thünen-Institute – Institute of Climate-Smart Agriculture	Braunschweig, Germany
Universidad de la República, Facultad de Agronomía, Departamento de Suelos y Aguas	Montevideo, Uruguay
University of Göttingen	Göttingen, Germany
Division of Quality of Plant Products	
Institute of Geography - Section of Cartography, GIS and Remote Sensing	
Institute for Numerical and Applied Mathematics	
Plant Pathology and Crop Protection	
Functional Agrobiodiversity	
University of Halle, Institute of Plant Nutrition	Halle, Germany
University of Hohenheim, Quality of Plant Products	Stuttgart, Germany
University of Kassel, Organic Plant Production and Agroecosystems Research	Witzenhausen, Germany
University of Peradeniya	Peradeniya, Sri Lanka

In teaching

Professor Dr. Ismail Cakmak
Sabanci University, Istanbul, Turkey

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