

ANNUAL REPORT 2018

RESEARCH ON SUSTAINABLE PLANT NUTRITION



Imprint

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"New results on magnesium are enormous."

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Preface

Dear reader,

at your hands is IAPN's annual report 2018 and we are happy to provide insights into our most recent activities in research and teaching as well as giving you an overview about news at IAPN.

2018 was a year of extreme drought that particularly struck Germany's agriculture in large regions and many crop stands suffered seriously. For IAPN this means that our major research subjects on the functions of mineral plant nutrients in plant water-use efficiency and drought tolerance address some of the most urgent questions in agriculture that also have high scientific and socio-economic relevance. It seems likely that in future cultivated plants will experience such situations more often and more often water will be a growth limiting resource in regions where drought hasn't been observed so far. Plant nutrients too are limited resources and their responsible and target-oriented use to achieve maximum use of the available water is the scientific challenge that drives us even more.

It is a central character of IAPN as part of an academic institution of research and teaching to be engaged in the formation of the next generation of scientists. A result of this are again changes within the scientific team. A highlight of 2018 was the very successful graduation of Dr. Ershad Tavakol who left IAPN right after. Also, Dr. Balint Jákli left University of Göttingen in summer 2018. For more than a year following his graduation he worked as postdoc scientist bringing forward our knowledge on remote sensing methods of early recognition of plant nutrient deficiencies. Both colleagues made excellent contributions and our best wishes are with them. In spring 2018, Setareh Jamali Jaghdani joined our team and for the next three years she will conduct research on functions of magnesium with respect to photosynthesis and the protection of the plant's photosynthetic apparatus. Additionally, the IAPN team was reinforced by Dr. Melanie Hauer-Jákli and Dr. Paulo Cabrita who contribute to diverse research and teaching projects which will be described in detail.

I invite you to read more on this and numerous other activities on the next pages.

You are also very welcome to visit IAPN's webpages at www.iapn.de for updated information on our ongoing activities. Here you may read about all kind of current activities for example the public 'IAPN in Dialogue' meetings where typically we take opportunity to discuss current issues in plant nutrition with visiting scientist from abroad.

Wishing you pleasant reading and interesting new perspectives.



Professor Dr. Klaus Dittert
Scientific director of IAPN





Measurements during an experiment on sunflower at IAPN: IAPN technician Ulrike Kierbaum (left) and a student (right) are working with Jun. Prof. Merle Tränkner (middle) in the greenhouse. During the experiment, a thermo-camera assesses the leaf temperature (in left of the photo) and measurements of leaf gas exchange record assimilation and transpiration rates (in the center of the photo). (Photo: D. Jákli)

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 KALI GmbH following both institutions' impetus to strengthen the exchange between academic research and formation activities and the private company sector. There is much common interest in questions of sustainable nutrition of plants as well as in ethically and environmentally sound strategies for the development of 21st century agricultural systems. Both partners have vital interest in promoting the formation of young scientists who, on the basis of 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 which means that it is closely linked to the University of Göttingen and contributes to the University's core responsibilities, academic formation and research. In both, research and education, the common rules of good scientific practice also apply to the University's associated institutes.

IAPN became active in 2012. Since, IAPN's scientific and technical personnel were built up and a large number of new 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.

In October 2016, the contract of cooperation between University of Göttingen and K+S KALI GmbH was extended for another six years.

IAPN's objectives

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 is committed to researching the role of intelligent fertilizer management in handling these global challenges, and in providing solutions. All research projects at the institute aim towards the development of concrete fertilizer recommendations for agriculture on the basis of the newest scientific results. IAPN works at the interface between science, teaching and agricultural practice. Developing approaches to an efficient exchange and transfer of knowledge is therefore also an important goal.

The activities of IAPN complement and enrich each other, they mainly include:

- **Research in applied plant nutrition**

Research at IAPN concentrates on water-use efficiency, nutrient-use efficiency, and remote sensing. One important research focus of the institute is the question of how to use optimum nutrient supply to raise the water-use efficiency of plants in order to ensure excellent yields even when water is scarce and to look at the entire soil/plant system in this context.

- **International and interdisciplinary 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 - like the International Symposium on Magnesium - and research visits, creating synergies for successful research and practical implementation of research results.

- **Teaching and knowledge transfer in applied plant nutrition**

The IAPN team is very active in offering classical lectures to students as well as laboratory and greenhouse courses, and offers opportunities for students to do their Bachelor's, Master's or PhD thesis. Visiting scientists spend time at IAPN. Students, agricultural advisors and extensionists from abroad may carry out internships for a limited period of time. And young colleagues with good potentials and backgrounds that match IAPN's expertise can pass two to three months internships. The transfer of knowledge and concepts is often bi-directional as visitors report on their perception of key challenges and discuss their ideas to achieve progress.





Since September 2013, **Martina Renneberg** works as a secretary for the management board at IAPN. Her responsibilities include the management of third-party funds of IAPN, all financial accounting including human resources and staff management of IAPN. Furthermore, she organizes and coordinates events at IAPN and is IAPN's contact person for communication within and outside the Göttingen Campus.

The IAPN Team

In 2018, the team of IAPN consisted of up to 10 members in administration, technical and laboratory assistance and scientific staff. The institute is headed by Professor Dr. Klaus Dittert, and Dr. Merle Tränkner holds the junior professorship. All administrative matters are managed by Martina Renneberg, and the technical and laboratory assistance is provided by Kirsten Fladung and Ulrike Kierbaum.

In July 2018, Annika Lingner successfully received a doctorate for her thesis "Water use efficiency of arable and grassland crops in legume-based intercropping systems". Following her graduation, she worked as a postdoc within the IMPAC³ project at IAPN.

After graduation of Merle Tränkner and Bálint Jákli in 2016 and of Ershad Tavakol in early 2018, a new generation of young scientists started working at IAPN in 2018. Setareh Jamali Jaghdani began her PhD studies in January 2018 and investigates the impact of magnesium (Mg) deficiency on the photosystem functionality and photosynthetic efficiency. Four months later, Dr. Melanie Hauer-Jákli joined the IAPN team. Her project aims at quantifying the effect of nutrient supply - especially Mg - on biomass and photosynthetic performance of various plant species. The findings of this project were already summarized in a manuscript, that is planned to be published in a peer-reviewed journal in 2019. In August 2018, Dr. Paulo Cabrita started working at IAPN on the project "The application of digital and sensing methods in plant nutrition" as well as other projects focused on the water-use efficiency of crop plants.

Between August and October 2018, Dr. Juliane Dao was member of the IAPN team as research assistant, teaching in cooperation with Junior Professor Dr. Merle Tränkner in the Bachelor's degree program of agricultural sciences at the University of Göttingen.

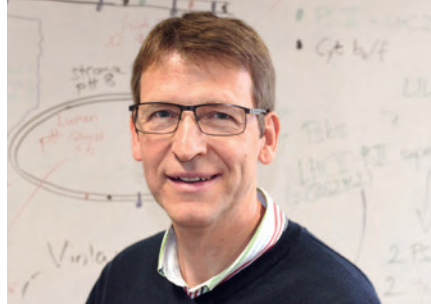
Throughout the year, the IAPN team was intensively supported by many graduate and undergraduate student assistants who helped in plant cultivation, measurements and preparations of numerous plant, soil, gas, biochemical and molecular samples. Their contribution is greatly acknowledged.

Who is who at IAPN?

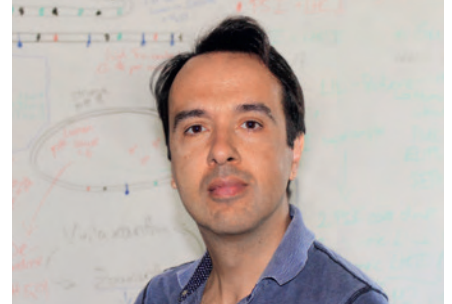
IAPN's achievements are always based on the excellent co-operation of the entire team. In this annual report, we will introduce IAPN staff members within the context of their activities and projects.



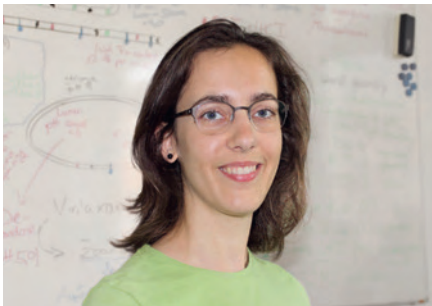
Jun. Prof. Dr. Merle Tränkner



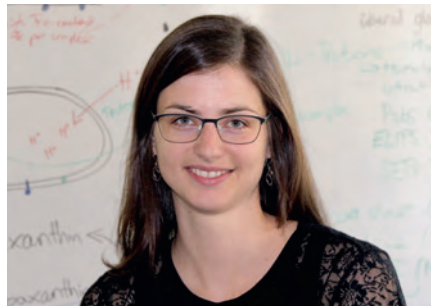
Prof. Dr. Klaus Dittert (scientific head)



Dr. Paulo Cabrita



Annika Lingner MSc



Dr. Melanie Hauer-Jákli



Setareh Jamali Jaghdani MSc



Ulrike Kierbaum



Martina Renneberg



Kirsten Fladung





Scanning of leaf area to determine growth rates and photosynthetic area. (Photo: D. Jákli)

Research at IAPN

IAPN topics

Today's challenges in agricultural research are numerous and more difficult than ever. The Western world's highly industrialized economies with their high-input/high-productivity agriculture face great environmental and economic difficulties - while economically less powerful countries strongly seek for promising strategies to simply provide enough and healthy nourishment to their people. A common denominator of challenges in both systems is the need to make better use of the resources that are used in agricultural systems. This applies in particular to land, soils, plant nutrients and water.

Research on water-use efficiency and nutrient-use efficiency

Research at IAPN addresses these issues, focusing especially on water-use efficiency and the role of plant nutrition in this context and on nutrient-use efficiency. Long-term objective is the development of site-specific, intelligent fertilization management systems, with special attention given to the nutrients potassium (K) and Mg. 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.
- Options for increasing nutrient-use efficiency in crop plants.

- Understanding alterations in the plants physiology as response to fertilization.
- Connections between plants nutrient supply and human health.
- New strategies for improving fertilizer recommendations and management.

Exploring remote sensing

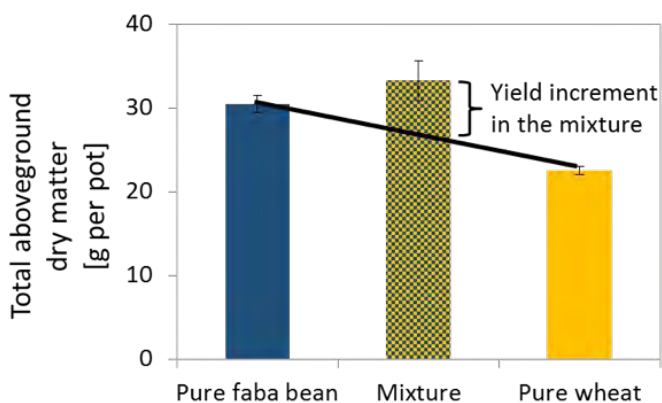
For early detection of stress symptoms in plants - as drought and nutrient deficiency - IAPN scientists use and further explore methods for remote sensing, including thermography, gas exchange measurement and stress detection by chlorophyll fluorescence. For remote imaging in field trials drone and satellite technology is used. Beside greenhouse and field trials, intensive laboratory studies are carried out at IAPN.

Since the early years of IAPN, research concentrated on aspects of water-use efficiency for crops inter alia in relation to the supply of the nutrients K and Mg. The first generation of PhD research projects has been completed in July 2018 when Annika Lingner successfully received a doctorate. In 2018, new research projects were started by Dr. Melanie Hauer-Jákli, Dr. Paulo Cabrita and Setareh Jamali Jaghdani.

PhD research project of MSc Annika Lingner

Intercropping systems and their water-use - investigations in field and greenhouse

After successful evaluation by the executing organization, the joint research project IMPAC³ ("Novel genotypes for mixed cropping allow for improved sustainable land use across arable land, grassland and woodland") could start into the second phase in beginning of 2018. It will now be continued until January 2020. In that time, research will be proceeded on questions of how mixed cropping can improve productivity and sustainability of agricultural systems to follow up previous findings. The overall observation in IMPAC³ was a positive mixture effect regarding aspects such as yield, root systems and resource use across all three land-use systems arable land, grassland and forest. The mixture effect in terms of yield production is defined as relative increment compared to the theoretical mean of both pure stands. This effect could as well be verified in greenhouse experiments on faba bean/wheat mixtures.



Positive mixture effect as biomass increment in faba bean-wheat mixed cropping. (Source: Lingner)

Field day with the executing organization

In order to get an impression of the work performed in the field, the responsible persons from the executing organization Jülich visited the study site Reinshof in June 2018. Recent achievements were explained by demonstrating various measurement techniques as well as presentations of scientific results. There were vivid discussions on the growth of faba bean, root development in the mixture and many other topics. Annika Lingner illustrated the application of spectral and thermal imaging with the drone. On exemplary images, the effect of nitrogen (N) fertilizer in non-legumes



Annika Lingner explaining results from thermal imaging to the persons responsible of the executing organization. (Photo: Isselestein)

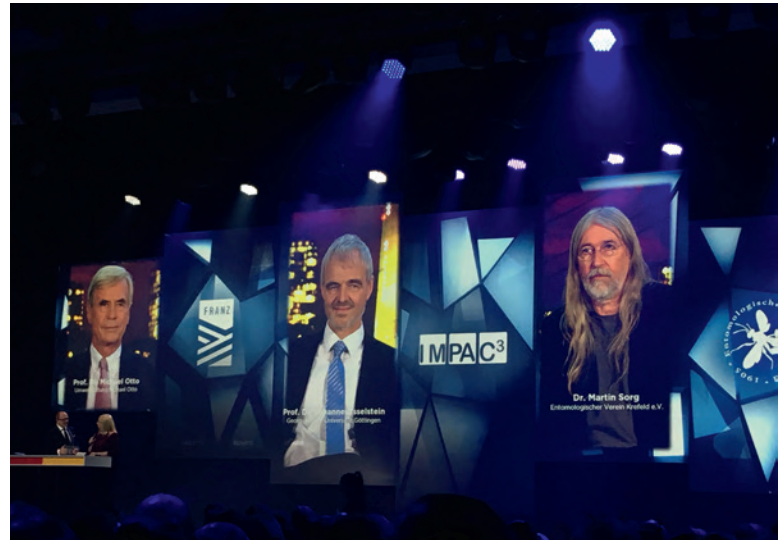
was clearly visible by decreased canopy surface temperatures in response to better growth. The visitors could then compare the positive effect of N fertilizer with the positive mixing effect of legumes.



Annika Lingner started her work as research associate at IAPN and the University of Göttingen in September 2014. She did her Bachelor degree in agricultural biology at the University of Hohenheim in 2011 and successfully completed her Master's studies in agriculture 2013 at the University of Göttingen. Afterwards she worked several months in a research project on the model legume *Medicago truncatula* in the Division of Plant Nutrition and Crop Physiology at the Faculty of Agricultural Sciences in Göttingen.

Nomination for the German Sustainability Award

The successful performance of the whole project as well as the partly already published results also led to the nomination for the German Sustainability Award in the research category, all dealing with agriculture related topics. From a large number of applicants, IMPAC³ was elected by an expert jury to be one of three finalists. In the following, a public voting finally decided on who would receive the award. In November 2018, a television broadcast in "nano", 3sat's science program, supported the election. At the gala in Düsseldorf in December 2018, the results from the public voting were announced. Winner in that category was the project F.R.A.N.Z. (Future Resources, Agriculture & Nature Conservation) which is jointly coordinated by the Environmental Foundation Michael Otto and the German Farmers' Association, also including scientists from the University of Göttingen. IMPAC³ and the project "Standardized Monitoring of Insects in Nature Reserves" were honored with a top three ranking.



Representatives of the nominated projects in the research category awaiting the announcement of the winner, in the center: Prof. Dr. Johannes Isselstein of IMPAC³. (Photo: private)



Delegation of the IMPAC³ project at the gala of the German Sustainability Award: Dr. Horst-Henning Steinmann, Dr. Juliane Streit, Annika Lingner, Paul Götsch, Prof. Dr. Johannes Isselstein (left to right). (Photo: private)



Annika Lingner with doctoral cap after the graduation ceremony. (Photo: IAPN)

Completion of the PhD thesis

During summer, Annika Lingner successfully finished her PhD thesis entitled "Water use efficiency of arable and grassland crops in legume-based intercropping systems". The thesis comprises different parameters related to water-use efficiency to have a detailed look at the complexity of species mixtures. The interrelation of genotype-specific properties and the crop stand is emphasized as well as the improved water-use efficiency of intercropping compared to non-leguminous species. For the defense in July 2018 many colleagues, project partners and associated researchers joined the defense talk and the subsequent informal get-together. After graduation, Annika Lingner continued as postdoc within the IMPAC³ project at IAPN and complemented her position by teaching in courses of the Division of Plant Nutrition and Crop Physiology.



Prof. Dr. Klaus Dittert congratulates Annika Lingner on the successful completion of her doctorate. (Photo: IAPN)



Following a Göttingen tradition, Annika Lingner climbs on the fountain "Gänselesel" to pin flowers and to give a kiss to the statue while being pelted with water balloons. (Photos: IAPN)

Research project of Dr. Melanie Hauer-Jákli

Critical leaf nutrient concentrations for plant growth and photosynthesis

Study aims

In this research project, starting in May 2018, the aim was to quantify the effect of nutrient supply – especially Mg – on biomass and photosynthetic performance of various plant species. The idea was to collect and combine data of all relevant existing scientific literature about Mg and plant growth of the last 70 years in a systematic literature study to calculate critical leaf Mg concentrations for crop growth. Therefore, an intensive search strategy using the online data bases *Web of Science* and *Google Scholar* was conducted. We gathered all literature that focused on the relation between Mg nutrition, tissue Mg concentrations and the parameters biomass, yield, net carbon dioxide (CO₂) assimilation, reactive oxygen species (ROS) as well as activities of enzymes and metabolites involved in scavenging ROS.

We found more than 200 studies related to our research questions. Nearly half of them provided enough information to be further statistically examined. We extracted the data and combined them in a meta-analysis to calculate the overall effect of Mg and to further find relationships between leaf Mg concentrations and parameters that can be related to plant growth and photosynthesis.

Our research questions were the following:

- 1) How is the effect of Mg supply on biomass formation, photosynthetic CO₂ assimilation and anti-oxidative enzyme activities?
- 2) What factors influence the magnitude of these Mg responses?
- 3) What leaf Mg concentrations are critical for growth and photosynthesis?

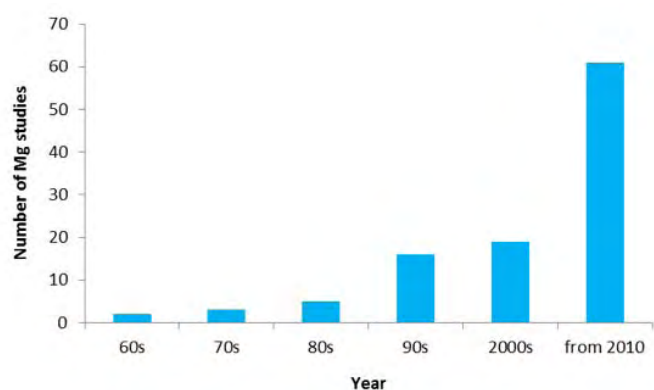


Figure 1: Number of Mg studies published during the last decades and used in the meta-analysis study. (Source: Tränkner)



Dr. Melanie Hauer-Jákli joined the IAPN team in May 2018, focusing on the project "Evaluation of critical nutrient concentrations". In 2015, she finished her PhD with the thesis entitled "Catch crops and sugar beet variety types at *Heterodera schachtii* infested fields – nematode-host interactions and options for nematode control" at the Institute of Sugar Beet Research (IfZ), Department of Agronomy at the University of Göttingen. Since July 2015, she worked on plant protection strategies in sugar beet cultivation at the Department of Systems analysis at IfZ.

Mg and biomass production

Mg is an important element for plant production. However, for a long time, it seemed to be neglected by agronomists and researchers because plant production appeared to be primarily limited by N, phosphorus (P) and K. This is reflected by the number of publications used in this study: from 1960 to 2009, 45 relevant studies about Mg in plant nutrition were published whereas 61 studies were published within the last years, from 2010 to 2018 (Figure 1).

In our study, we found that biomass, i.e., dry matter of the whole plant, can be significantly improved due to an adequate Mg supply compared to plants deficient in Mg. The effect of Mg on biomass of roots is even more pronounced than the effect on shoots.

Mg is important for many physiological and biochemical processes in the plant. For example, under Mg deficiency, carbohydrates produced in source leaves were found to accumulate and translocation to growing plant parts such as roots was inhibited. A decrease in root biomass compared to shoots and thus, an increased shoot-root ratio was often observed and described as one of the first symptoms under Mg deficiency. During our analyses, we found that there is also a considerable number of reports, where shoot-root ratios were not affected by Mg or even decreased under Mg deficiency. Our meta-analysis revealed that shoot-root ratios are unaffected by Mg supply, if the studied plants were raised under adequate Mg supply before the onset of Mg deficient treatments. In case studied plants were initially cultivated without Mg, the shoot-root ratio was increased compared to the well-supplied plants. Mg is very mobile within the plant and can be stored in great amounts in the vacuoles. We think, that redistribution of Mg within the plant under Mg deficiency of initially well supplied plants is the reason why in those cases, effects on plant growth could be compensated to a certain degree.

Importance of Mg for photosynthesis and photo-oxidative stress defense

Our study clearly showed that an adequate Mg supply significantly enhances photosynthetic CO₂ assimilation. Mg is very important for photosynthetic processes, because it is the central atom of chlorophyll and it directly affects Rubisco activity and activation.

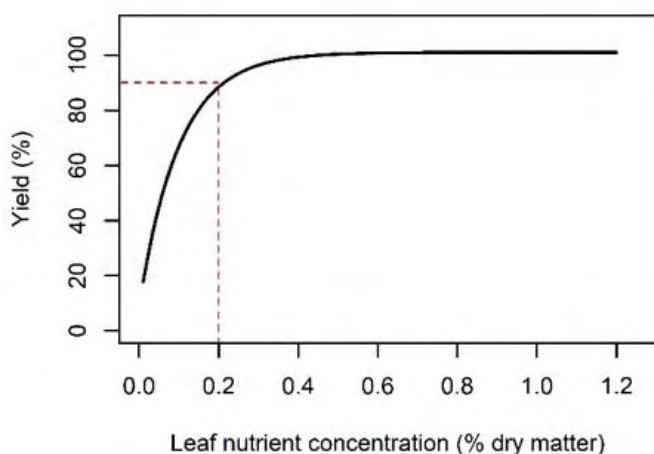


Figure 2: Theoretical relationship between yield and leaf nutrient concentration. The dashed line indicates the critical nutrient concentration producing 90% of maximum yield. (Source: Hauer-Jákli)

Restricted assimilation under Mg deficiency increases oxidative stress because electrons and excitation energy not used in photosynthesis induce excessive production of ROS, i.e., oxidative stress. We quantified that under Mg deficiency this oxidative stress is increased by one third compared to well-supplied plants. The activity of many enzymes and metabolites involved in scavenging of ROS were also found to be increased under Mg deficiency to detoxify ROS.

Critical leaf Mg thresholds for biomass and photosynthetic CO₂ assimilation

Leaf nutrient concentrations are an important diagnostic tool to determine the nutrient status of plants and therefore to decide about the requirement of fertilizer use. A prerequisite for the concept of critical nutrient concentrations is a specific relation between leaf nutrient concentration and the respective parameter that characterizes growth, such as dry matter, net CO₂ assimilation or yield. A critical nutrient concentration is defined as the nutrient concentration at which 10% loss of the specific growth factor occurs (Figure 2). For many plant species, these critical values do not exist for Mg, among them major crops such as potato and barley. Studies that relate leaf Mg concentrations to growth parameters of specific species are a possible source of determining critical leaf Mg values in case where those are so far missing.

We combined all available data and calculated the critical leaf Mg concentration for many crop and tree species. We found typical curvilinear relationships between Mg leaf concentrations and dry matter or CO₂ assimilation for many species. Most monocots had lower and most legumes higher critical Mg leaf concentrations for dry matter than dicots or non-legumes, respectively. Furthermore, critical values for net CO₂ assimilation were higher than for dry matter production for most species.

Our results may help to determine the Mg nutritional status of plants in the field or greenhouse and therefore, to optimize fertilization strategies.

The findings of this project were already summarized in a manuscript that will be published in a peer-reviewed journal in the course of 2019.

The technical assistants at IAPN

An important part of research and teaching at IAPN are experiments in the greenhouse, growth chambers, on the field and in the laboratory. In these activities the scientists of the institute are supported by two technical assistants.



Kirsten Fladung started her work as a technical assistant at IAPN in October 2012. She takes care of analyses of mineral elements in plant and soil samples by ICP-OES, atomic absorption spectrometry (AAS) and C/N analyser. She is involved in measurements of chlorophyll, ROS and activity assays of ROS detoxifying enzymes in plant tissues. Furthermore, Kirsten Fladung supports molecular activities such as protein isolation. She also assists PhD, graduate and undergraduate students with their plant experiments in the greenhouse and field.

Ulrike Kierbaum is working as a technical assistant at IAPN since July 2013. She provides support to undergraduate, graduate and PhD students of IAPN within their research projects. This covers preparing and coordinating plant experiments in growth chambers, greenhouse, on the field, and as well as laboratory analytics. In addition, she conducts ammonium, nitrate and phosphate analyses of soil extracts by Skalar segmented-flow analysis and is involved in measurements of toxic ROS and activity assays of ROS detoxifying enzymes in plant tissues.



Research projects of Dr. Paulo Cabrita

Dr. Paulo Cabrita started working at IAPN as a post-doctoral researcher on August 2018 on the application of digital and remote sensing methods in plant nutrition and water-use efficiency of crop plants.

Detection and quantification of Mg deficiency in field grown winter wheat using remote sensing

Mg is an essential macronutrient participating in many physiological processes, e.g. cofactor of many enzymes involved in respiration, photosynthesis, and the synthesis of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), structural stabilizer of several nucleotides, and part of the ring structure of the chlorophyll molecule. Its deficiency in crops, typically visible as interveinous chlorosis that occurs first in older leaves because of the mobility of this element, can affect biomass and yield formation severely. Due to the mobility of Mg in the phloem, the chlorophyll in the vascular bundles remains unaffected for longer periods than the chlorophyll in the cells between the bundles, causing the pattern of chlorosis typical of Mg deficiency. Under prolonged and extensive deficiency, the leaves may become yellow or white leading to senescence and premature leaf abscission eventually. However, similarly to other nutrient deficiencies, when plants display visible symptoms or even before they appear, plant growth and development has already been severely compromised, thus decreasing yield considerably. Therefore, the presymptomatic and non-invasive detection of nutrient deficiencies in plants is crucial for crop monitoring and to alleviate stress at early stages of plant development, thus avoiding irreversible damage and mitigate yield losses substantially. This project, made in collaboration with the Cartography, GIS and Remote Sensing Department from the



Figure 1: Satellite image of a wheat field (red line) and surrounding area, located close to Hannover, on December 11th 2018. (Image source: Cabrita; contains modified Copernicus Sentinel data 2018)

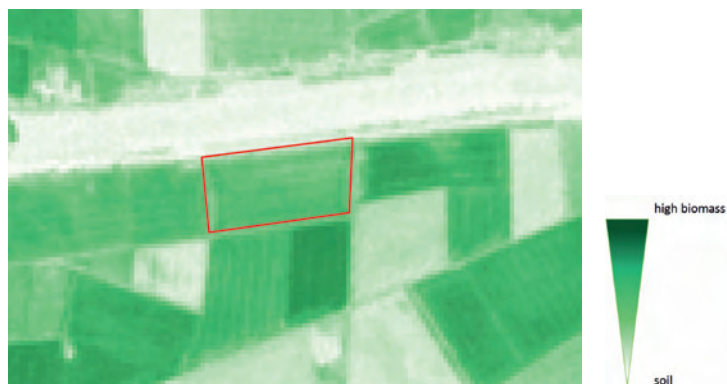
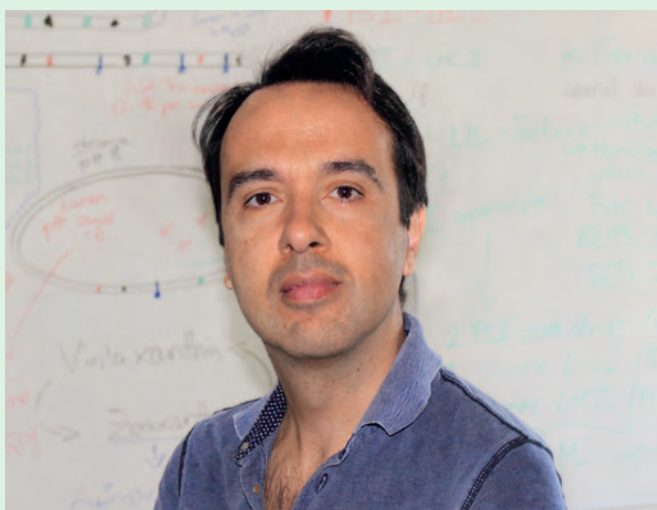


Figure 2: Satellite image showing the Normalized Difference Vegetation Index (NDVI) of a wheat field (red line) and surrounding area, located close to Hannover, on December 11th 2018. (Image source: Cabrita; contains modified Copernicus Sentinel data 2018)

Institute of Geography from the Georg-August-Universität Göttingen, intends to analyze the photosynthetic limitations and the consequent growth impairment in Mg deficient plants by using remote sensing methods. To this end, several morphological and physiological parameters will be determined using remote sensing methodology, including field spectrometry and satellite imagery analysis, and compared with parallel field sampling data collection.

Knowledge and understanding of leaf optical properties allows for non-destructive presymptomatic monitoring of plant physiological changes using current imaging techniques. These techniques can be applied from microscopic to airborne or satellite remote sensing observations and have been used to detect early signs of stress by monitoring changes in several physiological and morphological parameters. Making use of the optical properties of leaves and how they interact with light, i.e. by reflecting part of it, letting another part passing through, and absorbing the remaining part, one can compute vegetation indices that can be then related to several physiological and morphological parameters of interest. Apart from its non-invasive aspect, thus non-destructive, which allows in vivo observations of plants, this methodology is particularly useful as it enables continuous monitoring of plant development with time with high spatial resolution. Therefore, it is possible to follow the whole life cycle of crops completely.

In order to understand and analyze the effects of Mg deficiency on photosynthesis and the consequent hindrance on plant growth and development, a naturally Mg deficient field, close to Hannover, sown with winter wheat was chosen and will be monitored and surveyed at specific times of plant development for the 2018/19 campaign. Field data collection as well as satellite imagery analysis are complemented with weather and phenological data. Considering the differences in the Mg soil concentration observed on the field, and the Mg treatments scheduled to be applied on trial plots, special focus will be given to early stress detection and plants response to treatments and adversity. To this end, several physiological and anatomical parameters of interest, e.g. leaf area index, biomass accumulation, photosynthetic rate, photosynthetic pigment concentration, as well as water and nutrient status, will be measured locally and followed through satellite imagery analysis.



Before joining the IAPN team, **Dr. Paulo Cabrita** worked in Darmstadt on the application and development of remote sensing methods to monitor and determine morphological and physiological parameters both on test trials as well as on field level in forests and crops. He obtained his PhD in 2011 with the thesis "Experimental and theoretical studies of phloem transport with the inclusion of lateral solute exchanges and apoplastic conditions" at the Justus Liebig University Giessen.

Study of plant hydraulic mechanisms in response to drought
Water shortage affects yield considerably depending upon timing and severity of stress. However, the water relations at the whole plant and canopy levels and the way plants respond to water stress by distributing water, and consequently nutrients, between its different organs at specific times of plant development is not fully understood. This is more relevant as terminal drought is the most detrimental to yield production, and a greater understanding of the impact of terminal drought may help in developing more drought resistant cultivars. Therefore, more information about water relations within crop canopies is needed to understand their role in canopy resource distribution and leaf senescence, which are factors that can impact on crop productivity and potential yields greatly. In this respect, the non-destructive and continuous monitoring of water relations in different plant parts seems crucial because it provides much greater insight into how plants respond to their environment. Most measurements have traditionally been destructive and obtained at specific times in plant development, which in some cases limits one's ability to observe the whole dynamics of the processes involved. This project aims to investigate the hydraulic mechanisms used by plants from leaf to whole plant level in response to drought stress using non-invasive remote sensing methods. We then hope to contribute to a better understanding of the complex spatial and temporal dynamics of plant water relations across multiple scales from within-leaf to canopy level.

The plant water status can be assessed by the leaf patch clamp pressure probe, LPCP. The LPCP measures the attenuated pressure of a leaf patch in response to an externally applied magnetic force. It has proven itself advantageous over more standard but destructive methods of measuring plant water status by allowing the continuous monitoring of cell turgor for extensive periods of time. It has been used successfully on many different plant species, from small plants to trees including crops, under controlled and field conditions. The patch clamp pressure output, P_p , resulting from two small magnets attached to a leaf or a suitable plant part is inversely related to the leaf patch turgor pressure, P_c , which in its turn relates to the tissue, and ultimately cell-water content. Although, absolute values of the bulk leaf turgor pressure are not directly measured by the probe unless detailed calibration is previously conducted, the ability to observe the changes in P_c values continuously and remotely

over time provides access to a wealth of information not previously achievable by other methods. In this way, it is possible to follow the dehydration/rehydration kinetics, i.e. the internal redistribution of water, over diurnal scales and in response to treatments, e.g. through closure of stomata at midday or in response to hormones, light intensity or CO₂. In addition, the relative changes in the shapes of the P_p curves over time under specific conditions could be used to evaluate the severity and timing of the plant first signs of stress. Comparison between different plant species, genotypes or parts of the plant could also identify different mechanisms of tolerance to water stress.

The changes in leaf turgor pressure and the analysis of the hydraulic mechanisms involved in the distribution of water within the plant body under drought stress conditions will be then studied by monitoring P_p values of sunflower and squash, chosen as model plants. These measurements will be further complemented by measuring several physiological parameters of interest, e.g. evapotranspiration and photosynthetic rates, root water uptake, water potential, giving a clearer picture of the physiological changes and adaptations undertaken by plants under adverse water availability.



LPCP probe at IAPN: For assessing the plant water status a small patch of a leaf is clamped between two magnets. The force between the magnets applies a constant pressure on the leaf patch. A sensor chip is embedded in the upper magnet and senses the pressure transfer function of the patch - that is the attenuated pressure, P_p, in response to the pressure by the magnetic force. Data provided by the chip are continuously monitored and recorded. P_p is inversely related to the leaf patch turgor pressure, P_c, which relates to the tissue, and ultimately cell-water content. (Photo: D. Jáklí)

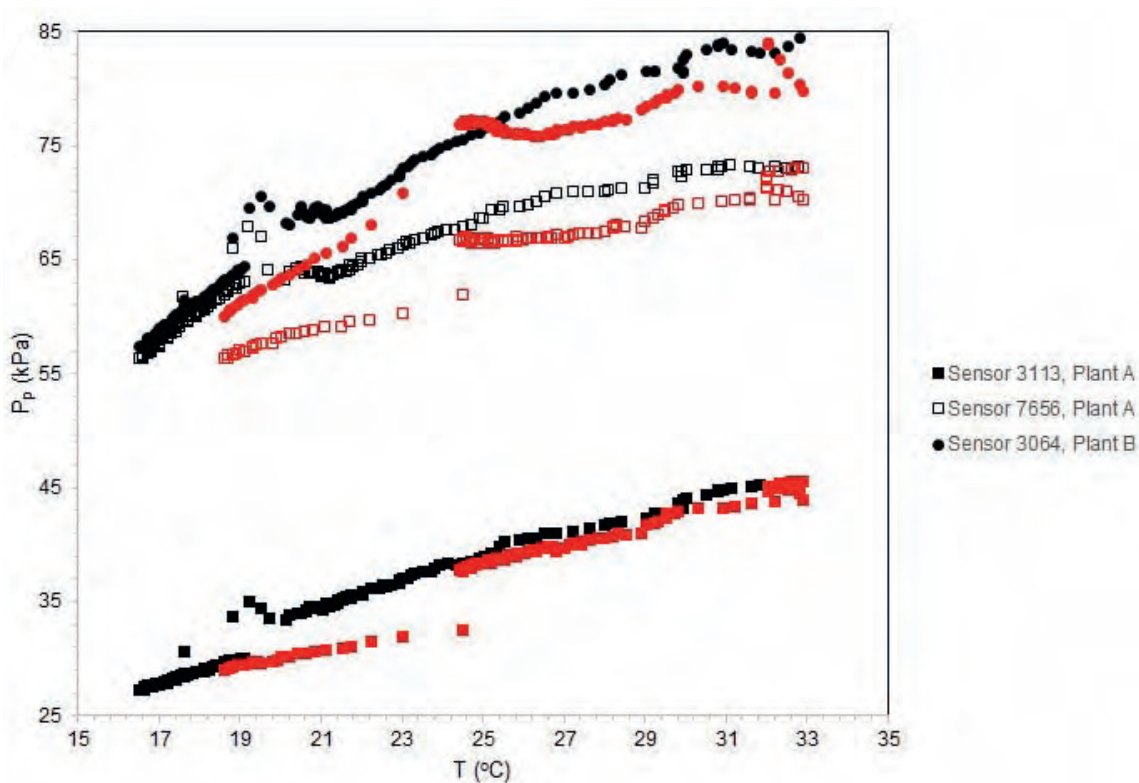


Figure 3: Patch clamp pressure, P_p, as a function of ambient temperature, T, on the leaves of two sunflower plants, grown in hydroponics in a greenhouse for 16/8 light-dark cycle. Black color: measurements during day, red color: during night. (Source: Cabrita)

PhD research project of MSc Setareh Jamali Jaghdani

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

Setareh Jamali Jaghdani started her PhD in January 2018. Her PhD project is entitled "Capacity and efficiency of photosynthesis and photoprotective mechanisms under Mg deficiency in crop plants - linking plant physiology with plant genomic and proteomic reactions", hence her studies within this project focus on Mg nutrition.

Mg is one of the most abundant cations, which is neglected in plant nutrition in many regions in the world and thus was termed the "forgotten element". Mg plays various important roles in plants during their growth and development. It is the core element of chlorophyll, a pigment in green plant tissues, and under Mg deficiency, the chlorophyll pigments in older leaves will be degraded possibly to supply more Mg for younger leaves. Moreover, being a crucial element within the photosynthetic apparatus, the assimilation of CO₂ can also be affected under Mg deficiency.



Symptoms of Mg deficiency in sunflower plants. The symptoms are firstly visible on older leaves due to chlorophyll degradation within them. (Photo: Jamali)

Under Mg deficiency, light energy becomes excessive and is beyond the utilization capacity of the photosynthetic machinery, which favors the production of ROS inside the photosynthetic apparatus. 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. They can either detoxify ROS via different enzymes or dissipate the excessive energy as heat, which is also known as non-photochemical quenching (NPQ). The mechanism of NPQ is not yet completely resolved and the impact of Mg nutrition on the functioning of NPQ is not yet fully understood. Thus, the PhD project of Setareh Jamali aims at understanding the changes in photoprotection and photosynthetic processes under various Mg supplies.

During the first year of her PhD, Setareh Jamali Jaghdani 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. She measured photosynthetic capacity via CO₂ assimilation (leaf level) which is a non-invasive method and photosynthetic efficiency via chlorophyll fluorescence measurements in a hydroponic system. She also estimated the level of chlorophyll degradation and biomass production regarding various Mg supplies.

She continues in the second year with isolation of chloroplasts from plants grown under Mg deficiency to determine the proteomic reactions. Therefore, she extracts and analyzes the proteins from the isolated chloroplasts, which are related to photosynthesis. In addition, she will analyze the expression of genes involved in NPQ regulation and of enzymes responsible for detoxification of ROS, such as superoxide dismutase (SOD), ascorbate peroxidase (APX) and glutathione reductase (GR).



Different Mg supplies in barley plants and the effects on plant biomass and plant growth. (Photo: Jamali)



Setareh Jamali Jaghdani completed 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 degree in Agricultural Engineering-Horticulture at the University of Tehran. Her PhD studies at IAPN with a scheduled duration of three years are supervised by Jun. Prof. Merle Tränkner and funded by K+S KALI GmbH.

Wilhelm-Rimpau-Award for outstanding Master's thesis

On June 12th 2018, Setareh Jamali Jaghdani was honored with the Wilhelm-Rimpau-Award by German Agricultural Society (DLG) for her Master's thesis entitled "Characterization of enhanced metabolism to ALS and/or ACCase inhibitors in *Alopecurus myosuroides* Huds. and *Lolium* spp. populations". In her thesis, she explored the highly topical subject of herbicide-resistance in black-grass and rye-grass, to both ALS- and ACCase-inhibitors. In her own words: "Regarding the population growth and climate change, we need to provide a more sustainable plant production in agriculture. Understanding the resistance mechanisms in different pests including weeds, helps us to come up with better management strategies which lead to more sustainable plant production." The independent jury commended the exceptional scientific and formal quality of Setareh Jamali's work. According to this panel of experts, the thesis is one of the very best final papers produced in recent years in the field of phytopathology and crop protection. The award ceremony took place at the occasion of the DLG Field Days in Bernburg-Strenzfeld, Germany.



Dr. Susanne Weigand (left) and Prof. Dr. Andreas Tiedemann from the Division of Plant Pathology and Crop Protection of the Georg-August-Universität Göttingen congratulate Setareh Jamali Jaghdani on the award. (Photo: IAPN)





About 260 experts from 11 countries participated in the 3rd International Symposium on Magnesium in China. (Photo: IMI)

International Knowledge Exchange

Interdisciplinary discourse with scientists and practitioners

IAPN consciously turns to international practice-oriented research and aims to expand its cooperation with a host of national and international research institutions, in various countries. It is very important to put the already available scientific knowledge into practice more intensively, but also to formulate open research questions jointly with national and local practitioners and scientists.

In 2018, members of the IAPN team participated in the 3rd International Symposium on Magnesium, the annual Meeting of the German Society for Plant Nutrition, and Jun. Prof. Dr. Merle Tränkner visited two oil palm plantations in Indonesia.



View to the auditorium during the presentation of Jun. Prof. Dr. Merle Tränkner. The symposium took place in the Grand Hyatt Hotel in Pearl River New City of Guangzhou. (Photo: IMI)

The 3rd International Symposium on Magnesium

From November 25th to 28th 2018 the 3rd International Symposium on Magnesium was held in Guangzhou, China. About 260 Mg experts from 11 countries participated in the intense and inspiring knowledge exchange about the crucial mineral, which is still subject of many research questions. IAPN took part in the Organizing Committee and the scientific discourse. In almost 30 keynote and oral presentations and also in 30 poster presentations leading scientists of various disciplines explained their recent findings and concepts on frontier issues of Mg nutrition research. Main topics were Mg dynamics in soils, Mg fertilizers and crop production, Mg in plant physiology and molecular biology, and Mg in animal and human nutrition. The attending industrial specialists and agricultural advisors gained valuable insights into the actual scientific work and contributed their practical experience to the discussion.



Prof. Dr. Klaus Dittert, scientific head of IAPN, chaired the first session on the opening day of the symposium. (Photo: IMI)



"Magnesium Mobility in Soils" was the topic of the keynote speech held by Prof. Dr. Andreas Gransee, managing director of IAPN. (Photo: IMI)



Dr. Merle Tränkner, junior professor at IAPN, presenting research results in her keynote speech on "Mg Nutrition and Photoprotection in Plants". (Photo: IMI)

"The team of IAPN is very pleased about the great response of scientists from so many disciplines towards the subjects of this symposium. We are very thankful to all members of the organizing committee and especially the team of the International Magnesium Institute (IMI) in Fuzhou, China, for getting this wonderful event going", says Prof. Dr. Klaus Dittert. He was member of the International Scientific Committee of the 3rd Mg-Symposium. This Committee was chaired by Prof. Dr. Fusuo Zhang (China), other members were Prof. Dr. Ismail Cakmak (Turkey), Prof. Dr. Andreas Gransee (Germany), Prof. Dr. Zed Rengel (Australia), Prof. Dr. Andrea Rosanoff (USA), and Prof. Dr. Philip White (United Kingdom).

IAPN Jun. Prof. Dr. Merle Tränkner summarizes: "The interdisciplinarity with its broad range of topics was very inspiring. There were talks about Mg nutrition in acid soils, another presentation dealing with Mg transporters in plants and another talk presented Mg nutrition with respect to human diets." Also representing IAPN was PhD student Setareh Jamali Jaghdani with a presentation and IAPN scientist Dr. Melanie Hauer-Jákli who presented a poster on "A Meta Analysis Study on the Effect of Mg on Photosynthesis and Plant Growth".



IAPN PhD student Setareh Jamali Jaghdani addressed the topic "Magnesium and its Effect on Photosynthetic Activities in *Triticum aestivum* and *Helianthus annuus*". (Photo: IMI)



"New results on Mg are enormous."

How international knowledge exchange advances research, teaching and practice - and which plant-nutrition issues will play major roles in the future.

An interview with four speakers of the 3rd Mg-Symposium:

Professor Dr. Klaus Dittert

Junior Professor Dr. Merle Tränkner

Professor Dr. Ismail Cakmak

Professor Dr. Andreas Gransee

Professor Dittert, in November 2018, the 3rd International Symposium on Magnesium took place in China. What happened in the time between this event and the very first Mg-Symposium, which took place in 2012, in Göttingen? How has research on the "forgotten element" developed since then?

That is not an easy question to answer. If you immerse yourself in a particular topic, you probably notice lots of new activities, and of course you see them in connection with the work you're doing yourself. But I do believe that setting up the IMI in Fuzhou, China, has brought on a real quantum leap for plant nutrition. China, as an aspiring science nation focuses a lot of energy and research by young scientists on plant nutrient Mg, and the contributions to the 3rd symposium and the sheer size of the event clearly showed that the term "forgotten element" will soon be a thing of the past. The new results regarding the functions in the plant metabolism are enormous, and the symposia visibly contribute towards a growing attention to the element Mg.

Professor Cakmak, the Sabanci University, at which you hold a professorship, is one of IAPN's cooperation partners, while both are connected to other institutions, such as the IMI in China. What can you tell us about joint activities in the field of knowledge exchange, how do participants benefit from each other - and what are the benefits for research?

Sabancı University and K+S KALI GmbH have been working together for more than ten years, regarding both research and training activities. This cooperation has intensified in recent years, since the foundation of IAPN, primarily by exchanging knowledge between Sabancı University and IAPN, and through mediating knowledge and experience by jointly organizing international conferences, such as the Mg-Symposia in Germany, Brazil and China. These joint conferences on Mg nutrition of plants, and also of humans, generated a wealth of valuable results. During the past five years, between 2014 and 2018, the number of scientific publications on Mg listed in *Web of Science*, for instance, has increased by 40% when compared to the number of manuscripts published between 2009 and 2013.

There has also been an exchange of students between IAPN and Sabancı University, even if these exchanges weren't quite as numerous as is desirable. During my time at University of Göttingen - within the scope of the Georg Forster Research Award, as well as short and long-term sabbaticals from my professorship at Sabancı University - I also contributed to ongoing student projects such as PhD and Master projects and to several course modules at IAPN.



Connecting nations, generations and disciplines as well as science and practice: knowledge exchange at the 3rd Mg-Symposium between Dr. Rodrigo Marcelli Boaretto, Brazil, Professor Dr. Ismail Cakmak, Turkey, Professor Doutor Rafael Otto, Brazil, and Felipe Furlan, Agronomist at K+S in Brazil (left to right). (Photo: IMI)

Professor Tränkner, among other results, the 2nd Mg-Symposium in São Paulo kicked off a dialogue on the relevance of Mg in Brazilian agriculture. Until then, Mg fertilization was rather unusual there. Are there any other examples of such immediate effects of the international knowledge exchange at IAPN on agricultural practice?

Organization of the 3rd Mg-Symposium in China was an important step in moving Mg fertilization to the focus of attention again. Naturally, a lot of the participants were scientists, who are involved in practice-related research on fertilization with Mg. But in addition to scientists, there were also many participants from the industry and consultants, who were very interested in the results presented at the conference. I am sure that this serves to transfer a lot of the knowledge exchanged between international scientists and Chinese participants to agricultural practice.

Professor Gransee, how does agricultural practice benefit from the international knowledge exchange at IAPN?

Many scientific results either do not find their way into agricultural practice, or they find it very slowly. Cooperation is therefore necessary between scientists and practice, for two reasons. The first reason is that consultants from agricultural businesses or other agencies can translate new results into the "language" of farmers, making them directly available to practice. This is however no one-way street: A lot of questions and issues that are induced by changing environmental conditions are of course initially noticed by farmers, in their daily work. The order of the day is actually that we pick up on these issues, and that we find solutions by using scientific methods. IAPN makes valuable contributions in both directions.

Professor Cakmak, an important aspect of the knowledge transfer to practice is to multiply knowledge and to further strengthen the existing network. How does the international exchange of knowledge - such as via symposia or the connection to the IMI - contribute to finding and promoting excellent young scientists? And how does it support these junior scientists in disseminating their expertise to local or national agriculture?

In my opinion, conferences are important international platforms for bringing young, talented scientists and students in touch with experienced scientists and professors. Oral and poster presentations are excellent opportunities for meeting young promising scientists with great sci-

entific potential, for possible future cooperation. Implementation and application of the knowledge gained is surely essential for the further development of promising junior scientists, as well as for improving the development of sustainable agricultural production.

Professor Tränkner, how do scientists and students at IAPN profit from the international knowledge exchange, and which role does it play in teaching at IAPN?

As far as I'm concerned there's really no way not to profit from the international knowledge exchange. There's a popular proverb, "Different countries have different customs." I guess this is also true for agriculture, so we could actually say, "Different countries have different agricultural customs". Even if it's the same plant species that's being cultivated, local conditions for growth may vary considerably: different soils, different climate zone, different availability of machines, fertilizer, etc. This is exactly why an exchange of knowledge is so interesting. For both, students and scientists, there should be as much international exchange as possible, as new impressions regarding scientific issues and agricultural systems expand knowledge, and widen the horizons.

This year I visited oil palm plantations in Indonesia, where cultivation is based on systems that can in no way be compared with our own local cultivation systems. Complexity and logistic requirements are simply enormous, so challenges and scientific approaches are also very different from ours. But - and this I consider to be very exciting - when looking at the total picture, you can see the cycle closing, and there's still a lot that can be transferred. Mg always has the same physiological functions, no matter whether in sugar beet or oil palms. As teachers at IAPN we try to pass this concept on to our students. Additionally, a lively exchange of knowledge enables us to be up-to-date at all times. Conferences are perfect for finding out about the latest research results, which can then be integrated in our courses to provide up-to-date contents to our students.



Jun. Prof. Dr. Merle Tränkner in dialogue with Indonesian plantation managers. (Photo: Tränkner)



Students from abroad carry out internships at IAPN - like Linus Amoako Graham from Ghana.
(Photo: Tränkner)

Professor Dittert, which concrete research topics related to plant nutrition do you consider to be top of the agenda in the international knowledge exchange? Which special scientific challenges do you see for IAPN?

In analogy with IAPN's research emphasis, international exchange is currently focusing on the role of mineral nutrition/supply for the stress physiology of crops. Which functions do minerals have in the plants' stress responses, and how can plants be supported in coping with stress. These issues are eminently important, worldwide. They are not only raised by global climate change, but also by the necessity to grow crops at less favorable locations: this is where plants are frequently exposed to stress.

One of the greater challenges we face in connection with our visiting scientists at IAPN is the difficulty of providing adequate housing or accommodation here in Göttingen. We have enormous problems with finding homes for our guests, particularly as these stays cannot be planned 12 months in advance.

One of the scientific challenges of our research subject is the difficulty to faultlessly measure the relevant quantitative performance of stressed plants in a reproducible way. It is indeed a very difficult task to develop a kind of standardized stress environment in a way that reliably allows allocating the observed effects to the specific nutritional and stress situation of the plant.



IAPN field trial in Ahlten, conducted on wheat which received different Mg fertilizer treatments. The aim is to study changes in the photosynthetic capacity, pigment composition and water-use efficiency due to different Mg soil concentrations. (Photo: Tränkner)

Professor Cakmak, in your opinion, which future questions will be of major importance in plant nutrition research?

There are several crucial future research topics, such as increasing productivity under conditions of climate change and water shortage. There is currently a lot of discussion and documentation in connection with these issues, not only by scientists, but also by politicians and policy makers. There is however one very important research topic, that has not yet been sufficiently discussed and explored. The current focus in agriculture is on raising productivity, while less attention is paid to the nutritional qualities and the nutritional value of the harvested crops. This is a problem of great humanitarian relevance. Today, approximately 800,000 people suffer from hunger, caused by insufficient access to food. More than 2 billion people however suffer from low nutrient contents of harvested crops, particularly from low levels of protein, micro-nutrients such as zinc, iron and iodine, and vitamin A. This problem is today known as hidden hunger. Plant production should therefore also concentrate on improving nutritional qualities, not only on increasing production. Future research programs need to focus increasingly more attention on the nutritional value of the harvested crops, and appropriate financial support for this research should be made available.

Professor Gransee, are there any urgent problems in agricultural practice that should move to the center of attention in the international knowledge exchange? And how are research and practice linked in order to formulate open research questions?

At this moment, the most pressing issues surely are those related to the impact climate change on agricultural activities. It is vital to develop methods that enable farmers to produce sufficient food under these changing conditions. Plant nutrition will play a special role in this adaptation. Among other research, IAPN studies have shown how modifying and adapting nutrient supply can significantly increase plants' stress tolerance.

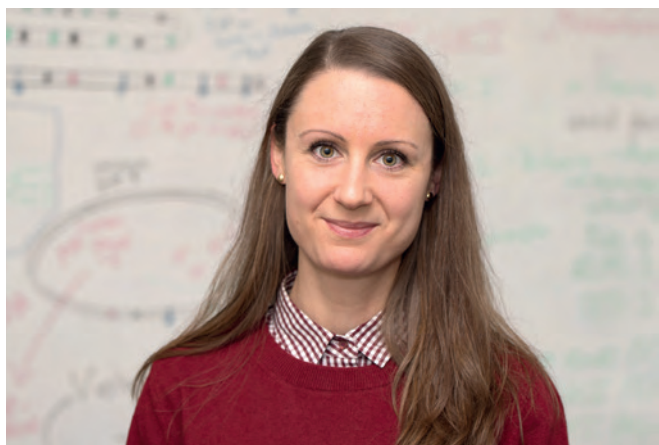
Another important issue is the role of plant nutrition in the development of resource-saving strategies. This specifically applies to the resource of water. Improved prediction methods may be helpful here, in order to better adapt nutrient provision. For this, research is required on the initial stress reactions of plants, and what kind of conclusions to draw from these in practice.

Professor Dittert, nearly eight years ago you took on scientific directorship of IAPN. How would you describe the development of IAPN since then, especially regarding international knowledge exchange? And where do you see a special role for IAPN in the future?

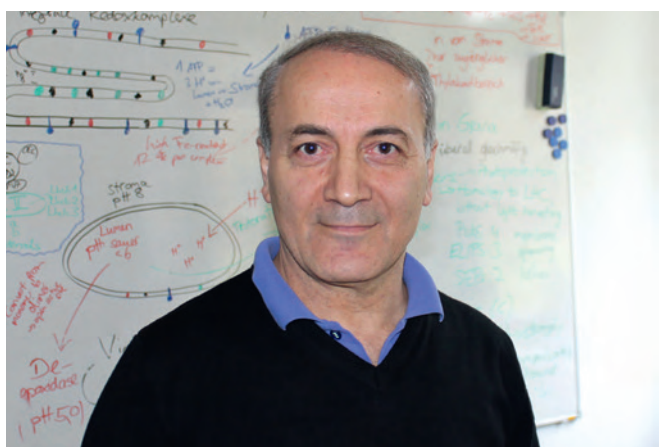
For science, the situation has become similar to that of the economy. Compared to the international community, Germany is a small country, and needs to distinguish itself, through quality. Standards for research and teaching are high in Germany, and this must also be the guideline for IAPN. Internationally, IAPN is well-connected, but in terms of size alone, compared to other institutions, it is not a big player. Our strategy in networking is not to try to go for as many partnerships as possible, but to seek out excellent and highly promising partners. We are specifically interested in professionally complementary research institutions, nationally as well as internationally. And we are particularly interested in an exchange with mostly young scientists from abroad, who in addition to expertise will take with them a bit of the Göttingen spirit when they return back home. They represent an excellent way for IAPN to not only attain and to impart new know-how, but also to sow the seeds for generating new knowledge.



Professor Dr. Klaus Ditter heads the Division of Plant Nutrition and Crop Physiology in the Department of Crop Sciences at the University of Göttingen. This position encompasses scientific directorship of IAPN.



Professor Dr. Merle Tränkner holds the junior professorship for applied plant nutrition at IAPN and the Faculty of Agricultural Sciences of the Georg-August-Universität Göttingen since June 2017. During her PhD, she studied the influence of Mg, K and N on the water-use efficiency of different crops and the stress physiology of nutrient deficiency. She also investigated the influence of K deficiency and drought stress on the proteome (i.e. the totality of proteins) in wheat, which is one of the most important crops globally.



Professor Dr. 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, he is professor of plant nutrition and nutritional physiology at Sabanci University, Istanbul, Turkey. 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 (www.harvestzinc.org).



Professor Dr. Andreas Gransee is head of Innovation Lab Ag Tech & Nutrition of the K+S KALI GmbH in Kassel, Germany. In this position he is responsible for the worldwide innovation process of K+S in the fields of AgTech and Nutrition. Since 2011, he is the director of the IAPN. In 2017, Andreas Gransee was one of the founding members of the IMI at the Fujian Agriculture and Forestry University (FAFU) located in Fuzhou, China. Since then, he is member of its scientific board. Andreas Gransee is professor of nutrient management at the University in Halle.

A visit on oil palm plantations

In November 2018, Jun. Prof. Dr. Merle Tränkner visited two oil palm plantations on Central Kalimantan and South Sumatra in Indonesia. For research purposes she went to see on-site palm oil production and came into dialog with plantation managers and workers. The oil palm is focused only limitedly in research and little is known about its physiology with respect to plant nutrition. This is due to oil palm being a perennial crop. Time periods between changes in fertilizer applications and detectable reactions, such as harvest yield, are much longer than in annual crops. Hence, studies conducted over several years are necessary to allow detailed insights on physiological reactions in oil palm. Additionally, the oil palm production is very complex and requires well-coordinated agronomic practices, which can be influenced by heavy rainfalls. "The production system of oil palms is very unique and hardly comparable to any other agronomic system in our climate zone. The plantation management involves remarkable logistics as the oil palm produces ripe fruits around every four weeks throughout the whole year and harvest of ripe fruit bunches has to be accomplished

within a short period of time", says Merle Tränkner. At harvest, the leaves under the ripe fruit bunch have to be cut to allow access to the fruit bunch. The leaf remains in the plantation to recycle nutrients and organic matter. The fruit bunch can then be dislodged from the palm using a long sickle. "It was impressive to see the harvest procedure by the trained harvester who can cut the fruit bunch within seconds."



Mg deficiency in an oil palm leaf. Under Mg deficiency, leaves are light sensitive. Areas which are exposed to sun light become pale green and show Mg deficiency symptoms whereas areas which are shaded remain green (arrow). (Photos: Tränkner)



To achieve a good quality of the fruit, harvest needs to be accomplished at the right time. The harvester uses a long sickle to dislodge the fruit from the palm so that it falls to the ground. (Photos: Tränkner)



Jun. Prof. Merle Tränkner, plantation managers and field workers meeting for a very interesting knowledge exchange on oil plant production and fertilization. (Photo: Tränkner)

Like most of the agronomic practices, also fertilizer application is done by hand. Trained plantation workers walk through the plantation row by row and spread the fertilizer around the oil palms. "I had the opportunity to do a fertilization myself. It's not as easy as it looks like to spread the fertilizer evenly." After the field visit, a group of field workers and managers came together and Merle Tränkner gave a presentation about the physiological functions of Mg in the plant. Often, fertilizer application is limited to N, P and K, though Mg deficiency was present in some field areas where soil was very sandy. Following the presentation, the plantation workers and Merle Tränkner had a vivid discussion. "I enjoyed very much the dialog with the group after the presentation. They were highly interested and asked many questions, not only related to Mg, but also about other nutrients. At the same time, they told me about their observations and experiences in the plantation. I learned a lot from the local plantation workers."



Jun. Prof. Dr. Merle Tränkner doing a fertilization by hand, accompanied by a plantation worker. The fertilizer needs to be spread evenly around the palms in the grove. (Photo: Tränkner)

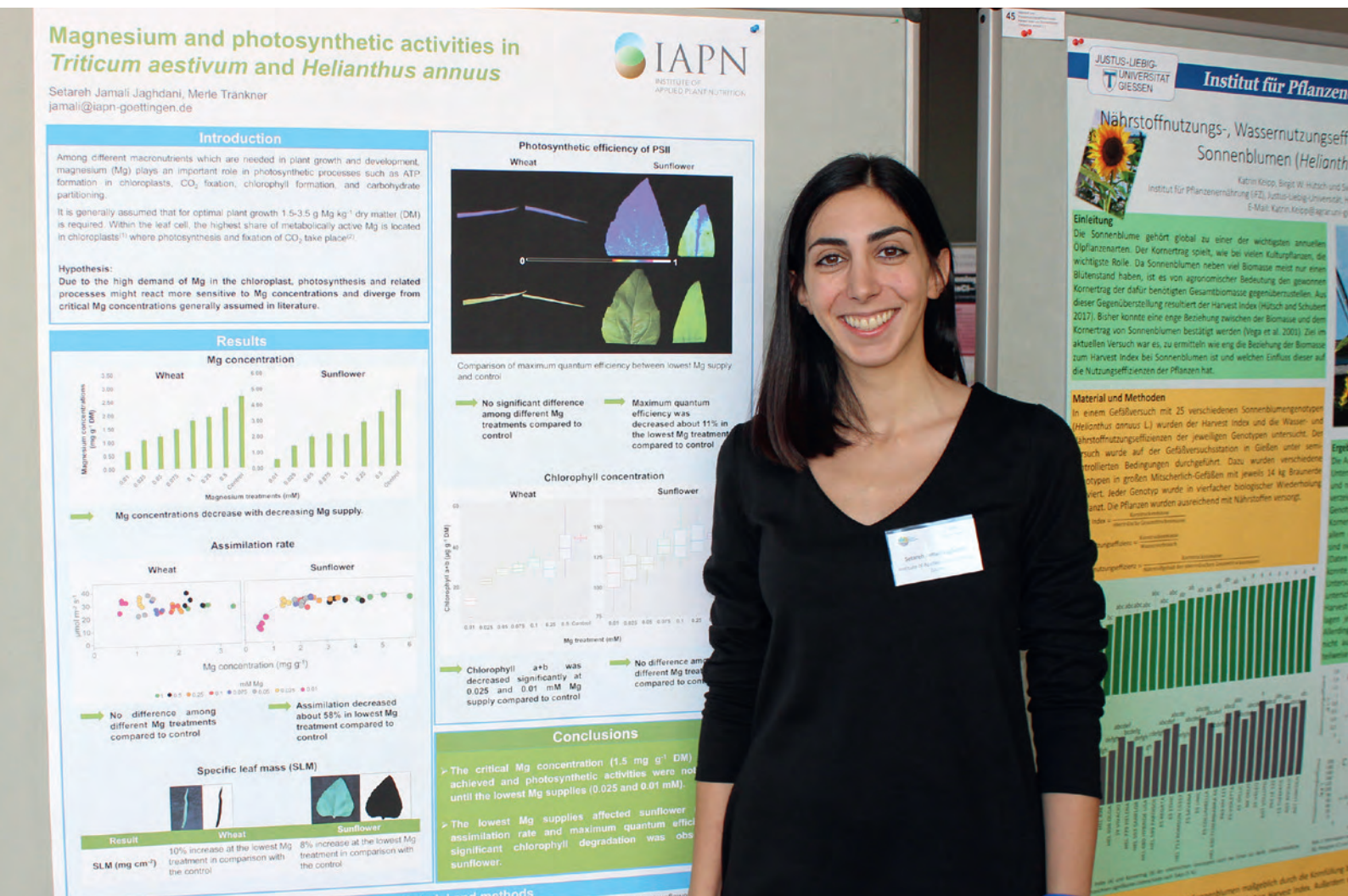
IAPN at the annual Meeting of the German Society for Plant Nutrition

On September 13th and 14th 2018 the annual meeting of the German Society for Plant Nutrition (Deutsche Gesellschaft für Pflanzenernährung, DGP e.V.) was held at the Osnabrück University of Applied Sciences. Topic of that year's event was "Process and product quality in the focus of plant nutrition". It especially addressed the question on which contributions plant nutrition can make for further improving the quality of fruits, vegetables, cereals, oilseed and flowers and for the efficiency and environmental compatibility of the production process. The speakers came from Germany and Belgium, representing universities, research institutes and a fertilizer company.

IAPN PhD student Setareh Jamali Jaghdani presented a poster on "Magnesium and photosynthetic activities in *Triticum aestivum* and *Helianthus annuus*", that was developed in cooperation with Jun. Prof. Dr. Merle Tränkner. "It was a great opportunity for me to join the conference of German Society for Plant Nutrition", says Setareh Jamali Jaghdani, "and have an insight about what other researchers are working on and to be able to share my research with others as well."

The German Society of Plant Nutrition was founded in 1968. It is a scientific forum of plant nutrition that brings together the disciplines of nutrition physiology, soil nutrient balance and fertilization. Prof. Dr. Klaus Dittert is second chair of the society.

Setareh Jamali Jaghdani represented IAPN at the annual meeting of the German Society for Plant Nutrition. (Photo: private)





IAPN technician Kirsten Fladung (right) supervises students during harvest of the required plant material for the Master course "Modern Plant Nutrition - Application of Molecular Methods in Plant Nutrition Research" (Photo: IAPN)

Teaching and Knowledge Transfer

Teaching at the University of Göttingen

An important objective of IAPN is to provide students with a solid training in plant nutrition physiology. For this, alongside traditional lectures and lab training, innovative forms of teaching are also used, which mean that university education is closely tied in with current research and practice. In this way, students are able to get insight into the global issues of plant nutrition during the course of their studies rather than having to wait until they have graduated. Interaction with visiting scientists at IAPN is particularly encouraged; they often bring current themes from agricultural practices in their home countries, and by exchanging ideas with students and scientists at IAPN are able to identify and work on knowledge gaps, in order to obtain rapid feedback from real-world agriculture. Of course, students have the option of doing their dissertations at IAPN, at undergraduate, Master's and PhD level.

Molecular Methods in Plant Nutrition

Jun. Prof. Dr. Merle Tränkner continued her teaching activities in summer term 2018. She offered a Master course entitled "Modern Plant Nutrition - Application of Molecular Methods in Plant Nutrition Research". The course combines theory with practical work in the laboratory over three weeks. In lectures, the theory of application methods is taught while

the focus is set on applications with DNA, RNA and proteins. Beside theory, the students work in the lab to learn the most important molecular methods. Students work in small groups of two and do the work according to the protocol which was handed out to them. "I wanted to offer a course in which students learn the basic, but most relevant methods like RNA extraction. Molecular methods require a very clean work, which starts not in the lab, but already with harvesting of plant material. So, at the first course day, students harvested the required plant material in the greenhouse", says Merle Tränkner.

The aim of the course is to introduce how molecular methods can be applied in plant nutrition research and how they have to be conducted. The course is offered for students of the Master program "Sustainable International Agriculture", which has a high share of students from all around the world. "Practical education during the agricultural studies is often inexistent due to financial restrictions in many home countries of the students, but at the same time the application of molecular methods has become more and more an important tool in plant nutrition research during the last years and should be considered in educating the students", Merle Tränkner explains. The course was supported by IAPN tech-

nician Kirsten Fladung who supervised the students during their work in the lab. "It was a wonderful challenge to teach the students clean and focused working skills. I was impressed to see how fast they were able to apply these skills successfully, particularly as they did not have any experience in molecular work", says Kirsten Fladung. The course was given in joint work with Dr. Birgit Pfeiffer.



At harvest, the plants are separated into shoot and root (left), roots are washed (center) and the biomass of the plants is weighed (right). (Photos: IAPN)

Introduction to scientific writing

When students begin their studies, usually little is known about good scientific practice, how to browse literature for specific topics and how to present and write about scientific contents. This is where the seminar "Scientific work and professional presentation in crop production" starts teaching Bachelor's students first steps for their development at the university. In that seminar, which was resumed and coordinated by Annika Lingner in winter 2018/2019, first insights are given into practical work from literature research over defining a given topic to correct citing. The students are provided with a broad variety of topics originated from all divisions in the Department of Crop Sciences in order to fit all students' interests. Those topics are individually supervised so that the students get specific feedback on their presentations and theses. In 2018/2019, ten students were supervised by members of IAPN. The overall aim of the seminar is that the gained knowledge and experience facilitates future scientific work on Bachelor, Master or PhD level.

Insights into lab work

First experience in the lab can be gained during the Bachelor course "Plant Nutrition". Here, various methods and techniques are performed by the students themselves, accompanied by theoretical lessons on the background. The emphasis of the course is on learning the distribution of several nutrients in the soil and their uptake by the plant. One of these exercises was guided by Annika Lingner with support from Simone Urstadt, technician at the Division of Plant Nutrition and Crop Physiology. In this exercise, the students learned how to estimate plant available P in the soil and how different protocols can influence the results. Vivid discussions on P availability and actual challenges in fertilizer application closed each session in 2018.

Writing a thesis at IAPN

Bachelor thesis by Henriette Elisabeth Quehl

In 2018, a Bachelor's thesis project was jointly implemented by IAPN's Jun. Prof. Dr. Merle Tränkner (co-supervisor) and Dr. Marcel Naumann (supervisor), research assistant at the Division of Quality of Plant Products, University of Göttingen. The Bachelor's student Henriette Elisabeth Quehl conducted a greenhouse experiment on potato plants that were differently supplied with K and partly exposed to drought stress. Potato as studied crop was chosen due to its high sensitivity towards drought situations which impact the quality of the tuber. During the experimental work, Henriette Quehl measured various parameters such as photosynthesis and transpiration rates, starch and sugar concentrations, and pigment compositions in the plant tissue. From the results, she could conclude that K supply can only alleviate slightly sensitivity of potato plants against drought stress and that particularly under drought conditions, a sufficient K supply is crucial for the plants' physiology. In November 2018, Henriette Quehl submitted her thesis entitled "Impact of K and drought stress on leaf gas exchange, formation of assimilates and content of chlorophyll and free amino acids in *Solanum tuberosum* L.". Owing to its high quality, the thesis was suggested for an award of the "Förderungsgemeinschaft der Kartoffelwirtschaft e.V.", association for the promotion of the potato industry in Germany. The decision of the committee will be made in 2019.



Bachelor's student Henriette Elisabeth Quehl measuring leaf gas exchange (GFS 3000, Walz, Germany) of potato plants that were differently supplied with K and partly exposed to drought stress. (Photos: Tränkner)

Hendrik Meemken receives award for the "Most Original Master Thesis 2018"

For his final paper, which he wrote at IAPN, Hendrik Meemken received the award for the "Most Original Master Thesis 2018". The award is granted by the Section of Agricultural Sciences of Alumni Göttingen e.V. The Master's thesis is entitled "Photosynthesis, chlorophyll fluorescence and ROS detoxifying enzyme activity under macro nutrient deficiency in sunflower". During his project, Hendrik Meemken was supervised by Jun. Prof. Dr. Merle Tränkner and PhD student Setareh Jamali Jaghdani.

New Master project: Mg supply and water-use efficiency in winter wheat

In autumn 2018, a new Master project has started at IAPN. A field experiment in the vicinity of Hannover was created in cooperation with a local farmer. The soil of the field is deficient in Mg and thus, highly suitable for the study which will focus on the impact of Mg supply on the water-use efficiency in winter wheat. The field trial is a continuation of the PhD project of Jun. Prof. Dr. Merle Tränkner which focused on evaluation of Mg deficiency in barley. However, the experiments were conducted under semi-controlled conditions and results have to be confirmed in the field. The field trial comprises various Mg fertilizer rates. In October, winter wheat was sown and soil samples were taken in November 2018 which were subsequently analysed for their Mg concentrations in order to identify fertilizer application rates in early spring 2019. After fertilization until summer, the Master's student will frequently perform measurements such as gas exchange which allows determination of water-use efficiency.



Award winner Hendrik Meemken together with IAPN staff-members Ulrike Kierbaum, Jun. Prof. Dr. Merle Tränkner, PhD student Setareh Jamali Jaghdani, Martina Renneberg and Kirsten Fladung (left to right). (Photo: IAPN)



In the course of a new Master project at IAPN soil samples are taken with a hydraulically operated trailer. In contrast to the manual soil sampling, the hydraulic soil sampler allows to obtain easily and fast samples of soil depth up to 90 cm. (Photos: Hanebut)

Application of digital and remote sensing methods in agriculture and numerical methods on transport processes in plants

As part of the activities involved in his research project "Detection and Quantification of Magnesium Deficiency in Field Grown Winter Wheat using Remote Sensing", Dr. Paulo Cabrita gave a presentation on November 7th 2018, within the Master seminar organized for geography students by the project partner Cartography, GIS and Remote Sensing Department, at the Institute of Geography from the Georg-August-Universität Göttingen. The presentation was meant to highlight some of IAPN's current research as well as to present the project goals, schedule and methodology and the collaboration planned with the Cartography, GIS and Remote Sensing Department. Additionally, its inclusion in the annual Master seminar was also intended to present possible Master's thesis research topics to geography students. In parallel, and similarly being part of the teaching activities conducted at IAPN, a Master's thesis project was also announced to students of the Faculty of Agricultural Sciences.

As part of his interest in transport processes in plants and in connection to his previous research experience on secretory systems in plants, Dr. Paulo Cabrita started a collaboration in a mathematics Bachelor's thesis project on the application of numerical methods to describe latex flow in plants at the Institute of Numerical and Applied Mathematics from the Faculty of Mathematics and Computer Science at the Georg-August-Universität Göttingen. Considering Dr. Paulo Cabrita's past experience in mathematical modelling of phloem transport and plant secretory systems, this collaboration with the Institute of Numerical and Applied Mathematics is meant to explore and extend the applicability of numerical methods as a tool to describe and contribute to a better understanding of transport processes in plants, specifically nutrient transport and distribution within the plant body.

Completed theses supervised by IAPN scientists in 2018

Jessica Albers, MSc Thesis (2018):

Photosynthetic efficiency and assimilate translocation under magnesium deficiency – a comparative study of magnesium supply regimes

Isa Bulut, MSc Thesis (2018):

Genotype-specific drought stress tolerance in winter faba bean (*Vicia faba* L.) on physiological and biochemical levels – a comparison between monocropping and intercropping with winter wheat (*Triticum aestivum* L.)

Sophía Teresa Cañás, MSc Thesis (2018):

Are photosynthesis and stomata co-regulated under deficiencies of nitrogen, phosphorous, potassium, magnesium and sulfur?

Fabian Diedrichs, MSc Thesis (2018):

Einfluss der Düngeintensität, der Bodenart und des Klimas auf den Rest-N-Min-Gehalt zur Ernte

Isabel Grabenhorst, BSc Thesis (2018):

Fernerkundliche Bewertung einer Stickstoffdüngung in Weizen gegenüber Gemenge mit Leguminosen

Mara-Tabea Hiller, MSc Thesis (2018):

Wassernutzungseffizienz auf verschiedenen Skalen in Abhängigkeit von der Kaliumversorgung in einem Kartoffelbestand

Dorinna Hüggenberg, MSc Thesis (2018):

Düngewirkungen von P und K auf Zuckerrüben in 35-jährigen Feldversuchen und ihre Vorhersagemöglichkeiten mittels Fernerkundung

Imke Koch, MSc Thesis (2018):

Einfluss verschiedener stabilerer N-Dünger auf den Ertrag und die Verlagerung von Stickstoff bei feuchten Bodenbedingungen in Kartoffeln

Michael Kraft, MSc Thesis (2018):

Legume Untersaaten in Raps

Jonas Lotze, MSc Thesis (2018):

Investigation of genotypic differences in photosynthesis and yield parameters of sugar beet hybrids

Hendrik Meemken, MSc Thesis (2018):

Photosynthesis, chlorophyll fluorescence and ROS detoxifying enzyme activity under macro nutrient deficiency in sunflower

Florian Meißner, BSc Thesis (2018):

Prüfung ausgewählter stickstofffixierender Bakterienkulturen zur Saatgutimpfung und Nachweis ihrer N₂-Fixierungsleistung in Mais

Valentin Paas, MSc Thesis (2018):

Canopy and leaf gas exchange of potato plants in response to varying soil moisture regimes and VPD

Henriette Elisabeth Quehl, BSc Thesis (2018):

Einfluss von Kalium und Trockenstress auf den Blattgaswechsel, die Assimilatbildung und den Gehalt von Chlorophyll und freien Aminosäuren in *Solanum tuberosum* L.

Helge Richard Rethmeyer, BSc Thesis (2018):

Dynamik der Stomataregulierung bei unterschiedlicher Kaliumversorgung in Sonnenblume (*Helianthus annuus* L.) und Sommerweizen (*Triticum aestivum* L.)

Guests at IAPN

The transfer of knowledge and establishing international networks in the field of plant nutrition are important tasks of IAPN. Visiting scientists and visiting students are therefore very welcome at the institute. Funded by public institutions like German Academic Exchange Service DAAD, non-governmental organizations or the private sector during their visit, they spend different amount of time at IAPN. Some bring in their own research ideas and in one way or another, all of them get involved with IAPN's research projects and methods. In 2018, two guests spent time at IAPN.

Prof. Dr. Ismail Cakmak from Turkey is a worldwide acknowledged scientist in the field of plant nutrition and human trace element nutrition being primarily based at Sabanci University, Istanbul, Turkey. In 2018, as in the two previous years, he worked as a visiting scientist at IAPN and also at the Department of Crop Sciences, in the Division of Plant Nutrition and Crop Physiology at the University of Göttingen. He is and was engaged in joint research activities of IAPN and Sabanci University. He also makes very valuable contributions to the strengthening of scientific connections between both institutions and for example the IMI. Opened in September 2017, IMI is a public-private partnership by K+S KALI GmbH and the Fujian Agriculture and Forestry University (FAFU) located in Fuzhou, China. Additionally, Prof. Dr. Cakmak contributed, alongside to IAPN Prof. Dr. Klaus Dittert and Jun. Prof. Dr. Tränkner to teaching activities. He also assisted PhD students in developing their publications. During his visit at IAPN, Ismail Cakmak contributed numerous lectures and talks for extensionists in Germany and abroad, and he wrote articles about recent topics of plant nutrition.



Prof. Dr. Ismail Cakmak from Sabanci University, Istanbul, winner of the Georg Forster Research Award of the Alexander von Humboldt Foundation in 2014. (Photo: Cakmak)



Linus Amoako Graham (right), Bachelor's student from Ghana, assisting Master's student Hendrik Meemken during an experiment. (Photo: Tränkner)

Linus Amoako Graham is a Bachelor's student of Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. He studies agriculture with specialization on arable crop production, sustainable management, plantation and industrial crop production and management. Linus Graham joined the working of IAPN as an intern for two months with the IAESTE internship program. Within his stay at IAPN, he assisted Master's students during their experiments and supported the IAPN team in a research project which aimed at investigating salt stress tolerance of crops and its enhancement by optimized fertilization.

FORSCHEN FÜR EINE NACHHALTIGE PFLANZEN- ERNÄHRUNG

WELTWEITE HERAUSFORDERUNGEN
ANNEHMEN



IAPN in Dialogue: Prof. Dr. Klaus Dittert, Dr. Ulrich Kleine-Kleffmann and Dr. Beate Deuker (left to right). (Photo: D. Jákli)

IAPN in Dialogue

Since 2013, IAPN runs the series of events 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.

Production and natural resources of mineral fertilizers

In 2016, approximately 190 million tonnes of N, P and K were used as plant nutrients worldwide, and the demand is rising. On November 14th 2018, "IAPN in Dialogue" focussed on how these fertilizers are manufactured, and on the expectable future availability of natural resources for production. A presentation by Dr. Ulrich Kleine-Kleffmann, Senior Technical Consultant of K+S KALI GmbH provided numerous current data, and was followed by a lively discussion, that was moderated by Prof. Dr. Klaus Dittert.

N: extracted from air

With about 105 million tonnes, N tops the list of plant nutrients used in 2016. The leading N fertilizer is urea ($\text{CO}(\text{NH}_2)_2$) with a worldwide market share of 58% (2014) - ahead of ammonium nitrate (NH_4NO_3) and calcium ammonium nitrate ($\text{CaCO}_3/\text{NH}_4\text{NO}_3$) - and a N content of 46%. One aspect is the production of N fertilizers; but it is also a great challenge to use the plant-available N in agriculture without major loss. As Dr. Kleine-Kleffmann said: "The work on how to improve the efficiency of N fertilization needs to be continued."

Initially, N fertilizer production was mainly based on guano and Chile saltpetre (NaNO_3). At the beginning of the 20th century, scientists sought chemical processes to convert airborne N - which to most plants is not directly accessible - into fertilizers. The Haber-Bosch process, which was introduced in 1912, made it possible to combine N from the air with hydrogen under high pressure and temperature, thereby producing ammonia, which is the basis of most N fertilizers. With this process the foundation had been laid for large-scale production. Technically refined in the meantime, it is still considered standard practice.

Hyper, super and triple super phosphate

In nature, phosphate most frequently occurs as apatite, with largest deposits in North Africa and the Near East. The most important deposits of apatite are to be found in sedimentary rock, with less frequent occurrence in igneous rock. Apatite is extracted by open-cast mining, and is initially processed mechanically by washing, crushing and sifting. Finely ground, this raw phosphate can already be used as hyper phosphate fertilizer, which is however absorbed only slowly by plants. In order to produce water soluble and rapidly effective phosphate fertilizers, raw phosphate is most frequently reacted with sulfuric acid to form either gypseous super phosphate with a P_2O_5 -content of 16 - 20%, or triple super phosphate with a P_2O_5 -content of 44 - 48%.

The problem with phosphate fertilizers, especially those extracted from sedimentary deposits, is their cadmium (Cd) content. Dr. Kleine-Kleffmann explains that the upcoming

new European Fertilizer Ordinance will for the first time include EU-relevant threshold values for Cd. The current discussion focuses on maximum values of 60 mg/kg P_2O_5 , with successive decreases within several years, all the way to 20 mg/kg P_2O_5 .

Potash mining

The most significant deposits of potash salts are situated in Canada, Russia, Germany and in China. Only in Germany do these K salt deposits also contain kieserite ($MgSO_4 \cdot H_2O$).

Mineral deposits containing K are typically found at depths of 500 to 1,600 meters. The crude salt is mined by drilling and blasting, and also by cutting. Another option is solution mining: "Water is heated to approximately 70 °C, and is then brought underground where it dissolves potash deposits. The saturated solution is then transported to the surface. Excess water is evaporated, causing the salt to crystallise", Dr. Kleine-Kleffmann describes the mining process. In addition to mineral deposits, potash may also be present in salt solutions such as the Dead Sea in Israel or the Quinghai Lake in China. K from these solutions is extracted by brine extraction and by 'solar evaporation'.

Typical crude salts to be found in Germany are hard salt and sylvinit, both of which contain a significant amount of sodium. This sodium needs to be removed. Two of the most common industrial treatment processes for fertilizer-quality K are flotation and hot dissolution. The ESTA® separation process developed by K+S does not require salt solutions and high energy expenditures for drying the products, as it makes use of the electrostatic charge of the particles for separation.



Geologists evaluate rock strata with potassic minerals in a K+S mine. (Photo: K+S)



Crude K salts containing kieserite and halite. (Photo: D. Jákli)

How much longer will resources last?

According to Dr. Kleine-Kleffmann, K resources will last approximately for 300 more years, but he adds: "If you've got adequate technological possibilities for accessing existing resources beyond readily available deposits, K supplies should last for several thousand years." Dr. Kleine-Kleffmann states that P reserves are also estimated to last approximately 300 years. Future options for production for both raw materials may also include raw materials recycling. For N fertilizers, exploitation of atmospheric N offers inexhaustible reserves, while natural gas and crude oil are finite. The Haber-Bosch process may in future use hydrogen generated from renewable energies.



Dr. Ulrich Kleine-Kleffmann explains the production of urea at one of the world's largest production plants in Saudi Arabia. Production capacity at this plant is 3,250 tonnes of urea, per day. (Photo: D. Jákli)

Publications

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

Cabrita, P. (2018) Resin flow in conifers. *Journal of Theoretical Biology* 453:48-57. <https://www.sciencedirect.com/science/article/pii/S0022519318302571>

Chen, Q., Wang, Z.-L., Zou, C.B., Fan, Y., Dittert, K. and Lin, S. (2018) Legacy effects of historical grazing affect the response of vegetation dynamics to water and nitrogen addition in semi-arid steppe. *Applied Vegetation Science*

Grahmann, K., Verhulst, N., Dittert, K., Govaerts, B. and Buerkert, A. (2018) High N fertilizer application to irrigated wheat in Northern Mexico for conventionally tilled and permanent raised beds: Effects on N balance and short term N dynamics. *J. Plant Nutr. Soil Sci.* 181, 606-620

Guo, L., Liu, M.J., Zhang, Y.A., Tao, Y.Y., Zhang, F., Li, G.Y., Dittert, K. and Lin, S. (2018) Yield differences get large with ascendant altitude between traditional paddy and water-saving ground cover rice production system. *Eur. J. Agron.* 92, 9-16

Hou, W., Yan, J., Jákli, B., Lu, J., Ren, T., Cong, R. and Li, X. (2018) Synergistic effects of nitrogen and potassium on quantitative limitations to photosynthesis in rice (*Oryza sativa* L.). *J. Agric. Food Chem.* 66 (20), 5125-5132

Jákli, B., Hauer-Jákli, M., Böttcher, F., Meyer zur Müdehorst, J., Senbayram, M. and Dittert, K. (2018) Leaf, canopy and agronomic water-use efficiency of field-grown sugar beet in response to potassium fertilization. *Journal of Agronomy and Crop Science* 204, 99-110

Köbke, S., Senbayram, M., Pfeiffer, B., Nacke, H. and Dittert, K. (2018) Post-harvest N₂O and CO₂ emissions related to plant residue incorporation of oilseed rape and barley straw depend on soil NO₃-content. *Soil and Tillage Research* 179, 105-113

Li, L., Jákli, B., Lu, P., Ren, T., Ming, J., Liu, S., Wang, S. and Lu, J. (2018) Assessing leaf nitrogen concentration of winter oilseed rape with canopy hyperspectral technique considering a non-uniform vertical nitrogen distribution. *Ind. Crop Prod.* 116, 1-14

Suriyagoda, L.D.B., Dittert, K. and Lambers, H. (2018) Arsenic in rice soils and potential agronomic mitigation strategies to reduce arsenic bioavailability: a review. *Pedosphere* 28, 363-382

Suriyagoda, L.D.B., Dittert, K. and Lambers, H. (2018) Mechanism of arsenic uptake, translocation and plant resistance to accumulate arsenic in rice grains. *Agriculture Ecosystems & Environment* 253, 23-37

Tao, H.H., Donough, C., Gerendas, J., Hoffmann, M.P., Cahyo, A., Sugianto, H., Wandri, R., Rahim, G.A., Fisher, M., Rötter, R.P., Dittert, K., Pardon, L. and Oberthur, T. (2018) Fertilizer management effects on oil palm yield and nutrient use efficiency on sandy soils with limited water supply in Central Kalimantan. *Nutrient Cycling in Agroecosystems* 112, 317-333

Tavakol, E., Jákli, B., Cakmak, I., Dittert, K., Karlovsky, P., Pfohl, K. and Senbayram, M. (2018) Optimized potassium nutrition improves plant-water-relations of barley under PEG-induced osmotic stress. *Plant Soil* 430, 23-35

Tränkner, M.; Tavakol, E. and Jákli, B. (2018) Functioning of potassium and magnesium in photosynthesis, photosynthate translocation and photoprotection. *Physiol. Plantarum*, 163, 414-431

Wirtz, I.P., Hauer-Jákli, M., Schenke, D., Ladewig, E., Märländer, B., Heimbach, U. and Pistorius, J. (2018) Investigations on neonicotinoids in guttation fluid of seed treated sugar beet: Frequency, residue levels and discussion of the potential risk to honey bees. *Crop Protection* 105, 28-34

Conference talks – papers – posters

Sommerakademie der Deutschen Bundesstiftung Umwelt DBU. Das richtige Maß - Zukunftsstrategien für Phosphor und Stickstoff. June 4th to 6th 2018, Kloster Drübeck, Germany

Dittert, K. (2018) Die neue Düngegesetzgebung muss schon mittelfristig deutlich nachgebessert werden. Tagung der Evangelischen Akademie Loccum. Mist! Zu viel Gülle, Nährstoffe und Keime ... (Gewässer-) Belastungen und Schutzmaßnahmen. October 23rd to 24th 2018, Kloster Loccum, Germany

Grahmann, K., Verhulst, N., Govaerts, B., Dittert, K. and Buerkert A. (2018) Challenges of ¹⁵N field studies to measure N fertilizer recovery under irrigated conservation agriculture. ISTRO conference, September 27th 2018, Paris, France

Hauer-Jákli, M. and Tränkner, M. (2018) A Meta-analysis Study on the Effects of Mg on Photosynthesis and Plant Growth. The 3rd International Symposium on Magnesium, November 25th to 28th 2018, Guangzhou, China

Jamali Jaghdani, S. (2018) Magnesium and its effect on photosynthetic activities in *Triticum aestivum* and *Helianthus annuus*. The 3rd International Symposium on Magnesium, November 25th to 28th 2018, Guangzhou, China

Jamali Jaghdani, S. and Tränkner, M. (2018) Minimum magnesium supply and its effect on photosynthetic activities in *Triticum aestivum* and *Helianthus annuus*. International Conference of the German Society of Plant Nutrition (DGP), September 13th to 14th 2018, Osnabrück, Germany

Lingner, A., Dittert, K. and Pfeiffer, B. (2018) The cropping system matters - Contrasting responses of winter faba bean genotypes to drought stress. Statusseminar PLANT 2030, February 5th to 7th 2018, Potsdam, Germany

Lingner, A., Dittert, K. and Pfeiffer, B. (2018) The cropping system matters - Contrasting responses of winter faba bean genotypes to drought stress. EUCARPIA - Symposium on Breeding for Diversification, February 19th to 21st 2018, Witzenhausen, Germany

Römer, W., Claassen, N., Steingrobe, B., Hilmer, R., Möllers, C. and Dittert, K. (2018) Einfluss der Phosphor- und Kalium-Versorgung des Bodens auf Ertrag und Qualität von Winter-raps. - Effect of available soil P and K on yield and quality of winter oilseed rape. In German. International Conference of the German Society of Plant Nutrition (DGP), September 13th to 14th 2018, Osnabrück, Germany

Rummel, P., Pfeiffer, B., Pausch, J. and Dittert, K. (2018) Quality of carbon compounds of maize root and shoot litter controls short-term CO₂ and N₂O emissions from agricultural soils. 20th Nitrogen Workshop, June 25th to 27th 2018, Rennes, France

Schickhoff, D., Lebender, U., Tierling, J., Brueck, H. and Dittert, K. (2018) Impact of N-fertilizer forms on N₂O-emissions in a fertigated potato system. 130. VDLUFA-Kongress, September 18th to 21st 2018, Münster, Germany

Tränkner, M. (2018) Mg Nutrition and Photoprotection in Plants. The 3rd International Symposium on Magnesium, November 25th to 28th 2018, Guangzhou, China

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
Fraunhofer	München, Germany
Fraunhofer-Institut für Intelligente Analyse- und Informationssysteme IAIS	Sankt Augustin, Germany
Fraunhofer-Institut für Umwelt, Sicherheits- und Energietechnik UMSICHT	Oberhausen, Germany
Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB	Stuttgart, 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
International Plant Nutrition Institute	Penang, Malaysia
Julius Kühn-Institut, Institute for Crop and Soil Science	Braunschweig, Germany
K+S Analytik- und Forschungszentrum (AFZ)	Unterbreizbach, Germany
K+S KALI GmbH	Kassel, Germany
LUFA Nord-West, Institut für Düngemittel und Saatgut	Hamel, Germany
Sabancı 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 Göttingen	Göttingen, Germany
Division of Quality of Plant Products	
Institute of Geography - Cartography, GIS and Remote Sensing Section	
Institute for Numerical and Applied Mathematics	
Plant Pathology and Crop Protection	
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 Kiel, Institute of Plant Nutrition and Soil Science	Kiel, Germany
University of Peradeniya	Peradeniya, Sri Lanka

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