IAPN
INSTITUTE OF
APPLIED PLANT NUTRITION

ANNUAL REPORT 2021

RESEARCH ON SUSTAINABLE PLANT NUTRITION

Imprint

Author: Institute of Applied Plant Nutrition (IAPN)

Editorial staff: Prof. Dr. Klaus Dittert, Dr. Setareh Jamali Jaghdani, Dr. Uta Devries

Pictures and figures: Cabrita, Chatzistergos, Falk, IAPN, ICRISAT, D. Jákli, Jamali Jaghdani, K+S, Liu, Tränkner

November 2022

IAPN – Institute of Applied Plant Nutrition

at Georg-August-Universität Göttingen

Carl-Sprengel-Weg 1

37075 Göttingen, Germany

www.iapn.de

Contents

Preface

Dear readers,

we all and also the team of IAPN look back at a year that again was strongly influenced by the Covid pandemic. In 2021, much of the knowledge dissemination activities and international exchange with scientists and students from abroad was only done to a quite reduced extent and again even the university teaching was mostly offered in digital formats. Hence for months, life at IAPN was somewhat more quiet and some of the core tasks were halted, but the situation left space for starting some new projects and for summing up others.

One of the great events in 2021 was the PhD graduation of Setareh Jamali Jaghdani, who was the first PhD student of Junior Professor Dr. Merle Tränkner. Setareh Jamali Jaghdani's research project has been dealing with the physiology, photoprotection, and light utilization in plants' leaves. Light energy that is essentially needed to drive photosynthesis can frequently turn into a problem when plants run into stress because of critical growing conditions such as drought, excess or shortage of minerals, or heat. Then, the productive light energy conversion reaches its limits much earlier, and excessive light energy needs to be dissipated. Dr. Setareh Jamali Jaghdani provided new knowledge on how magnesium affects the different enzymatic energy dissipation processes.

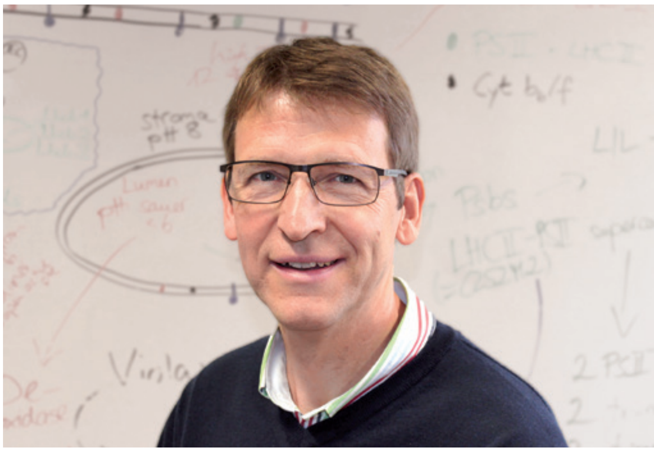
In June 2021, Merle Tränkner left IAPN for a new leading research position in the agricultural sector. The IAPN team thanks her for the fruitful and very good cooperation over the last years and wishes her all the best in her new tasks. While Merle Tränkner was leaving, the University of Göttingen appointed Professor Dr. Ismail Cakmak as honorary professor. He received this honor due to his continuous support in research and teaching at IAPN and the University of Göttingen.

Readers interested in new findings in applied plant nutrition are referred to pages 13 ff., where Dr. Paulo Cabrita and Setareh Jamali Jaghdani provide insights into their latest findings on non-invasive and digital methods for plant nutrient and water status and light protection. Tingting Liu started her project on the interaction of mineral nutrition and the development and functioning of plant roots. Her particular focus is on the apoplastic root barriers that are essential for efficient nutrient and water uptake and protection against losses.

We hope you will find an interesting reading.

With best wishes

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 was head of IAPN's junior research group until May 2021, led 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 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 2021, the team of IAPN consisted of up to nine members in scientific staff, administration, and technical as well as laboratory assistance. The institute's scientific director is Professor Dr. Klaus Dittert, and until May 31st, Professor Dr. Merle Tränkner has held the junior professorship. All administrative matters are managed by Martina Renneberg. The technical and laboratory assistance is provided by Kirsten Fladung and Ulrike Kierbaum who have been supported by Wael Alyoussef until June 30th.

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.

Dr. Setareh Jamali Jaghdani was graduated on August 20th. Her PhD project focused on the influences of Mg deficiency on photosynthetic processes and photoprotective mechanisms in various crop plants. The research results of her final year of study were published in the article "The impact of magnesium deficiency on photosynthesis and photoprotection in *Spinacia oleracea*" *(Plant Stress)*. Since August, she continues her work at IAPN as a postdoctoral researcher in cooperation with K+S Minerals and Agriculture GmbH and supports the IAPN team in research.

In the course of the scientific work at IAPN, new interesting research topics came into focus. Tingting Liu was up for the challenge and started her PhD studies. Since June 2021, she investigates how the deficiency of K and phosphorus (P) affects apoplastic barriers in soil grown maize roots.

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 in autumn 2021: Ulrike Kierbaum, Dr. Paulo Cabrita, Martina Renneberg, Professor Dr. Klaus Dittert, Tingting Liu MSc., Kirsten Fladung, Dr. Setareh Jamali Jaghdani. (Photo: IAPN)

Merle Tränkner takes on new tasks

Merle Tränkner took on new challenges in June 2021. Since 2017, she had been junior professor for "Applied Plant Nutrition" at IAPN and at the Department of Crop Sciences at the University of Göttingen. In addition to research and teaching, her professorship included heading the scientific junior research group at IAPN as well as being one of the primary contributors to the international knowledge exchange. Before, from 2012 to 2016, she had carried out her PhD project at IAPN.

Merle Tränkner in the Bachelor's course "Plant Nutrition meets Plant Physiology – Experimental Work at the Junction of Disciplines". (Photo: IAPN)

Together with the work of Dr. Bálint Jákli and Dr. Ershad Tavakol – with whom Merle Tränkner formed the first generation of IAPN's PhD students – , her PhD research laid the foundation for many subsequent findings at the institute. In her studies, she mainly focused on Mg and K deficiency in various crop plants. Her studies in barley plants under Mg deficiency revealed significant decrease in biomass WUE. Moreover, significant increases in the production of reactive oxygen species (ROS) were observed, where the activities of ROS antioxidant enzymes were increased. It could be concluded that severe Mg deficiency decreases the capacity of the antioxidative machinery and consequently leads to severe oxidative stress in plants.

Questions about the role of Mg in the antioxidative machinery were continued to be studied during Merle Tränkner's time as junior professor. Beside other studies, she supervised the PhD project of Setareh Jamali Jaghdani, entitled "Capacity and efficiency of photosynthesis and photoprotective mechanisms under magnesium deficiency in crop plants". The project is covered in more detail in the "Research" section of this annual report.

Topical research results and methods directly informed Merle Tränkner's interactive Master's and Bachelor's courses. Several awards for students who were supervised by Merle Tränkner confirmed the excellent scientific level of the young researchers at IAPN and the University of Göttingen. Together with her team at IAPN, she presented newest results at the International Symposium on Magnesium in Guangzhou (China) in 2018 and at other national and international congresses. Merle Tränkner also always sought the exchange with agricultural practice. For example, in 2018 she visited oil palm plantations in Indonesia where she gave a presentation about the physiological functions of Mg.

In 2021, Merle Tränkner took opportunity to accept new tasks in a leading research position with a well-known player in the agricultural sector. The IAPN team would like to express their warmest gratitude to her for her exceptional commitment to IAPN as well as the successful cooperation. We wish her all the best for the future and her new tasks.

Setareh Jamali Jaghdani was graduated

A miniature plant research lab: the doctoral hat of Setareh Jamali Jaghdani depicts some of the technology and methods used in her PhD project – including a gas flux analyzer and some of the equipment for the documentation of the trials. (Photo: Chatzistergos)

Congratulations to Setareh Jamali Jaghdani (center) by her examination committee: IAPN's scientific director Professor Dr. Klaus Dittert, Professor Dr. Peter Jahns of the Institute for Plant Biochemistry at the University of Düsseldorf, Dr. Merle Tränkner, supervisor of the PhD project, and Professor Dr. Andreas von Tiedemann of the Division of Plant Pathology and Crop Protection at the University of Göttingen (from left to right). (Photo: IAPN)

Setareh Jamali Jaghdani pinning flowers on the fountain "Gänseliesel". Since decades, it is a tradition in Göttingen: after receiving the doctoral hats, the graduated students climb on the fountain and give the Gänseliesel a kiss while being pelted with water balloons. (Photo: Chatzistergos)

An IAPN scientist choosing the newest fully expanded leaf in a wheat plant in order to measure the leaf gas exchange. (Photo: K+S)

Research

Focusing on 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.

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 WUE in the soil/plant system.
- Understanding alterations in the plants' physiology in response to fertilization.
- New strategies for improving fertilizer recommendations and management.

In 2021, IAPN's research activities were restricted by the Corona pandemic. Still, our scientists achieved significant progress in their research. Some of the major results were published in 2021. The following pages will introduce you to IAPN's research projects.

The physiological role of leaf aerenchyma and its importance in assessing plant-water relations

Research project conducted by Dr. Paulo Cabrita

Most plants have to cope with living under adverse environmental conditions, in which water availability is one of the most important and limiting factors affecting growth. Either being surrounded by dry air, dim light or facing limiting water uptake from the soil, which can vary dramatically and seasonally, plants have developed different strategies in order to live under such challenging conditions.

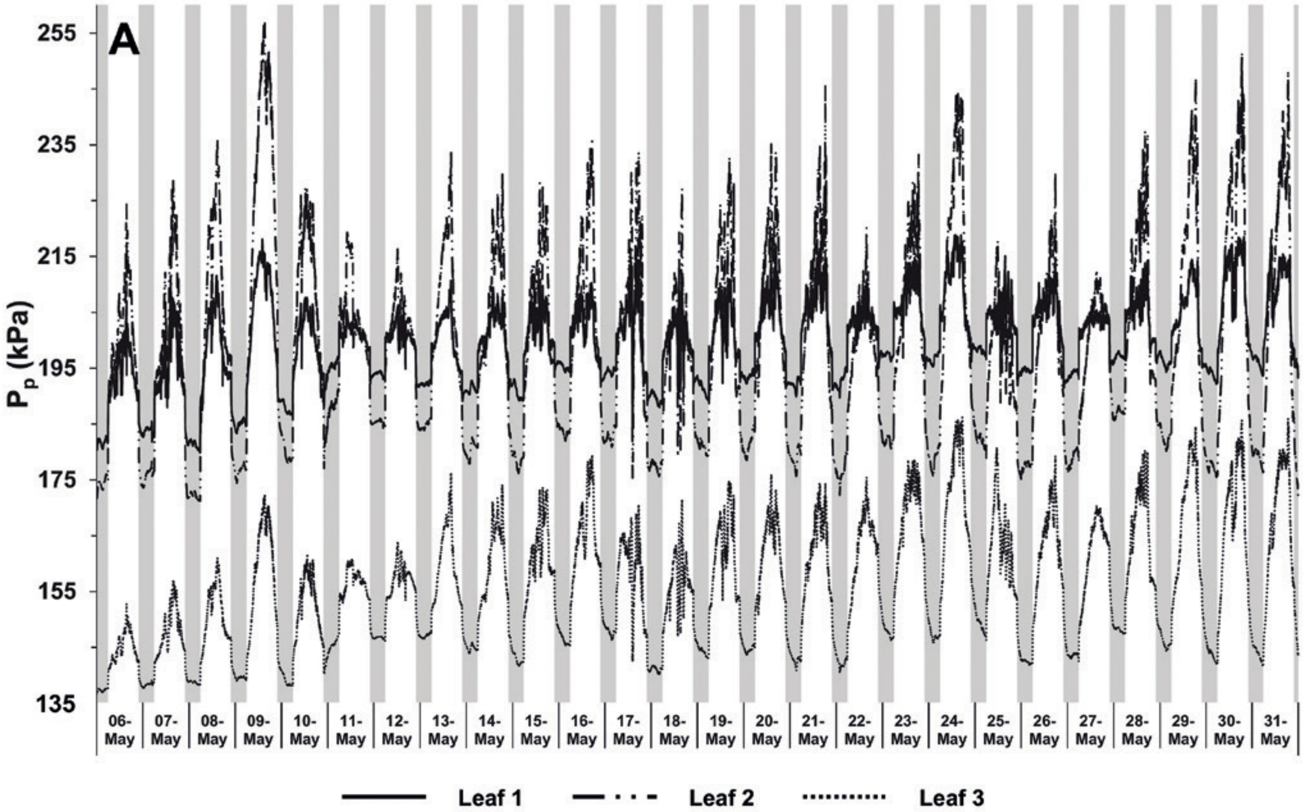
Some plant species present aerenchyma in their leaves, which in the case of plants of the genus *Hippeastrum* is characterized by lacunae running throughout the leaf, making most of the mesophyll volume. The genus *Hippeastrum* comprises 143 species and more than 600 hybrids and cultivars of high economic value as ornamental plants within the family Amaryllidaceae.

In this project, the physiological role of the leaf aerenchyma and its importance to plant water relations were studied combining leaf gas exchange measurements with leaf patch clamp pressure (LPCP) probes. Both these methods are non-invasive and allow the continuous monitoring of photosynthesis and the plant water status, including long term measurements. Results from plants of *Hippeastrum* 'Red Lion' cultivar were then compared to those from banana (*Musa acuminata* Colla [AAA group] 'Dwarf Cavendish'), which presents a completely different leaf structure. 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 $\mu mol.m^{-2}.s^{-1}$ at 1 m above ground during the photoperiod. Air temperature, relative humidity, and pressure in the greenhouse were recorded continuously, and water deficit was imposed by withholding watering.

The diel pattern of the leaf patch clamp pressure, P_p, of *Hippeastrum* plants (Figure A) is reverse to that of banana (Figure B). In banana, 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 in banana leaves.

A plant of the species *Hippeastrum* 'Red Lion', cultivated in an IAPN trial of Paulo Cabrita on the physiological role of leaf aerenchyma and its importance in assessing plant-water relations. (Photo: D. Jákli)

On the other hand, the leaf patch clamp pressure, P_p, of *Hippeastrum* leaves is inversely related to the pressure inside the lacunae (i.e., leaf aerenchyma). That is, in plant species in which the leaf aerenchyma constitutes most of the mesophyll volume, P_p reflects changes in the leaf aerenchyma pressure, P_a, reversely. As plants transpire and temperature increases throughout the day, so does the leaf

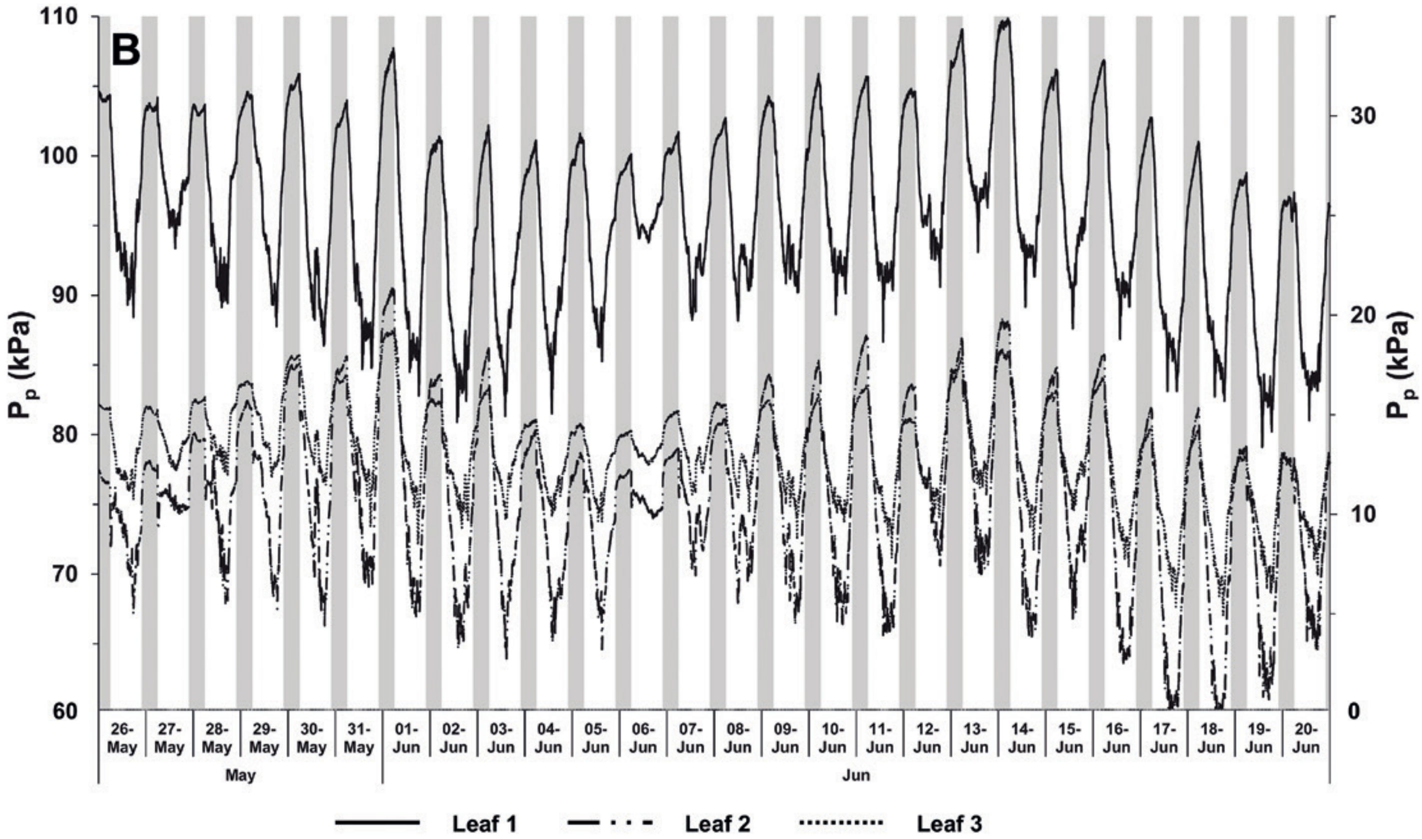


Figures A and B: Diel changes of the leaf patch clamp pressure P_p observed on three leaves of banana (A) and *Hippeastrum* (B) plants. P_p values of leaf 2 of *Hippeastrum* plant shown on the right vertical axis. Grey shadowing indicates the 8 h nighttime. (Source: Cabrita)

aerenchyma pressure, P_a. Concomitantly, the leaf patch clamp pressure, P_p, decreases (Figure B). At night, with transpiration ceased, the leaf aerenchyma pressure, P_a, decreases back to values similar to those of the night before, which is thus seen by the simultaneous increase in P_p (Figure B).

Reflecting the physiological changes in a different leaf structure, the diel changes in the leaf patch clamp pressure, P_p, in banana leaves illustrate the changes in its turgor pressure reversely, i.e., its water status. As the plant transpires and photosynthesizes during the day, the expected decrease in the leaf turgor pressure is observed by the simultaneous increase in the leaf patch clamp pressure, P_p (Figure A). At night, with no transpiration or photosynthesis, leaf turgor increases back to its normal range making the leaf patch clamp pressure, P_p, to decrease (Figure A). The increase of the daily maximal and minimal P_p values as well as their difference with time in banana plants reflect the concomitant decrease in the leaf turgor pressure, i.e., plant water status, resulting from the decreasing water availability to the plant from the soil.

Whereas in *Hippeastrum* leaves the daily changes in those same parameters result more from the effect of changes in environmental conditions surrounding the plants (e.g., tem-



perature, humidity), thus affecting transpiration, photosynthesis, and leaf aerenchyma pressure ultimately. The bulbous nature of *Hippeastrum* plants buffers them from immediate changes in water supply from the soil. Nevertheless, changes in the leaf aerenchyma pressure, P_a, are closely related to the photosynthetic performance of *Hippeastrum* plants and their water status eventually.

This work presents a novel interpretation of the LPCP probe measurements, while measuring physiological parameters and addressing plant-water relations of species that exhibit leaf aerenchyma. The LPCP probe allows us to observe non-invasively and continuously the dehydration/rehydration dynamics and the internal redistribution of water within the plants over diel scales in response to treatments or changes in the surrounding environment. However, a good understanding of the leaf structure and how its components relate spatially is needed as it affects the interpretation of P_p data.

Digital assessment of crop nutrient status

Research project conducted by Dr. Paulo Cabrita

The project initiated in June 2019 in cooperation with K+S Minerals and Agriculture GmbH and Spacenus GmbH, based in Darmstadt, on developing the digital product Agricultural Nutrient Assistant (ANA) was concluded in May 2021.

The concept of ANA was designed to provide support for farmers in precision farming, namely, on assessing the status of specific nutrients in plants using spring wheat (*Triticum aestivum* L.) and spring rapeseed (*Brassica napus* L.) as model crops. For that purpose, the crops were submitted to different nutrient deficiencies to collect data to train and test artificial intelligence (AI) models.

The antagonistic effects between several plant nutrient elements is a quite well-known phenomenon that develops from imbalances in nutrient availability to plants and is related to the competitive uptake of different elements in the soil solution. Chemical form of added nutrients, water availability, temperature, and pH are among the main factors affecting plant nutrient uptake.

As illustrated in the figure, there is a gradual decrease of the concentration of K in spring wheat plants with N supply and plant development. The K concentration decreases as plants grow, increasing in size, and are submitted to increasing N supply. However, under a strong reduction of K supply (seen by its strong decrease in concentration at all developmental stages) the antagonistic effect of the increasing N availability on K accumulation in spring wheat plants seems to disappear, as significant differences in the K concentration are mostly visible at later stages of plant development under higher N supply levels.

Under a strong reduction in Mg supply, K uptake is favored as its concentration ranges within control levels and even surpasses them under higher N supply at later stages of plant development. This result is similar to that observed with other cations taken up by plants (e.g. calcium; not shown in the figure). The K uptake and accumulation in spring wheat plants grown under strong reductions in P and sulfur (S) supplies showed similar patterns. The competitive nature of plant nutrient uptake, the factors affecting it, including the soil chemical composition, must therefore be considered when developing adapted fertilization regimes for crops envisaging sustainable nutrient management practices.

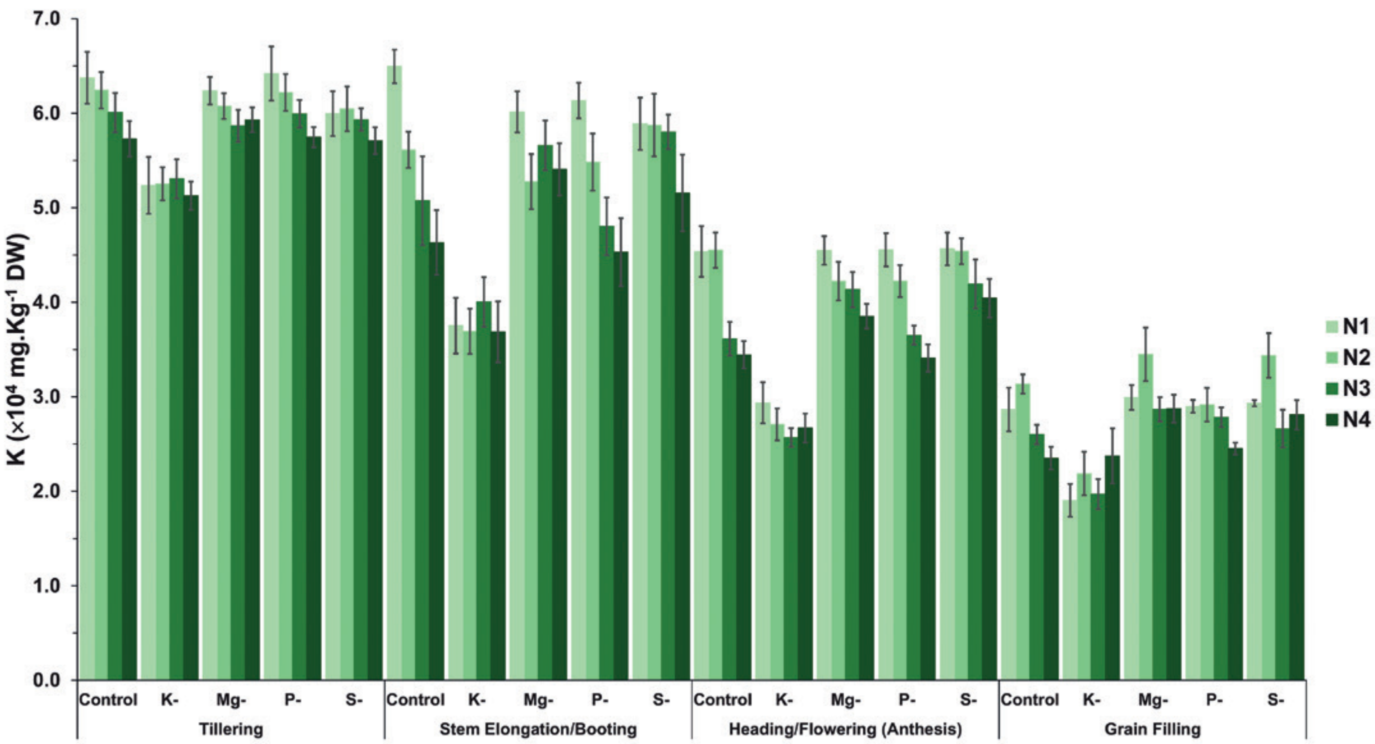


Figure: K concentration (per unit dry weight, DW) in spring wheat (*Triticum aestivum* L.) plants grown in hydroponics at different growth stages as a function of N supply (N1 the lowest to N4 the highest) and specific nutrient supplies. K-, Mg-, P-, and S- refer to a strong reduction of K, Mg, P, and S supply compared to control plants. (Source: Cabrita)

IAPN's technical assistant Wael Alyoussef collecting wheat samples in an experiment, which was part of the project "Digital assessment of crop nutrient status". (Photo: Tränkner)

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

PhD research project of Dr. Setareh Jamali Jaghdani
Supervisor: Junior Professor Dr. Merle Tränkner

Setareh Jamali Jaghdani started her PhD project in January 2018. Within the first part of the project, she investigated the influences of seven Mg deficiency levels on wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annuus* L.) to find the critical Mg concentration where the photosynthetic efficiency and physiological processes are affected. Mg is the core element of the chloroplast where photosynthesis takes place. It is also known that up to 35 % of the total Mg in plants is found in the chloroplasts.

In the research project of Setareh Jamali Jaghdani, sunflower (*Helianthus annuus* L.) plants were submitted to various Mg supplies. The sunflower plants that received the lowest Mg supply were adversely affected in their photosynthetic processes. (Photo: Jamali Jaghdani)

When the light is absorbed by photosystem II in the chloroplasts, it has three pathways to follow: 1) photochemistry (photosynthesis); 2) re-emission as chlorophyll fluorescence; 3) dissipation as heat (non-photochemical quenching, NPQ).

Within the first part of the project, Setareh Jamali Jaghdani and Merle Tränkner wanted to tackle the accepted hypothesis which claims that Mg concentrations below 1.5–3.5 g Mg kg^{-1} dry matter are critical. The IAPN scientists believe that the accepted numbers are very general and are not pointing at any specific physiological and biological process. Within this project they concluded that based on the plant genus, the various photosynthetic and physiological processes are affected differently. Therefore, various processes are not affected equally under Mg deficiency. In their study, photosynthetic processes in wheat plants were not influenced under the induced Mg deficiency, whereas sunflower plants were adversely affected under the lowest Mg treatment. The results of this project part were published in *Plant Physiology and Biochemistry (PPB)* in September 2019.

In the second part of her PhD project, Setareh Jamali Jaghdani focused on experiments with barley (*Hordeum vulgare* L.). Based on the outcome of her first project part, she was able to select the critical Mg treatments to be given to barley plants. She induced three Mg deficiency treatments in order

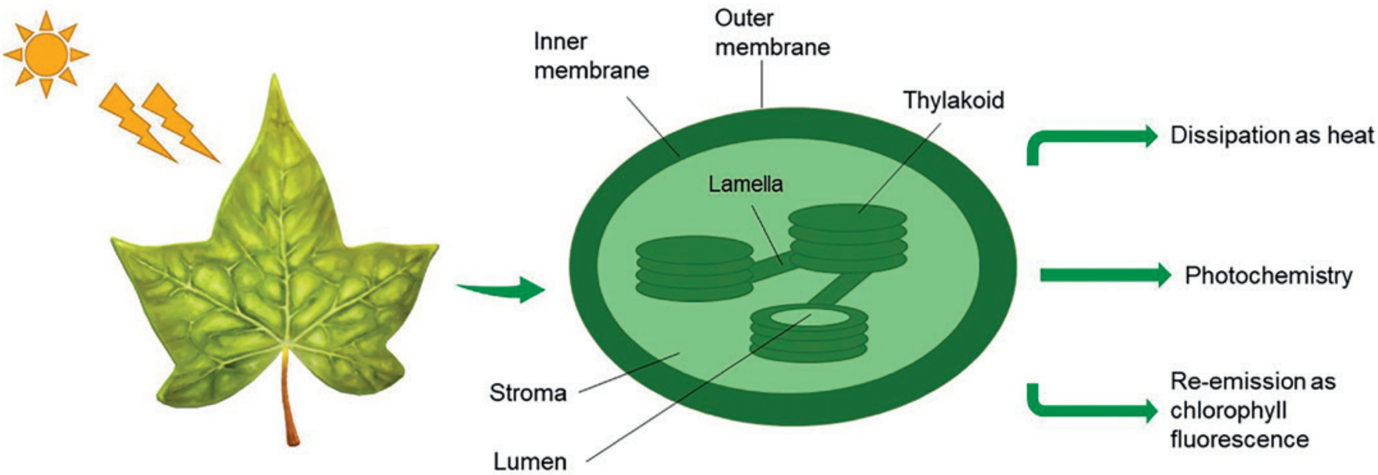


Figure 1: Chloroplast structure and the possible pathways for the absorbed light energy. (Source: Jamali Jaghdani)

to investigate the photosynthetic and photoprotective parameters under Mg deficiency. She observed that the carbon dioxide (CO_2) assimilation is severely reduced under the given Mg deficiencies. The negative impact of Mg deficiency was also observed in photosynthetic efficiency and electron transfer rate in barley.

In order to study the photoprotective mechanisms, she investigated the fold expression of the genes involved in reactive oxygen species (ROS) scavenging. ROS are toxic and cause cell death. Plants have evolved mechanisms to degrade and break ROS compounds. It was observed that the fold expression of ROS scavengers including catalase (CAT), superoxide dismutase (SOD), and glutathione reductase (GR) under Mg deficiency was significantly increased.

The other photoprotective mechanism that was studied by her was the changes in NPQ. The main cycle that is involved in NPQ is called the violaxanthin cycle. As the light absorption increases, the pH in the thylakoid lumen (located in chloroplasts) will be reduced. The reduction in the pH activates violaxanthin. The conversion of violaxanthin to zeaxanthin

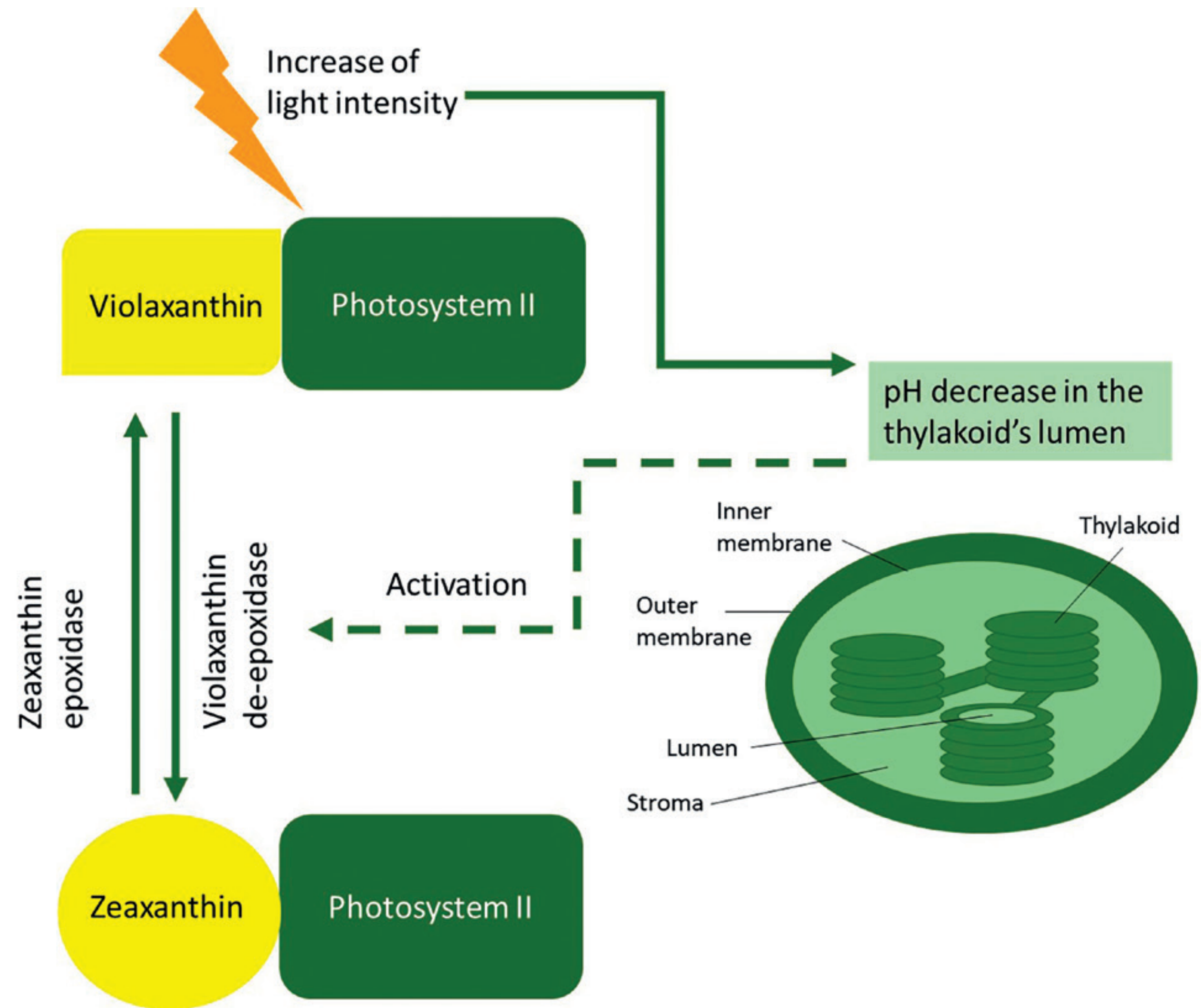


Figure 2: Schematic illustration of the violaxanthin cycle. At high-light intensities, the pH in the thylakoid lumen decreases and activates violaxanthin. At first, violaxanthin is converted to antheraxanthin by violaxanthin de-epoxidase, and subsequently antheraxanthin is converted to zeaxanthin. When the light intensity decreases, zeaxanthin is converted back to violaxanthin by zeaxanthin epoxidase. (Source: Jamali Jaghdani)

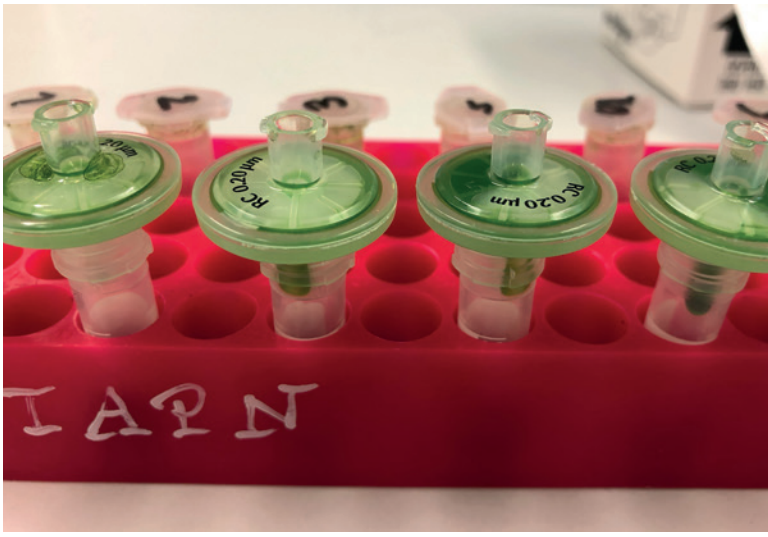
Assessing the pigment content in leaves, using the optical sensor Dualex, allowing real time results with non-destructive means. (Photo: Jamali Jaghdani)

consequents in dissipation of the excessive light energy (NPQ) (Figure 2). A significant increase in the total concentration of violaxanthin pigments was observed.

However, it was concluded that the increase in the quantity of violaxanthin pigments was not related to the enhanced NPQ but to other photoprotective mechanisms. The results of this project part were published in *Plant Science* in November 2020.

The third and final project part included spinach (*Spinacia oleracea* L.) plants. In order to study their physiological and photosynthetic responses under Mg deficiency, Setareh Jamali Jaghdani induced three Mg deficiency levels on these plants and estimated the photosynthetic efficiency and photoprotective responses. The results of the study revealed that the Mg deficiency had a direct impact on CO_2 assimilation and biomass production. However, no significant influence on photosynthetic light reactions was observed. Furthermore, no direct influence on photoprotective mechanisms was detected. No increase in the concentration of the pigments involved in NPQ was observed. Moreover, she investigated the level of the gene expression of violaxanthin de-epoxidase and zeaxanthin epoxidase (Figure 2) where no increase in the level of fold expression could be estimated. It was concluded that plants which are high-light tolerant (such as spinach) are less vulnerable to photo-oxidative stresses caused by Mg deficiency. The results of this project part were published in *Plant Stress* in October 2021.

The PhD project of Setareh Jamali Jaghdani contributes to a better understanding of the influences of Mg deficiency on physiology, photosynthesis, and photoprotective mechanisms in different crop plants. It provides more detailed insights and helps to close the knowledge gap that exists regarding the critical Mg concentrations for specific physiological and biochemical processes. Furthermore, it helps to better implement the fertilization strategies.



High-performance liquid chromatography (HPLC) measurements were one of the methodologies that Setareh Jamali Jaghdani used in quantification of pigments involved in the xanthophyll cycle. The extracts of the plant's pigments are filtered before the HPLC measurements. (Photo: Jamali Jaghdani)

Effects of P and 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

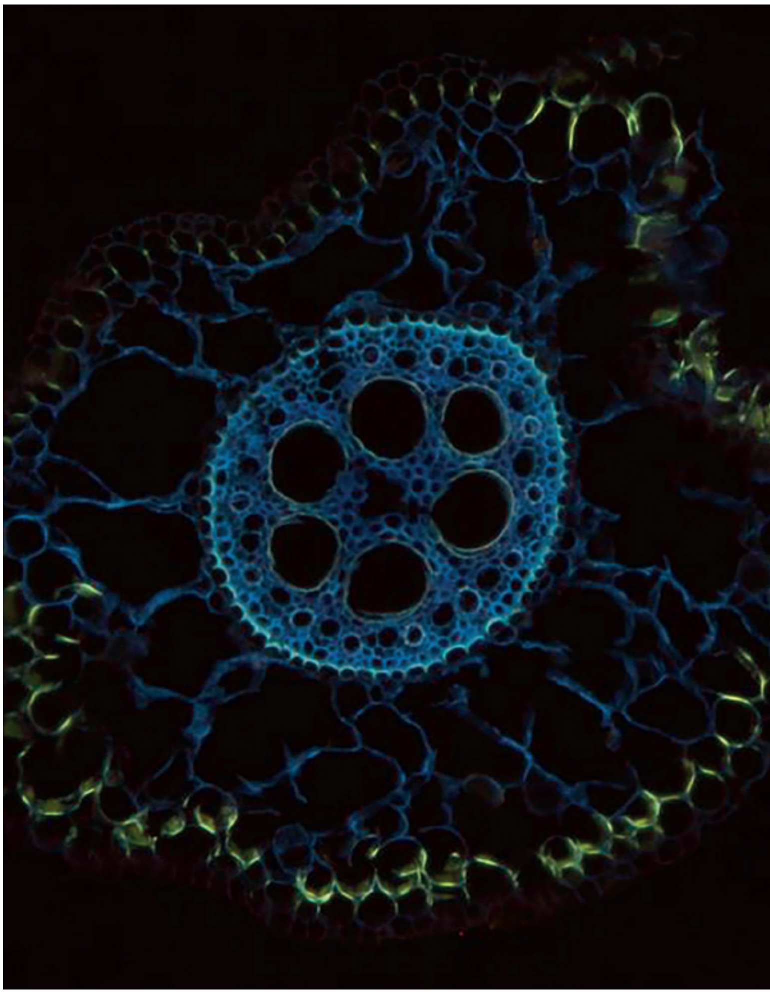
In her PhD research project, Tingting Liu investigates the molecular genetic mechanisms and physiological responses of root apoplastic barriers (including Casparian bands and suberin lamellae) to P and K deficiency in soil-grown maize roots.

Roots play a main role in the nutrient and water uptake from surrounding soil. The nutrients are transported into the root central cylinder through three radial pathways: the apoplastic, the symplastic, and the coupled transcellular pathway. Both Casparian bands and suberin lamellae act as apoplastic root barriers in the endo- and exodermis in plant roots. The increase of suberization of roots in response to abiotic stresses provides a: (i) barrier to prevent uncontrolled passive water loss during water deficit, (ii) barrier impeding toxic ions during salinity, or (iii) barrier against radial oxygen loss in roots under hypoxia conditions. This has been extensively shown in the past. However, the effect of mineral nutrient supply on root barrier development and its physiological effects are not completely understood.

Such cell wall modification in roots occurs during cell differentiation that includes different development stages from the formation of Casparian bands, formation of suberin lamellae, and secondary cell wall deposition, corresponding to different root zones. Here, Tingting Liu's focus is on the development of apoplastic barriers under P deficiency and K deficiency and their effect on nutrient and water transport.

During her pre-test, the development of apoplastic barriers was observed through microscopic staining. Nutrient content in maize and soil before planting and after harvest were measured and compared. For future experiments, she will continue to study the effect of K deficiency on apoplastic barriers. Gas chromatography will be used to do further composition analysis of apoplastic barriers. Transcriptomic analyses will be carried out to understand the genetic mechanisms.

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



Through berberine-aniline blue staining, Casparian bands in endodermis and exodermis of maize roots grown in P deficient soil are observed. (Photo: Tingting Liu)

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 single plant nutrients. Of course, students have options of doing a thesis at IAPN, at undergraduate, Master's and PhD level.

Writing a Master's thesis at IAPN

Comparing improved management strategies in rainfed cropping systems to increase soil organic carbon stocks and water-use efficiency in the semi-arid tropics of India

Master's thesis projects are opportunities for collaboration of universities, i.e., the University of Göttingen, and external research institutions. IAPN student Margarethe Sophie Karpe did her Master's thesis in a joint project of IAPN and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The Master's thesis is entitled "Comparing improved management strategies in rainfed cropping systems to increase SOC stocks and water-use efficiency in the semi-arid tropics of India." The project was funded by the ATSAF-CGIAR++ Junior Scientists Program. Supervisors were Dr. Andrew Smith (ICRISAT) and Professor Dr. Klaus Dittert (IAPN). Both IAPN and ICRISAT share the common mission to address issues of sustainable resource use in agriculture to reach global food demand and to aim at making the findings implementable by agricultural practitioners.

Efficient resource use is a global challenge and a key focus of agricultural research. In drylands, low soil organic carbon (SOC) concentrations and variable rainfall are major limitations to agriculture, threatening yield stability and food security. However, increasing SOC has great potential to improve the soil productivity and farmers' livelihoods, as well as mitigations on climate change.

In the presented Master's thesis, data from ICRISAT was used to identify and evaluate management solutions that may mitigate the problems of low SOC and limited water availability in Maharashtra (India). Via modelling, it was investigated how farm management decisions have an impact on soil carbon sequestration and productivity in order to propose more sustainable management options, including appropriate crop rotations, irrigation, and N fertilization.

A critical step of the thesis project was to find a way to analyze big data generated from the previously run process-based crop model simulations. Process-based crop models are tools that mimic crop growth to predict yield and other agroecosystem outputs such as SOC. Widespread crop management practices in various locations within five districts of Maharashtra were simulated under current and under improved management regimes and changing climate conditions. Using a decision tree algorithm for data mining of the simulated data, best site-specific management was identified to maximize SOC, productivity, or water-use efficiency, respectively.

The results showed that the soil type together with the land-use management, especially crop rotation choice, were influential determinants for changes in SOC stocks. The performance of cropping systems was highly site-specific. Improved fertilization was beneficial for SOC and water-use efficiency. However, the Indian farmers face limitations in the availability of inorganic and organic fertilizers.

Moreover, machine learning algorithms such as decision trees have a great potential to analyze big data, such as data retrieved from process-based crop models. It is a promising approach to develop practical decision tools for farmers, such as mobile phone applications, to facilitate more sustainable farming.

Indian farmer harvesting sorghum, a staple crop in Maharashtra which is well-adapted to drought. (Photo: ICRISAT)

Collecting ground data for crop model setup. (Photo: T. Falk, ICRISAT)

Pollinators are attracted to strawberry plants with a higher number of flowers. (Photo: Tränkner)

The effects of fertilization, arbuscular mycorrhizal fungi (AMF), and pollination in strawberries (*Fragaria ananassa* var. Korona)

In 2021, a Master's thesis project was jointly implemented by IAPN's Junior Professor Dr. Merle Tränkner (co-supervisor) and Dr. Svenja Bänsch (supervisor), postdoc at the Division Functional Agrobiodiversity at the Faculty of Agricultural Sciences of the University of Göttingen. The Master's thesis was submitted by Carman Kirsch and it was entitled "The effects of fertilization, arbuscular mycorrhizal fungi (AMF), and pollination in strawberries (*Fragaria ananassa* var. Korona)".

It is known that when strawberry plants are supplied with enough nutrients, light and water, they will produce high quality fruits as well. Arbuscular mycorrhizal fungi enhance the nutrient uptake by plants. Moreover, previous studies have shown that pollinators, such as wild bees, select pollens with high protein concentrations. Therefore, this study focuses on the influence of arbuscular mycorrhizal fungi on fruit quality and yield of strawberry which is a pollination-sensitive plant in terms of fruit quality.

The study pursued to respond to the following questions: Are arbuscular mycorrhizal fungi capable of compensating the inadequate nutrient supply? Can we achieve higher fruit quality when the visits by the pollinators increase? Are the pollinators attracted by plants that grow with arbuscular mycorrhizal fungi? Do we observe bigger fruits on plants in symbiosis with arbuscular mycorrhizal fungi?

The experiment was conducted at the experimental botanical garden of the University of Göttingen. Pollinator abundance, flower visits, and flower size were examined. Sugar to acid ratio and total soluble solids were analyzed on fully developed fruits. Root staining revealed that the arbuscular mycorrhizal fungi colonization was successful.

The results of this study reveal that the number of flowers is a key factor for the pollinator's visits rather than the colonization level with various arbuscular mycorrhizal fungi. However, arbuscular mycorrhizal fungi improved the quality of plants when pollinators were eliminated. Previous studies have shown that the pollinators influence the sugar to acid ratio adversely whereas the arbuscular mycorrhizal fungi had no negative impact on the sugar to acid ratio.

Completed theses supervised by IAPN scientists in 2021

Immo Branding, MSc Thesis (2021):
Effect of catch crop *(Fodder radish)* mulching at vegetation period end on soil mineral nitrogen and N_2O-emissions

Constantin Theodor Tobias Dröge, BSc Thesis (2021):
Einfluss von Nähr- und Wirkstoffbeizen auf die Ertragsentwicklung von Winterweizen

Theresa Ebert, BSc Thesis (2021):
Effect of catch crop biochemical composition on GHG emissions

Marius Eckhoff, MSc Thesis (2021):
Estimation of the Farm-Specific Nitrate Concentration in Leachate through the Basic-Emission-Monitoring with the Aid of Nitrogen Balance Data

Vencke Kirsten Grüning, MSc Thesis (2021):
Ökotoxikologische Bewertung von organischen Düngemitteln – Probleme und Lösungsansätze

Margarethe Sophie Karpe, MSc Thesis (2021):
Comparing improved management strategies in rainfed cropping systems to increase SOC stocks and water-use efficiency in the semi-arid tropics of India

Carmen Kirsch, MSc Thesis (2021):
The effects of fertilization, arbuscular mycorrhizal fungi (AMF), and pollination in strawberries *(Frageria ananassa)*

Tobias Kunze, MSc Thesis (2021):
Scouting the impacts of magnesium deficiency on photosynthetic mechanisms in *Spinacia oleracea*

Simon Marx, MSc Thesis (2021):
Influence of mixed cultivation of winter wheat (*Triticum aestivum* L.) and winter field bean (*Vicia faba* L.) on soil-borne greenhouse gas emissions in the following crop Italian ryegrass (*Lolium multiflorum* Lam.)

Knowledge Exchange

Interdisciplinary discourse with scientists and practitioners

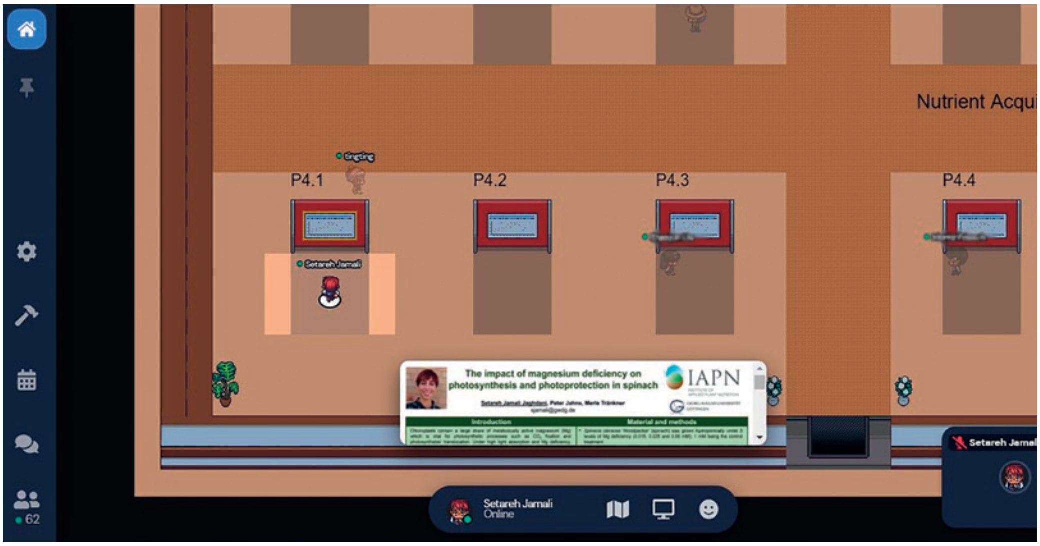
IAPN strives to expand its international and national cooperation with professionally complementary institutions and researchers. In addition, IAPN consciously turns to practice-oriented research. The institute aims to transfer the already available scientific knowledge into practice more intensively,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

IAPN at the 53rd Annual Conference of the German Society of Plant Nutrition

From September 22nd to 24th, the Annual Conference of the German Society of Plant Nutrition (Deutsche Gesellschaft für Pflanzenernährung e.V., DGP) took place in an online format due to the Covid-19 restrictions. The conference was organized by Kiel University and held under the topic "Germany meets Denmark – Challenges and Perspectives for Plant Nutrition in 2030". Invited speakers were from Denmark, France, and Germany. Paulo Cabrita and Setareh Jamali Jaghdani presented posters about their latest research projects.

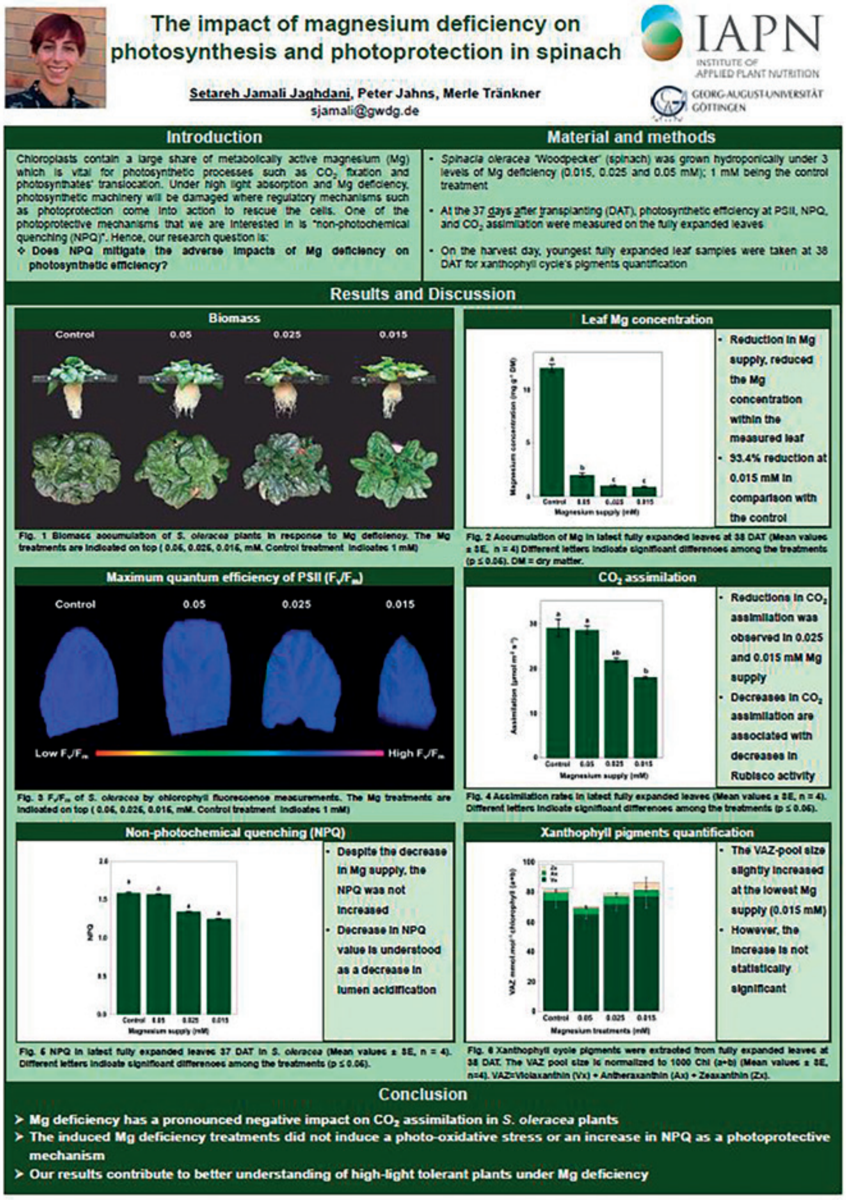
The first poster of Paulo Cabrita, in collaboration with Merle Tränkner, was entitled "Effect of Magnesium on Nitrogen Uptake and Crop Yield in Spelt (*Triticum spelta* L.) using Remote Sensing Methods". It presented the latest results of a field trial conducted in 2020 near Hannover, on a field considered naturally deficient in Mg. The trial focused on the effects of Mg availability on N uptake in what is called Mg-induced N uptake, by testing different Mg and N fertilization regimes. Plants responded to an increase in N supply with increasing yield and biomass, however, the effect of Mg on N uptake was reflected mostly by an increase in the harvest index. Using satellite image analysis combined with field sampling, results suggest that the effects of Mg on N uptake are diverse and might depend on the time and, possibly, form of Mg application compared to plant development.

His second poster, with the title "Non-invasive assessment of the physiological role of leaf aerenchyma and its relation to plant water status", presented a novel interpretation for the results obtained while applying the leaf patch clamp pressure (LPCP) probe on plants in which the aerenchyma constitutes most of the mesophyll volume. The LPCP probe is used as a non-invasive indirect measurement of the leaf turgor pressure and, ultimately, the plant water status. However, when applied on leaves in which the aerenchyma present constitutes a big fraction of the mesophyll volume, its results translate changes in the aerenchyma pressure instead, as measurements on *Hippeastrum* plants show. Leaf aerenchyma air pressure depends on the changes in the leaf vapor pressure occurring during photosynthesis. Therefore, the LPCP output pressure in *Hippeastrum* can be still related to plant water status and leaf turgor pressure through the gas-exchange processes that occur in the leaf aerenchyma, namely, during photosynthesis.



Within the online format of poster presentation at the Annual Conference of the German Society of Plant Nutrition, the participants could select their avatars as how they wanted to be represented. They could move their avatars within different poster halls and exchange comments and ideas with other scientists. This screenshot shows Setareh Jamali Jaghdani's avatar standing in front of her poster. The participants could click on the poster and view the original size. (Source: Jamali Jaghdani)

Setareh Jamali Jaghdani presented her poster regarding her latest research with the title "The impact of magnesium deficiency on photosynthesis and photoprotection in spinach" that was developed in cooperation with Professor Dr. Peter Jahns from the University of Düsseldorf and her direct supervisor Junior Professor Dr. Merle Tränkner. "Despite the limitations caused by Covid-19, it was a great chance to virtually meet other scientists in plant nutrition research and exchange information with them", says Setareh Jamali Jaghdani.



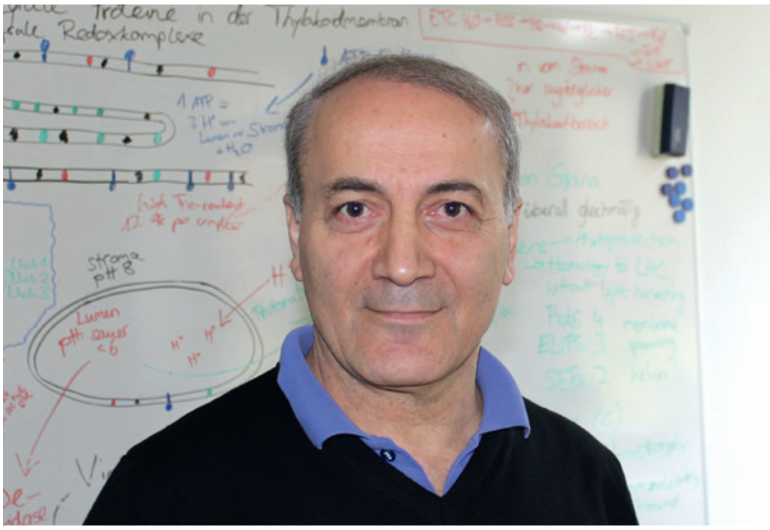
Setareh Jamali Jaghdani's poster at the 53rd Annual Conference of the German Society of Plant Nutrition in September 2021. (Source: Jamali Jaghdani)

Professor Dr. Ismail Cakmak receives honorary professorship at the University of Göttingen

In autumn 2021, the Faculty of Agriculture at the University of Göttingen appointed Professor Dr. Ismail Cakmak as honorary professor beginning with the winter semester 2021/22. The inaugural lecture took place at a faculty event on November 3rd 2021. Subject of the lecture was "Fertilizers: an underestimated strategy against the still persistent global problem of Hidden Hunger".

Ismail Cakmak is worldwide highly recognized for his expertise in the field of plant nutrition and plant physiology, in which he connects basic research with practical application. Since 2000, Ismail Cakmak is professor of plant nutrition and nutritional physiology at Sabanci University, Istanbul, Turkey, where he is working in the study program "Molecular Biology, Genetics and Bioengineering". Among other projects, Ismail Cakmak coordinates a global research project on the role of fertilizer strategy in improving the concentrations of micronutrients (especially zinc) in cereal grains, the HarvestZinc project. In recognition of his scientific strengths, the importance of his research activities to human nutrition, and his achievements in the international scientific community, he has received a number of very prestigious awards – like the Georg Forster Research Award of the Alexander von Humboldt Foundation or the Agricultural Science Prize of the World Academy of Sciences.

Ismail Cakmak conducted research as a guest scientist at IAPN and the University of Göttingen for several years: in 2014 and from 2016 to 2018, he worked at IAPN and at the Department of Crop Sciences, in the Section of Plant Nutrition and Crop Physiology of the Faculty of Agriculture.



Professor Dr. Ismail Cakmak. (Photo: IAPN)

During this time, he was engaged in joint research activities of IAPN and Sabanci University, and he made very valuable contributions to the strengthening of scientific connections between both institutions and for example the International Magnesium Institute (IMI) in Fuzhou, China. Additionally, he contributed, alongside to Professor Dr. Klaus Dittert and Junior Professor Dr. Merle Tränkner, to teaching activities.

Publications

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

Jamali Jaghdani, S. (2021) Magnesium deficiency induced responses in crop physiology: impacts on photosynthesis, light utilization, and photoprotection.
http://dx.doi.org/10.53846/goediss-8921

Jamali Jaghdani, S.; Jahns, P. and Tränkner, M. (2021) The impact of magnesium deficiency on photosynthesis and photoprotection in *Spinacia oleracea*. Plant Stress, 2, 100040; https://doi.org/10.1016/j.stress.2021.100040

Kesenheimer, K.; Augustin, J.; Hegewald, H.; Köbke, S.; Dittert, K.; Räbiger, T.; Quinones, T. S.; Prochnow, A.; Hartung, J.; Fuß R.; Stichnothe, H.; Flessa, H. and Ruser, R. (2021) Nitrification inhibitors reduce N_2O emissions induced by application of biogas digestate to oilseed rape. Nutrient Cycling in Agroecosystems, 120(1), 119-120.
https://doi.org/10.1007/s10705-021-10127-8

Mugo, J. N.; Karanja, N.; Gachene, C.; Dittert, K. and Schulte-Geldermann, E. (2021) Response of potato to fertilizers applied on different soil types in Kenyan Highlands. Agronomy Journal. https://doi.org/10.1002/agj2.20827

Mugo, J. N.; Karanja, N. N.; Gachene, C. K.; Dittert, K.; Gitari, H. I. and Schulte-Geldermann, E. (2021) Response of potato crop to selected nutrients in central and eastern highlands of Kenya. Cogent Food & Agriculture, 7(1).
https://doi.org/10.1080/23311932.2021.1898762

Rummel, P.S.; Well, R.; Pausch, J.; Pfeiffer, B. and Dittert, K. (2021) Carbon availability and nitrogen mineralization control denitrification rates and product stoichiometry during initial maize litter decomposition. Applied Sciences, 11(11).
https://doi.org/10.3390/app11115309

Rummel, P.S.; Well, R.; Pfeiffer, B.; Dittert, K.; Floßmann, S. and Pausch, J. (2021) Nitrate uptake and carbon exudation – do plant roots stimulate or inhibit denitrification? Plant and Soil, 459(1). https://doi.org/10.1007/s11104-020-04750-7

Wang, H. T.; Ma, S. T.; Shao, G. D. and Dittert, K. (2021). Use of urease and nitrification inhibitors to decrease yield-scaled N_2O emissions from winter wheat and oilseed rape fields: A two-year field experiment. Agriculture, Ecosystems & Environment, 319. https://doi.org/10.1016/j.agee.2021.107552

Conference talks – papers – posters

Cabrita, P. (2021): Non-invasive assessment of the physiological role of leaf aerenchyma and its relation to plant water status. 53rd Annual Conference of the German Society of Plant Nutrition (DGP), online, September 22nd–24th 2021, Kiel, Germany

Cabrita, P. and Tränkner, M. (2021): Effect of magnesium on nitrogen uptake and crop yield in spelt (*Triticum spelta* L.) using remote sensing methods. 53rd Annual Conference of the German Society of Plant Nutrition (DGP), online, September 22nd–24th 2021, Kiel, Germany

Jamali Jaghdani, S.; Jahns, P. and Tränkner, M. (2021): The impact of magnesium deficiency on photosynthesis and photoprotection in spinach. 53rd Annual Conference of the German Society of Plant Nutrition (DGP), online. September 22nd–24th 2021, Kiel, 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
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
University of Düsseldorf, Institute for Plant Biochemistry	Düsseldorf, Germany
University of Göttingen	Göttingen, Germany
Agroecology Group	
Division of Quality and Sensory of Plant Products	
Functional Agrobiodiversity	
Plant Pathology and Crop Protection	
University of Halle, Institute of Plant Nutrition	Halle, Germany
University of Hannover, Institute of Botany	Hannover, 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

IAPN – Institute of Applied Plant Nutrition
at Georg-August-Universität Göttingen
Carl-Sprengel-Weg 1
37075 Göttingen, Germany
www.iapn.de