IAPN
INSTITUTE OF
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RESEARCH ON SUSTAINABLE PLANT NUTRITION

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Preface

Dear reader,

2017 was an exciting year at IAPN as it brought many changes and news that designated the onset of a second generation period. In spring Dr. Ershad Tavakol finalized his PhD graduation. After graduation of Dr. Merle Tränkner and Dr. Bálint Jákli in autumn 2016, this marked the completion of the first group of IAPN PhD students who focused on functions of plant nutrients that interact with water-use efficiency and drought tolerance. Based on their studies, the IAPN scientists presented their scientific results at several national and international conferences and their research papers were published in international scientific journals.

Moreover, after the cooperation agreement between the University of Göttingen and K+S KALI GmbH had been updated and extended in autumn 2016, an important step forward has been done by opening the junior professor position. An independent assessment panel selected Dr. Merle Tränkner for appointment in this position which took place in summer 2017. – Congratulations. – Also, Dr. Bálint Jákli continued his research at IAPN – however, at the end of the year he took a scientific assistant post-doc position in the neighbouring Section of Plant Nutrition and Crop Physiology of the Department of Crop Sciences at Göttingen University which is very close to IAPN.

Similar to previous years, IAPN continued its knowledge transfer and university teaching activities. The "IAPN in Dialogue" series went on in November addressing the production of oil palm, plant nutrition and sustainability issues with four experts in the field of oil palm research presenting different viewpoints. Finally, in autumn 2017, the International Magnesium Institute (IMI) was founded at Fuzhou University in Southern China. The IMI can be seen as twinned institute particularly addressing the role of magnesium in the sustainable cultivation of crops in Asia. There are a number of links between IAPN and IMI, and together with additional partners, both institutes agreed to host the next Magnesium Conference in autumn 2018 in Guangzhou, China. At IAPN we send our best wishes for a good start of activities at IMI and hope for fruitful cooperation. Now on behalf of all IAPN staff I wish you interesting further reading on details and some insights into our activities.

Prof. Klaus Dittert

Scientific Director IAPN

The IAPN at a glance

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

The Institute of Applied Plant Nutrition (IAPN) in Göttingen was initiated by Georg-August-University of 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. The IAPN is an Associated Institute according to Lower Saxony's tertiary education legislation which means that it is closely linked to the University 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 Georg-August-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 and Master students, who thereby get closely involved in IAPN's research activities. Moreover, many links to sections of the Department of Crop Sciences and other University institutes were established and co-operations were brought on their way.

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

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 centre of the photo). (Photo: D. Jákli)

IAPN's Objectives

IAPN's objectives are to conduct scientific research and to contribute to closing knowledge gaps by scientific research, teaching and knowledge dissemination in the field of applied plant nutrition. Crops of high quality, production with high resource use efficiency and the search for lowest environmental impact are the cornerstones of its research and teaching concept. In addition to classical university activities IAPN offers internships to foreign scientists. Funded by public institutions like German Academic Exchange Service DAAD, non-governmental organizations or the private sector, visiting scientists spend 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. 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.

The close connection of the IAPN and the University of Göttingen helps both partners pursuing their objectives:

- **Research in applied plant nutrition:** Always starting from thorough revision of published scientific literature, most research topics aim at advancing solutions for applied research questions. Nevertheless, it is often needed to address fundamental research questions to improve the general knowledge on nutrient physiology in certain fields. As detailed in the research section of this report, improving water-use efficiency is one of today's great challenges in agriculture and IAPN is dedicating much of its energy in this field.
- **University teaching in applied plant nutrition:** The IAPN team is very active in offering classical lectures to students, laboratory and greenhouse courses covering plant nutrient physiology and many aspects of the research methods that have been established and, IAPN offers opportunities for students to do their bachelor, master or PhD thesis. With this, they provide very significant contributions to the overarching goals of IAPN.
- **Knowledge transfer to applied research and extension:** Students, agricultural advisors and extensionists from abroad may spend internships at the IAPN for a limited period of time. Young colleagues with good potentials and backgrounds that match IAPN's expertise can pass two to three months internships. Young colleagues with good potentials and backgrounds that match IAPN's expertise can pass two to three months internships. Here they get involved with our research and discuss the needs of their own particular project.

Team of the IAPN (left to right): Kirsten Fladung, Dr. Ershad Tavakol – he left IAPN at the end of 2016 –, Ulrike Kierbaum, Prof. Klaus Dittert, Jun.-Prof. Merle Tränkner, Annika Lingner, Dr. Bálint Jákli and Martina Renneberg. (Photo: Herwig)

The IAPN Team

In 2017, the team of IAPN consisted of seven members in administration, technical and laboratory assistance and scientific staff. The institute is headed by Professor Klaus Dittert. All administrative matters are managed by Martina Renneberg and the technical and laboratory assistance is provided by Kirsten Fladung and Ulrike Kierbaum. In close cooperation with the scientific team, they take care of growing plants in greenhouse experiments, conduct analyses of mineral elements in plants and soils and, they run many of the established biochemical analytics such as activity assays of reactive oxygen species (ROS) detoxifying enzymes.

With the successful graduation of Ershad Tavakol in February 2017, the "first generation" of PhDs at IAPN has finished. His former IAPN colleagues Bálint Jákli and Merle Tränkner graduated a few months before in 2016. The PhD thesis of Ershad Tavakol was published under the title "Physiological and molecular responses of contrasting barley cultivars to limitations of potassium and water availability". Since January 2017, he works for K+S KALI GmbH, but is still involved in research activities of IAPN through joint project work and research cooperations.

In June 2017, Dr. Merle Tränkner took up the position of the junior professorship "Applied Plant Nutrition" at IAPN and the Faculty of Agricultural Sciences at Georg-August-University Göttingen. Annika Lingner in the fourth year of PhD studies in the framework of the IMPAC-project "Novel genotypes for mixed cropping allow for improved sustainable land use across arable land, grassland and woodland" is about to finish her studies.

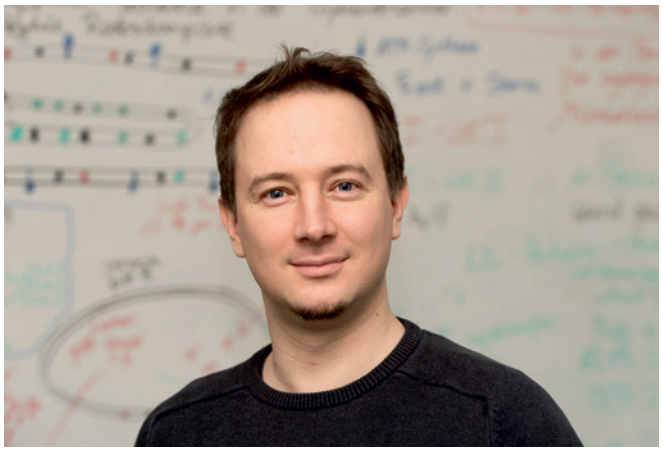
Throughout the year, the IAPN team was intensively supported by many graduate and undergraduate student assistants who helped in plant cultivation, measurements and preparations of numerous plant, soil, gas, biochemical and molecular samples. Their contribution is greatly acknowledged.


The first generation of PhDs at IAPN has finished: Bálint Jákli, Merle Tränkner and Ershad Tavakol (left to right). (Photos: IAPN)

Ershad Tavakol following a very special tradition: In Göttingen successfully graduated PhDs have to bring flowers to the "Gänseliesel" and give her a kiss. The statue "Gänseliesel" is the landmark of Göttingen, it stands in the middle of the Rathausmarkt. (Photo: IAPN)

Research at IAPN

Doctoral students and young scientists make up an important part of the research work at IAPN. That is why we have asked two young scientists this year to share their experience: Dr. Bálint Jákli and Dr. Merle Tränkner. Both completed their doctoral studies successfully in 2016 at the IAPN.



In his dissertation, **Bálint Jákli** examined the importance of essential plant nutrients, in particular of potassium, on water use efficiency and drought stress tolerance of crop plants. Since January 2017 he has been working as a research assistant at the Department of Crop Sciences of the University of Göttingen and at the IAPN.

Mr. Jákli, your research focus is on crop water use efficiency. What exactly is that?

The term "water use efficiency" (WUE) can be interpreted in many ways. Basically, it describes the relationship between the biomass produced by plants and the amount of water consumed. The higher the WUE, the more biomass is formed per unit of water consumed. High WUE can be a huge advantage in terms of yield in water-limited regions. Our research is about the physiological mechanisms that underlie WUE and how they are regulated by essential plant nutrients.

Kofi Annan said back in the year 2000 that we need a "blue revolution" in agriculture: we need to increase water productivity. What lies behind this demand and where do you see the global challenges for plant-based research?

Global population growth is forcing us to continue increasing our food production. It is, at the same time, next to impossible in global terms to increase the amount of agricultural land available for plant food production because demand is increasingly in conflict with fodder and energy crop production. Besides, settlement and infrastructure are taking up more and more space. Pollution and climate change are also taking increasing chunks of land out of agricultural use. The per capita land available for plant production is, in fact, steadily declining. This means that we need to increase yields on existing land in a more sustainable and resource efficient way than we have done so far.

Drought is a major problem, and not only in regions classically associated with it, such as the Mediterranean or Africa. Even in some areas of Germany, climate change is making conditions drier during critical phases of plant growth. Improving water use efficiency is one way to better adapt plants to these conditions. Mr. Annan's call involves much more than that, though; it extends to include the global availability of new technologies and cropping strategies, as well as tolerant varieties.

Which specific question have you focused on in your work?

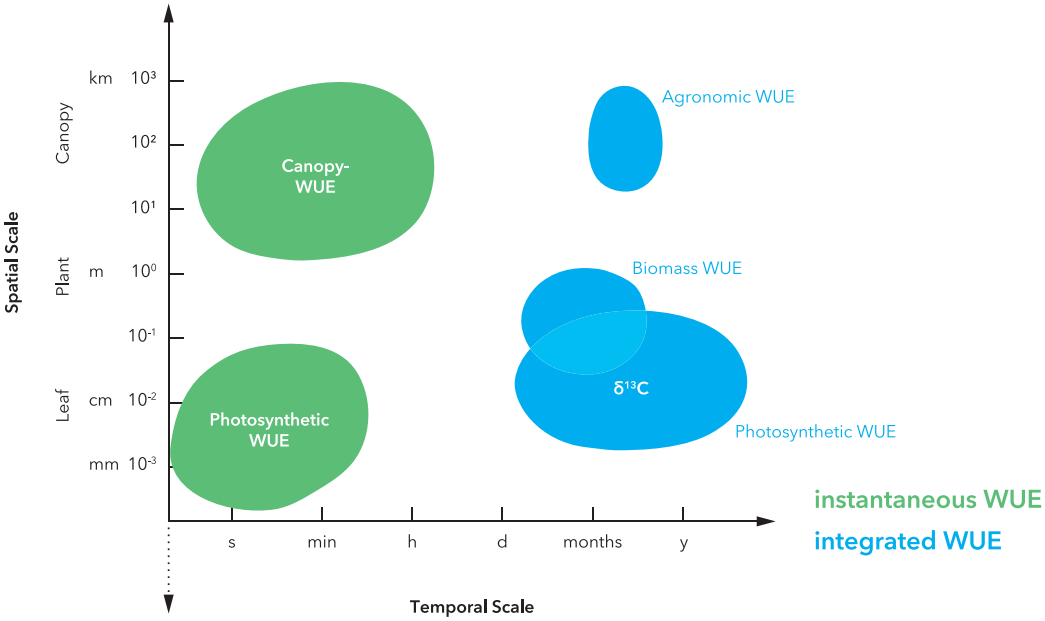
Over the past five years, I have been studying the extent to which adapted plant nutrition can improve the water use efficiency of our crops. However, as I mentioned earlier, WUE is a relatively flexible term and can have different meanings depending on the context it is used in. The first step was to systematically define the term. We observed that WUE works on several very different scales, both temporally and spatially.

Could you give examples of this?

Well, the farmer, for example, is ultimately interested in the simple question 'How much water did my plants need to produce the harvested crop?' Both the spatial and the temporal scales are

relatively large here, extending over the total field stock within a growing season. The result is a single number – the so-called agronomic WUE – for a wheat stock it's about 2g of grain per kg of water. But the question is: what does this number entail? It is determined by the sum of all the processes that have played out during the entire growth period, both within the plants themselves and the external processes that acted on them.

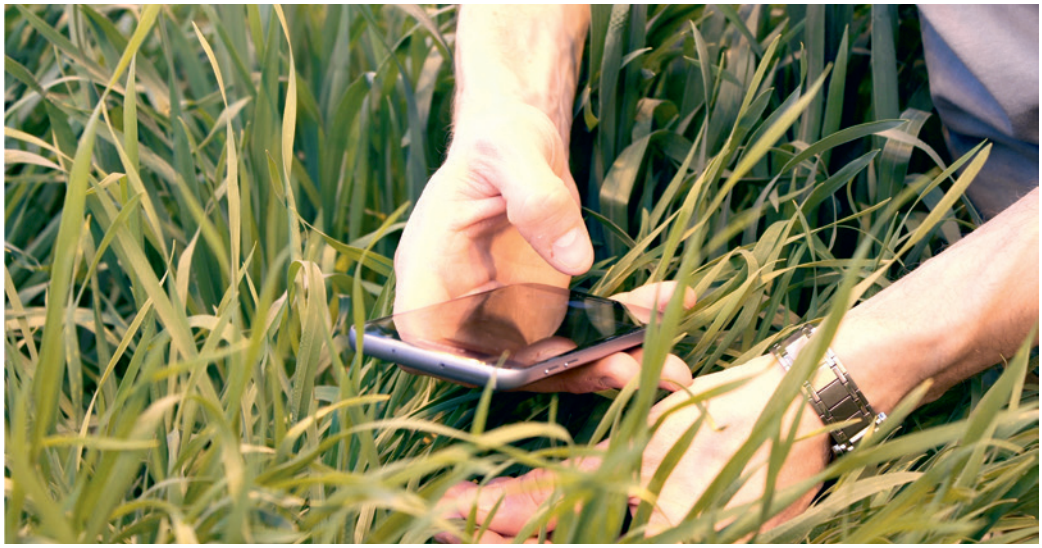
On one of the smallest scales, the agronomic WUE is determined by the photosynthetic gas exchange, i.e. the exchange of CO_2 and water vapour between the plant and the atmosphere. During photosynthesis, the plant absorbs CO_2 via the stomata on the underside of the leaf, thereby building up energy-rich compounds as sugars. In this case, water vapour is released via the stomata. These two processes are called assimilation and transpiration. The ratio of both gives the photosynthetic WUE. It takes place on much smaller scales, it is regulated on small areas of individual leaves within seconds to minutes. In the end result, however, it adds up to the large-scale agronomic WUE.



Is your research significant for agricultural practice in Germany too?

Yes of course. But one generally has to differentiate between the challenges for plant nutrition in industrialized countries, such as Germany, and in developing countries. The latter is about establishing nutrient management in the first place, with enormous potential for increasing yields. In Germany, we want to reduce the inputs into our environmental systems, while still maintaining and expanding the very high yield levels already achieved.

Drone-based remote sensing of canopy water use efficiency. (Photo: Lingner)



Spectral phenotyping of wheat plants using a smartphone. (Photo: Rethmeyer)

Do you have a concrete research result?

In my doctoral thesis, I showed that potassium fertilization is indispensable for exploiting the location-dependent yield potential, but that the quantities applied can be greatly reduced. However, the equation isn't that simple: The demand for potassium is not only determined by crop and soil, but also depends on the weather, which is subject to annual fluctuations. Minor potassium deficiency will not cause any loss of yield in good years, but it can be dramatic in dry conditions, especially during early plant development. In order to be able to individually respond to such events whilst at the same time acting in a more resource-efficient and sustainable way, we need fast analysis methods that tell us the condition of the stock at any given time.

Which methods are used to research water use efficiency?

The common methods for measuring water use efficiency are relatively time consuming, expensive and can in parts only be done by experts. Modern technology offers us opportunities to visualize a wide variety of plant processes, using the optical properties of plants. The human eye only processes information from a small part of the electromagnetic spectrum, which our brain interprets as colour. Modern sensors can, however, capture information from the entire spectrum. Every change in the growth condition of a plant is reflected somewhere in the spectrum of its reflections, we just have to find this information and interpret it correctly. This means that with the appropriate sensor technology, which is e.g. operated by drones or satellites, we should not only be able to recognize a stress state, but also be able to classify it. But we are still pretty much at the beginning of this kind of application.

IAPN is highly committed to knowledge transfer, and makes an important contribution to teaching at the University of Göttingen. What is important to you when working with agricultural students?

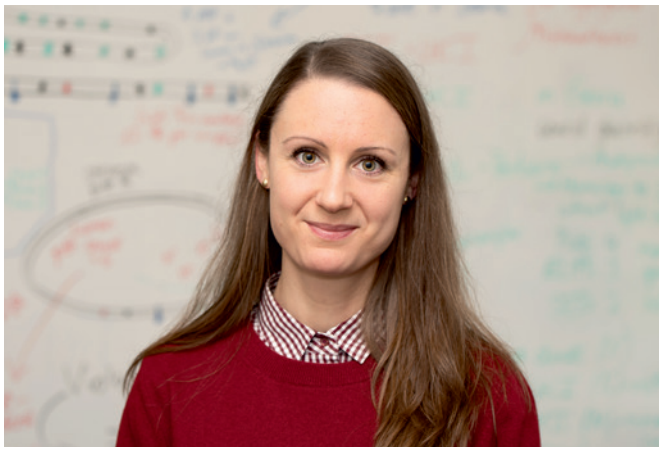
Studying is not just about learning content. Students need to be given the space to critically question content. And for that space to emerge, technical knowledge of the most diverse disciplines must be linked and integrated into a larger context. It is not just about communicating knowledge, but understanding. That is why we at IAPN strive to combine different teaching formats, for example, to experience the subject matter of the lectures directly in scientific experiments.

If a good fairy were to come along and grant the scientist Bálint Jákli three wishes, what would they be?

1. Radical rethinking in politics, business and the public when it comes to the future of our planet. We are faced with unprecedented global problems. Sustainability means protecting the livelihood of future generations. We don't even do that for our children, muchless our children's children, and we know it. Ah, but you were asking about science.

2. I would like to see more attractive working conditions – especially long-term contracts – for non-professorial teaching staff, because they are the people who for the most part actually do the teaching and research at universities.

3. The ultimate device with which I interpret a plant and learn everything about it, from the species and age to stress status and current levels of energy, substance and information exchange with the environment. As an alternative, I'll be happy to go with the new mobile gas exchange system LI-6800 from the company Licor for the determination of photosynthetic gas exchange. It's a really great instrument, and it already exists.



Merle Tränkner became Junior Professor for "Applied Plant Nutrition" at IAPN and the Faculty of Agricultural Sciences of the Georg-August-Universität Göttingen in June 2017. During her PhD, she studied the influence of magnesium, potassium and nitrogen on the water use efficiency of different crops and the stress physiology of nutrient deficiency. She also investigated the influence of potassium deficiency and drought stress on the proteome (i.e. the totality of proteins) in wheat, which is one of the most important crops globally.

Ms. Tränkner, what do you like about the work involved in a Junior Professorship?

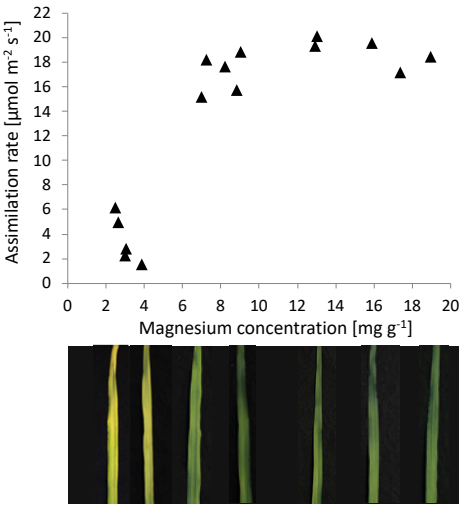
Like any other professorship, the junior professorship is a combination of research and teaching, which makes the work enormously varied. In addition, there are the special challenges that go with plant-based research: Every experiment with plants is different, because plants are living organisms that react to environmental conditions and never behave statically. This means that as researchers we always have to be extremely flexible and sometimes have to react quite spontaneously. An example would be when we see that it makes obvious sense to conduct a measurement at a much earlier time than was originally planned in the experimental design. I am always fascinated by the evaluation of data we have collected during measurements. The data give insights into the physiological processes of the plant that are not possible to have with the naked eye.

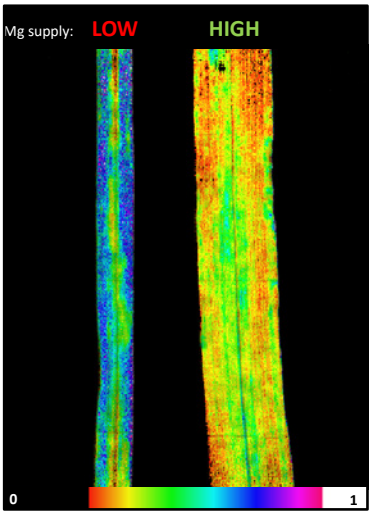
Alongside the research work, I really enjoy the teaching. I agree with Bálint Jákli when he says that the lectures shouldn't only focus on teaching factual knowledge that is crammed till the exam is over and then replaced with new facts. Students should develop an understanding that enables them to abstract and that will benefit them in the long term. I find that the students are very inquisitive and highly motivated, which of course is a great support to my own motivation.

A special attraction at the IAPN is the focus on knowledge transfer through events, such as the series "IAPN in Dialogue". As a Junior Professor, I can now actively participate in the topic selection, design and implementation of the events.

What research questions will you be looking to in the coming years?

During my PhD, I was mainly focused on the plant nutrient magnesium. Magnesium has many functions in the processes of photosynthesis. The photosynthetic performance of a plant is greatly reduced when there is a magnesium deficiency. The reason for this is that the plant cells are damaged by light radiation and the associated high energy supply. Plants have developed protective mechanisms against this damage that I would like to investigate in my time as a Junior Professor. A second research topic will continue to be water use efficiency. I would like to focus in particular on the question "How does magnesium affect water use efficiency?". In my PhD, I explored the fact that magnesium changes water use efficiency. I'd like to move on now to clarify the "how".





Left: Decreasing leaf magnesium concentrations lead to reduced assimilation rates and reduction of chlorophyll concentration as visible by yellowing of leaves.
Right: Due to reduced assimilation capacity, light energy is in excess to what can be used in photosynthesis and can damage the plant. To protect leaves from damage, the excess light energy is converted to thermal energy, which is assessed as non-photochemical quenching (NPQ).
The leaf on the left suffers Mg deficiency and has higher NPQ, indicated by more blue and purple colours. The false color scale at the bottom depicts values from 0 to 1.

What specifically is on your schedule for 2018?

IAPN is offering a doctoral position that I would like to see filled by the beginning of the year if possible. This, of course, involves supervision of the doctoral student. Then this summer, for the first time, I will be offering my new module "Modern Plant Nutrition - Application of Molecular Methods in Plant Nutrition Research" for Master's students. It is a practical module with laboratory exercises which I will organize and prepare with the technical assistants Kirsten Fladung and Ulrike Kierbaum. In autumn, the 3rd International Symposium on the role of magnesium in plant production, food quality and human health is taking place in China, where I will present research results and keep up the good contacts we have with our Chinese colleagues.

Is there a topic that is especially close to your heart?

Yes, two in fact. The first, generally speaking, concerns the use of imaging technologies. These are used to display structures in high resolution. I am thinking for example of a range of different kinds of microscopy and camera systems that I believe should be used more frequently in plant research, true to the motto "A picture is worth a thousand words". It's really important to look to other research disciplines for established technologies and to see if they can be beneficial to agricultural research.

Bálint Jákli has already mentioned the second thing that really is close to my heart: I think we should dedicate as much attention to the careful use of natural resources in the agricultural sector as to increasing or maintaining agricultural productivity. The optimal situation would be to achieve by maximum conservation of resources with minimal input a maximum productivity. Precise land management already plays an important role, and the development of beneficial technologies and sensors has been making great progress in recent years. It is important to continue these developments because the potential for high-precision land management is far from exhausted.

PhD Student Annika Lingner uses remote sensing in field trials via drone. (Photo: Herwig)

IAPN Topics

Research projects of Dr. Bálint Jákli

Dr. Bálint Jákli received his doctoral degree in December 2016. In 2017, he continued at IAPN as a post-doctoral researcher working on the topics described in the following.

Quantitative limitation to photosynthesis under nutrient deficiency

During photosynthesis, plants absorb solar energy to assimilate atmospheric CO_2 and produce energy-rich organic compounds that are used for metabolism and growth. The actual rate of CO_2 assimilation is determined by numerous interlinked biochemical, biophysical and environmental factors, that can roughly be classified into (i) the conversion of solar energy into energy that is bound in organic molecules and (ii) the diffusion of CO_2 from the atmosphere into the leaf chloroplasts where it is (iii) biochemically fixed into carbohydrates by the enzyme ribulose 1,5 bisphosphate (RubisCO). When essential mineral nutrients are not available in sufficient amounts, the rate of photosynthetic CO_2 assimilation will eventually drop. Under nutrient deficiency, photosynthesis is limited by either one of the processes (i, ii, iii) or by a combination of two or more. The quantitative contribution of (i), (ii) or (iii) to the total limitation of photosynthesis is supposed to be nutrient-specific, depending of the physiological functioning of the different mineral nutrients.

In earlier studies at IAPN (Jákli et al., 2016, J. Plant Nutr. Soil Sci 179) it was shown that, under potassium deficiency, the major limitation to photosynthesis resulted from low rates of CO_2 diffusion through the leaf mesophyll, followed by reduced RubisCO activity. So far in plant nutrition, quantitative limitation analyses were only performed on potassium deficient plants. The concept of such analyses however, provides detailed information of plant performance under nutrient deficiencies. In 2017, this approach was therefore applied to quantify the relative limitations to photosynthesis under a range of nutrient deficiencies, including nitrogen, phosphorus, magnesium and sulfur. The project included the practical work for the thesis of Sofía Cañas, master student in agricultural science at the University of Göttingen.

Scale-effects on water-use efficiency in a long-term potassium trial

Since 2014, IAPN cooperates in a joint project with the German Weather Service (Deutscher Wetterdienst, DWD) and SKW Piesteritz. Together, we evaluate the effects of potassium fertilization in doses and forms (compared to 0 K fertilization) in a stationary field trial that has been established 1995 in Cunnersdorf near Leipzig, Saxony, in the Central German dry zone. Together with the DWD, soil and plant water balances are computed and water-use efficiencies (WUE) are calculated as crop yield per unit of water used by the crop canopy. Additionally, WUE is evaluated on the small-scale level of photosynthetic leaf gas exchange and the instantaneous canopy level. The results of the 2015's field campaign on sugar beet WUE are currently in press and will be published early 2018 (Jákli et al. 2018, J. Agron. Crop Sci., in press). In 2017, master student of agricultural science Mara Tabea Hiller conducted the practical work for her MSc. thesis on the WUE of potato in the Cunnersdorf experiment.

Measuring CO_2 and H_2O fluxes of potato in the field using a transparent canopy chamber (Cunnersdorf 2017). (Photo: B. Jákli)

Measuring the gas exchange of climate chamber grown potato plants. (Photo: B. Jákli)

Regulation of transpiration in response to low water availability and high VPD

Two modern climate chambers (Fitotron, Weiss Technik, UK) were acquired by the Division of Plant Nutrition, University of Göttingen, in summer 2017. A first experiment was run by Valentin Paas, master student of agricultural science, under the supervision of Bálint Jákli (IAPN) and Prof. Andrea Carminati (Soil Physics, University of Bayreuth). In this experiment, potato plants were grown in soil substrate and subjected to different levels of soil moisture availability. In the climate chambers, temperature and relative humidity were varied between 18–40 °C and 30–60%. Different combinations between temperature and relative humidity were used to create large variation of vapor pressure deficit (VPD) – the driving force for plant transpiration – in the climate chambers. The regulation of CO_2 and H_2O exchange between plants and atmosphere, mediated by the stomata, was evaluated using leaf and canopy gas exchange measurement techniques combined with thermal imaging. The results of this study will be presented 2018 in the thesis of Valentin Paas.

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

PhD research project of M.Sc. Annika Lingner

The current shifts in precipitation patterns towards extreme weather events require sustainable agricultural systems with improved resource use efficiency and stress tolerance to water scarcity. A promising approach is the use of multi-cropping systems, which are characterized by multiple species grown on the same cultivated area. Such cropping systems with mixed stands, often called intercropping, may increase the efficiency of light, and water use as well as nutrient uptake due to complementary stand and root architecture. Intercropping of cereals with legumes is a common practice as it reduces input of mineral N fertilizer and increases protein contents of the harvested products.

Suitable genotypes for intercropping

Intercropping can lead to an increment in yields compared to the respective pure stands. The performance of the system generally depends on various factors and factor combinations such as genotypic characteristics and environmental conditions. The suitability of a specific genotype is governed by complex interactions and genotypes with best ranking in pure stands do not necessarily perform equally well in intercropping systems. Therefore, one of the major goals of the project is the identification of genotypes that show superior performance in mixed crop stands. More evaluations of the performance of genotypes in intercropping systems are needed in order to improve our knowledge of the use efficiency with respect to the resources water, light and nutrients.

Pure stand of winter faba bean from a greenhouse pot experiment with a transparent chamber for instantaneous measurements of gas exchange. (Photo: Lingner)

Investigations on different scales

In the framework of the project IMPAC³ (Novel genotypes for mixed cropping allow for IMProved sustainable land use ACross arable land, grassland and woodland) several aspects of the genotype-specific performance of different species mixtures are studied. Here, Annika Lingner investigates the effects of water partitioning between component crops and the efficiency in water use of intercropped vs. pure stands of species mixtures in arable land and grassland. Due to the complexity of intercropping systems, it is necessary to assess parameters for water use and drought stress tolerance at different scales. Biochemical and physiological mechanisms of plants grown under controlled conditions in the greenhouse provide precise information about responses of the crops to water scarcity. In contrast, data assessment of field experiments takes into account more complex growth conditions such as weather events, variations in soil structure and occurrence of pests. Findings of both approaches need to be related to each other to obtain detailed understanding of the dynamics of competitions and synergies in intercropping systems.

Testing of the legume winter faba bean for water use efficiency in mixtures with winter wheat

Among legumes, faba bean is a promising option to replace the high input crop soybean as locally produced protein source for food and feed. Yet to date, its potential is not fully explored as there are only very few winter-hardy varieties on the market, which are able to benefit from rainfall events during winter. As faba bean is a very sensitive crop to water limitations, genotype-specific physiological properties of different winter faba been genotypes to temporal water deficit were investigated in order to identify stress adaptation and drought tolerance in more detail. Under semi-controlled growth conditions in the greenhouse, two contrasting experimental lines (S_004 and S_062) of winter faba bean (Vicia faba L.) differing in growth habitus and maturity were cultivated in soil substrate and subjected to drought stress induced by deficit irrigation. Their performance was tested in pure stands (see photo to the left) as well as in mixtures with winter wheat (Triticum aestivum L. cv. Genius). Plant biomass production and water use efficiency (WUE; calculated as total aboveground biomass per water consumption during the growth period) were investigated as well as relative water content (RWC) and proline content of leaves (see photo to the right).

Harvest of the greenhouse experiment with winter faba bean and winter wheat in intercropped and pure stands for evaluation of biomass production, relative water content of leaves and other methods. (Photo: Lingner)

The cropping system matters – Contrasting responses of winter faba bean genotypes towards water deficit

Winter faba bean genotypes showed contrasting responses to drought stress in pure stands or in intercropping. With water deficit, biomass was reduced in genotype S_004 only in pure stands while genotype S_062 had impaired biomass production only in intercropping. This observation was confirmed by findings based on measurements of relative water content (RWC), CO_2 assimilation and transpiration which indicated continuation of photosynthetic processes of genotype S_004 in intercropping under water deficit. Moreover, WUE was increased in intercropped stands with winter faba bean genotype S_004 and in pure stands of winter faba bean S_062. In summary, winter faba bean showed little interference of water deficit for genotype S_062 in pure stands while genotype S_004 exhibited little interference of water deficit

when grown in intercropping. It can be concluded that there is genotypic variation in the performance and drought tolerance of winter faba bean. Thus, for intercropping systems the right choice of the winter faba bean genotype is important.

Screening water use efficiency in the field

In addition to the observations in the greenhouse, mixtures of winter faba bean with winter wheat as well as mixtures of white clover with ryegrass and chicory as compared to their respective pure stands were also tested in field experiments (see photos on the right). The examination of the crop stands throughout the growing cycle focuses on identifying key indicators of tolerance to drought events as well as remote sensing techniques for early detection of stress symptoms. Two separate approaches were used to measure the water use efficiency (WUE) as a ratio of assimilation per transpiration of each crop stand: i) stable isotope discrimination of ^{13}C in plant tissues for intrinsic WUE was analyzed in arable crops and grassland at critical phases during the vegetation period, ii) net CO_2 exchange and evapotranspiration as assessed by gas exchange of the different crop stands were directly measured (GFS 3000, Heinz Walz GmbH, Germany) using a mobile canopy chamber.

Assimilation of carbon isotopes as an indicator for water use

In order to assess the water use efficiency in the field, carbon stable isotope discrimination was measured once per vegetation period in arable crops and grassland. The earlier tested genotypes of winter faba bean (S_004 and S_062) showed similar responses in carbon stable isotope discrimination, while other faba bean genotypes displayed less discrimination which is indicative of higher water use efficiency in the field. In grassland, clear effects of nitrogen fertilizer were observed in ryegrass treatments. Nitrogen seemed to lower the water use efficiency as determined by carbon isotope discrimination. The same effect was observed with mixtures of white clover and ryegrass, showing lower water use efficiencies than pure stands of white clover.

Intercropping of winter faba bean and winter wheat in alternating rows. (Photo: Lingner)

Nitrogen fertilizer and mixtures with chicory increase water usage

Similarly, evapotranspiration was increased with application of N fertilizer in non-leguminous species in grassland, indicating higher production rates but concurrently increased use of water resources. Higher evapotranspiration was determined in mixtures of white clover with chicory compared to mixtures including ryegrass, which showed lower water consumption, probably due to different rooting systems. In contrast, white clover had highest net-photosynthesis and thus most efficient water use while the mixture of white clover and ryegrass showed lower water use efficiency. Concurrently, the arable crops had similar water use efficiencies, only showing a tendency of higher net-photosynthesis and therefore also water use efficiency in mixed cropping plots of winter faba bean and winter wheat towards the end of the vegetation period.

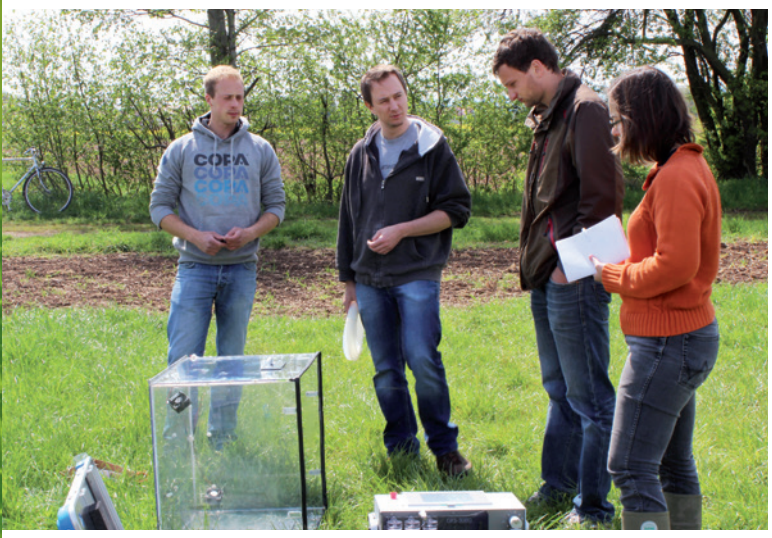
Drone-based remote sensing of NDVI and surface temperature

In continuation of previous years' studies, drone-based monitoring of crop stands in arable land and grassland was also done in 2017. With the quadcopter (EagleLive Raptor, EagleLive Systems, Germany), equipped with a multispectral (ADC Micro, Tetracam Inc., California) and a thermal camera system (PI 400, optris, Germany), characteristics of the crop stands were evaluated. Visible and near-infrared reflection of the crop stands were used for calculating the Normalized Difference Vegetation Index (NDVI) that provides information about biomass production und photosynthetic activity of the different crop stands in the field. Additionally, the canopy surface temperature served as proxy for water use and transpiration. Both parameters indicated that mixed cropping systems improved productivity and WUE.

Towards the end of 2017 Annika Lingner completed almost her PhD studies. She will finalize manuscripts of the main findings for publication in peer-reviewed scientific journals. Annika Lingner is planning to graduate in summer 2018.

Intercropping of white clover and perennial ryegrass. (Photo: Lingner)

Knowledge Transfer



How much CO_2 can be absorbed by an agricultural ecosystem from the atmosphere? Does this affect the water use efficiency of the agricultural ecosystem? Dr. Bálint Jákli and Annika Lingner, researchers of IAPN, investigate these questions together with students of agricultural sciences at Göttingen University. (Photos: IAPN)

Teaching at the Georg-August-University, Göttingen

An important objective of the IAPN is to provide students with a solid training in plant nutrition physiology. For this, alongside traditional lectures, seminars 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 the 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 the 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 the IAPN, at undergraduate, Master's and PhD level.

Insights into experimental work

Jun.-Prof. Merle Tränkner has commenced teaching in winter term 2017/2018. She offers a Bachelor course entitled "Plant Nutrition encounters Plant Physiology – Experimental Studies Involving both Fields". The course combines theory with practical research work. In lectures, the physiological functions of plant nutrients and the concept of water use efficiency are taught. The focus is set on the strong impact of plant nutrition on plant physiology. As a guest lecturer, Prof. Ismail Cakmak gave a lecture about "Why do plants need micronutrients?" Next to lectures on theory, students conduct their own experiment in the greenhouse where they grow plants with several nutrient deficiencies. During the experimental period, they perform several measurements creating their own dataset which they analyse later on. "I wanted to offer a course in which students learn all relevant steps related to experimental work. Starting from practical experimental work with plants, via generating a data set, to statistical evaluation and interpretation of the data, students present their results at the end of the lecturing period. So on one hand they learn how to create data plots and on the other hand they get familiar with giving presentations," says Merle Tränkner. One aim of the course is to prepare students for practical work in connection with their Bachelor thesis, as many students conduct experiments only at the very end of their Bachelor studies,

Bachelor students during harvest of plants at the end of their experiment. In the bachelor course offered by Jun.-Prof. Merle Tränkner the students run their own experiment and work in a self-organized way. At harvest, the plants are separated into shoot and root, roots are washed (student at the right) and biomass weight of the plants is determined (students at the left). (Photo: IAPN)

and only if they decide to include a practical component in their Bachelor thesis project. "The course is conceived as such that the awareness of basic processes is increased, for example how long does it take to analyse data or which systems exist to grow plants in the greenhouse." The course is given in jointly with Dr. Bálint Jákli.

A view on the element phosphorous

Furthermore, Merle Tränkner is engaged in the course "Plant Nutrition" of Dr. Bernd Steingrobe, a scientist at the Section of Plant Nutrition and Crop Physiology of University Göttingen. Within this course, she took over the supervision for the practical part dealing with phosphorous in soil. Students work in the lab and extract plant available phosphorous from soil by applying different methods. In theory sessions, the dynamics of phosphorous in soil are imparted to the students and linked to their practical work. Merle Tränkner is supported by Simone Urstadt, a technician of the Section of Plant Nutrition and Crop Physiology.

Jun.-Prof. Merle Tränkner with two bachelor students learning how to do measurements of leaf gas exchange. (Photo: IAPN)

Jun.-Prof. Merle Tränkner explaining to bachelor students the phosphorous availability in dependence of soil pH. Her teaching activity is part of the course "Plant Nutrition", which combines theory sessions and lab work. (Photo: IAPN)

Completed theses supervised by IAPN scientists in 2017

Nina Bacchi, M.Sc. Thesis (2017):
Pflanzenphysiologische Parameter von Gemengen mit Winterackerbohne *(Vicia faba L.)* und Winterweizen *(Triticum aestivum L.)* unter Trockenstress

Dirk Gert Becker, B.Sc. Thesis (2017):
Wassernutzungseffizienz eines Wintergerstenbestandes *(Hordeum vulgare L.)* unter Berücksichtigung kleinräumiger Bodenheterogenität

Michaela Böhme, M.Sc. Thesis (2017):
Physiologische Parameter der Trockenstresstoleranz verschiedener Genotypen der Winterackerbohne *(Vicia faba L.)*

Marieke Böttcher, B.Sc. Thesis (2017):
Effektivität und Wirtschaftlichkeit verschiedener Verfahren zur Platzierung von organischen Flüssigdüngern zu Mais

Julia Hartmann, M.Sc. Thesis (2017):
Untersuchungen zur Phosphorverfügbarkeit und -aufnahme aus Phosphor-Recyclingdüngern in zwei Praxisversuchen

Julius Hartmann, B.Sc. Thesis (2017):
Auswirkungen des Einsatzes von Piadin-Nitrifikationshemmer auf den Nitratgehalt im Boden nach der Erntefrucht Raps

Emil-Dennis Perchuc, B.Sc. Thesis (2017):
Variabilität der Wassernutzungseffizienz bei Nährstoffmangel – Beeinflussen Kalium-, Magnesium- und Stickstoffversorgung die Wassernutzungseffizienz unterschiedlich?

Daniel Schickhoff, B.Sc. Thesis (2017):
Fahrspureffekte durch Gülle-Strip-Till in Mais unter besonderer Berücksichtigung bodenphysikalischer Parameter

Ronny Schmidt, M.Sc. Thesis (2017):
Drohnenbasierte Fernerkundung von Gemengeanbau mit Leguminosen in Acker und Grasland

Henrik Asmus Sinjen, M.Sc. Thesis (2017):
Einfluss von Wurzelexsudat-Komponenten und des pH-Wertes auf Treibhausgasemissionen aus Böden

Jakob Streuber, B.Sc. Thesis (2017):
N_2O-Emissionen in Abhängigkeit des N_{min}-Gehaltes des Bodens nach Einarbeitung von Maisbiomasse

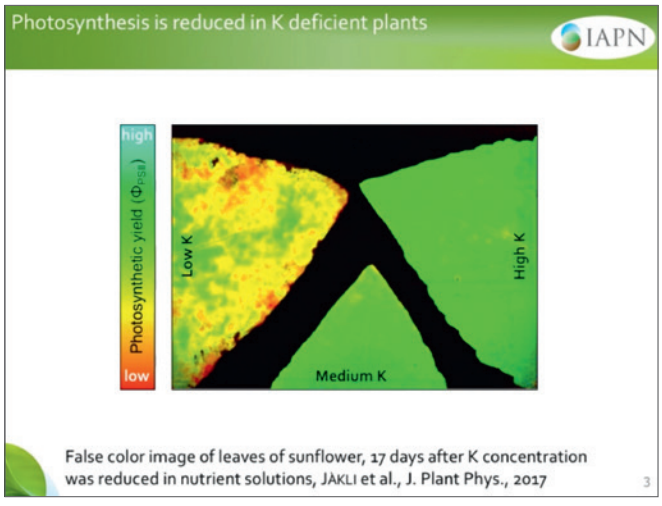
Marie-Christine von Minckwitz, B.Sc. Thesis (2017):
Anbauverfahren antiker Kulturen im Vergleich Rom – Ägypten

Phillip Walter, M.Sc. Thesis (2017):
Standortabhängigkeit der Wassernutzungseffizienz von Reinsaaten und Gemengen in den Landnutzungssystemen Acker und Grasland

Results from IAPN PhDs presented at Frontiers of Potassium 2017

The international conference "Frontiers of Potassium" was held in Rome, Italy, from 25th to 27th of January by the International Plant Nutrition Institute (IPNI). Nearly 130 scientists and agronomists from 37 different countries attended the conference which was related to the theme of the Global 4R Nutrient Stewardship Framework: applying the right potassium source, at the right rate, at the right time, and in the right place.

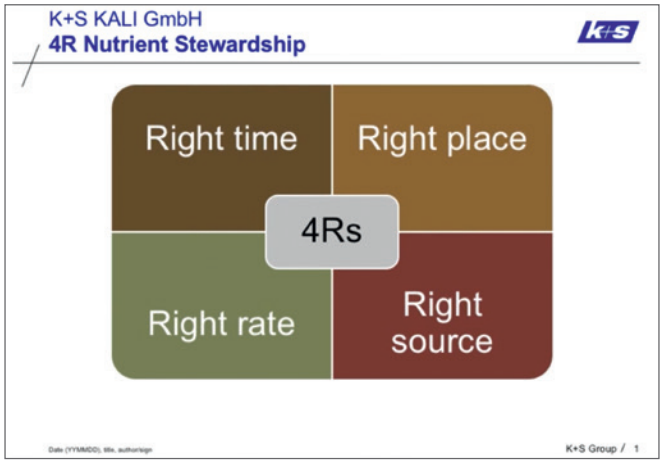
Bálint Jákli gave a talk about "Restricted CO_2 diffusion through the leaf mesophyll and not stomatal regulation limits photosynthesis in K deficient crop plants". The fact that potassium (K) is required for the opening of stomata has strongly contributed to the general opinion that K deficiency results in an inhibition of stomatal control. In his talk, Bálint Jákli outlined that the impairment of net CO_2 assimilation during photosynthesis is caused by impeded mesophyll diffusion of CO_2, most likely initiated by alterations in leaf anatomy. Reduction of stomatal conductance under K deficiency is thus an adaptation to low CO_2 utilization by photosynthesis, and stomatal functioning is maintained. The results presented were published 2017 in *Journal of Plant Physiology* 209:20-30 with the title "Quantitative limitations to photosynthesis in K deficient sunflower and their implications on water-use efficiency".



Slide of the presentation given by Bálint Jákli: Sunflower leaves which were exposed to K deficiency have lower photosynthetic efficiency as shown by false colour image obtained during measurements of chlorophyll fluorescence. The talk with accompanying presentation is available in full-length on YouTube: https://www.youtube.com/watch?v=7dPT4RR0eN8

Ershad Tavakol presented results which he obtained during his PhD at IAPN. On a poster entitled "The Effects of Potassium Deficiency and Osmotic Stress on the ROS antioxidant Balance and Whole Genome Transcriptional Response of Barley", he displayed data about the increased production of reactive oxygen species and the antioxidant activities of barley, which was grown under K deficiency and drought. Ershad Tavakol also showed results obtained by whole genome expression profiling and could thereby demonstrate that plants suffering drought and potassium deficiency reduce the capacity to absorb light and increase the production of the plant hormone abscisic acid.

Merle Tränkner also presented results on a poster entitled "Comparative Study on Proteome Changes in Response to Potassium Deficiency and Drought in *Triticum aestivum* Roots". She obtained the results in a proteomic study during her PhD period in cooperation with Prof. Christian Zörb (Institute of Crop Science, University of Hohenheim). Merle Tränkner demonstrated on her poster the changes in the protein expression pattern of wheat roots in response to potassium deficiency and drought. The proteomic results clearly showed that general plant defence mechanisms are triggered when plants suffer drought and potassium deficiency.



Slide of the presentation given by Andreas Gransee: The 4R Nutrient Stewardship consisting of the right time, right rate, right place and right source of fertilizer. The talk with accompanying presentation is available in full-length on YouTube: https://www.youtube.com/watch?time_continue=2&v=wUUqa-myhOIs

Andreas Gransee, managing director of the IAPN, has also attended the conference and contributed with a talk about "Potassium sulphate as a key to crop quality" in the session related to the right source of the 4R Nutrient Stewardship. In his talk, he outlined the effect of the potassium source on yield and quality parameters and showed results of selected crops like pine apple, where replacing potassium chloride by potassium sulphate can increase the size, weight and quality aspects, e.g. sugar content. Furthermore, Andreas Gransee showed that in potato, the use of potassium sulphate increased tuber yields, and in citrus, potassium nitrate (KNO_3) fertilizer induced highest fruit yield. At the end of his talk, he concluded that the form of potassium which is fertilized, is particularly important for chloride sensitive crops and that the "R"-principle of right form needs more attention in fertilizer management systems.

The IAPN team at the 18th International Plant Nutrition Colloquium (IPNC)

The IPNC, the most important international conference on plant nutrition, was held from 21st to 24th August 2017 in Copenhagen under the main theme "Plant Nutrition for Global Green Growth". The IPNC is held every 4th year and researchers from all around the world get together for exchange and transfer of knowledge by presenting their latest research findings in talks and posters. Close to 600 participants from more than 50 different countries attended the IPNC 2017. All scientists of the IAPN team participated in the conference and had several contributions.

Merle Tränkner gave a talk entitled "Photoprotective responses and PSII (Photosystem II) functionality under Mg deficiency" in the session about nutrient functions in plants. She presented results which were obtained by experimental work on barley. Under Mg deficiency, the capacity for CO_2 fixation is decreased and energy acquisition from photon absorption is in excess of what can be used in photosynthesis. This surplus energy can damage the photosystem II and inhibit irreversibly photosynthesis. To avoid any damage, plants evolved protective strategies, which can be summarized as photoprotection.

In the same session, Ershad Tavakol, former PhD student at IAPN, gave a talk on "Potassium supply mitigates photo-oxidative damage under osmotic stress by avoiding ROS generation and improving metabolism." Under drought conditions and potassium deficiency, plants suffer from excessive production of toxic compounds known as reactive oxygen species (ROS). High ROS concentration is deleterious to the plants and is avoided by enzymatically detoxifying ROS below critical levels. The presented results on the interaction of such detoxification capacity and K nutrition were obtained during his PhD.

A third contribution of IAPN was the talk of Bálint Jákli. His presentation was entitled "Restricted CO_2 diffusion through the leaf mesophyll and not stomatal regulation limits photosynthesis in potassium deficient sunflower". A major physiological effect of K deficiency is the impairment of net CO_2 fixation during photosynthesis, which results in a reduction

of crop growth and can lead to substantial yield losses. This impairment of CO_2 fixation is caused by a lower capacity of the leaf mesophyll to conduct CO_2 from the intercellular airspace into chloroplasts (the site where CO_2 is fixed) resulting in a limitation of CO_2.

A poster contribution was made by Jessica Albers, Master student under supervision of Merle Tränkner. The poster, entitled "Is Beta vulgaris able to fully recover from Mg deficiency in young growth stages after resupply?" presented results which Jessica Albers obtained during the experiments of her master study project. She showed that sugar beet suffering Mg deficiency in their early growth stages can recover and readapt photosynthesis and growth rates after steadily increasing resupply of Mg. Jessica Albers presented her poster in an oral mini-presentation.

Dr. Rolf Härdter (K+S KALI GmbH), Jessica Albers, Prof. Klaus Dittert, Annika Lingner, Jun.-Prof. Merle Tränkner (IAPN), Stefanie Wegener and Dr. Heike Thiel (K+S KALI GmbH) at the IPNC in Copenhagen (left to right). (Photo: IAPN)

Scientific exchange visit in Beijing, China

From 18th to 20th of September, Klaus Dittert, Ismail Cakmak, Bálint Jákli and Merle Tränkner visited the Department of Plant Nutrition at the China Agricultural University in Beijing. The IAPN members were invited by Prof. Dr. Fusuo Zhang, Director of the Centre of Resources, Environmental and Food Security at China Agricultural University and Director of the International Magnesium Institute IMI, to give guest lectures to Chinese agricultural students and participate in a student training.

Ismail Cakmak opened the lecture session with his presentation about synergistic and antagonistic relations between mineral nutrients during root uptake and transport to the shoot. In his second lecture he focused on critical functions of magnesium and potassium in plants. This topic was complemented by the lecture of Bálint Jákli who presented the importance of potassium in agroecological systems, starting at the geology and the potassium cycle in soil to physiological functions of potassium in plants, and the lecture of Merle Tränkner who presented the physiological functions of magnesium in plants with particular regard to photosynthetic processes. Klaus Dittert explained in his presentation how stable isotopes can be used in studies analyzing nutrient uptake efficiency and nutrient loss. During the student training, PhD students and one IAPN scientist gathered in small groups and the students presented their research results which were discussed with the scientist.

"It was an impressive experience. The students were very attentive during our lectures and took a lot of notes. They are highly motivated to learn and ambitious to conduct excellent research. It was a great pleasure to discuss the German and Chinese research projects with them", states Merle Tränkner. "Yes", agrees Bálint Jákli, "the students were very interested in their own and our study subjects. While working in groups, they were open to new ideas and appreciated the suggestions we made to improve their approach and interpretation of research results. We will work together on publications in the future months."

Prof. Klaus Dittert giving a lecture in front of students of the International Magnesium Institute (IMI) and of China Agricultural University (CAU) at CAU Beijing. (Photo: IAPN)

The event "IAPN in Dialogue" sometimes takes place at the premises of the institute's greenhouse. (Photo: Dach)

A special form of knowledge transfer: "IAPN in Dialogue"

Since September 2013 IAPN runs the series of events called "IAPN in Dialogue". Within this series researchers and practitioners from around the world report about their projects. In 2017 one event of the series with international experts took place in Göttingen.

Can oil palm cultivation be sustainable?

Palm oil is part of our daily lives. Within the series "IAPN in Dialogue" was discussed how a sustainable cultivation of oil palms can be developed. Four international experts were guests at IAPN. They held a lively discussion with students and scientists of Göttingen University at November 8, 2017. The dialogue was moderated by the IAPN´s new Junior Professor Dr. Merle Tränkner.

In dialogue (left to right): Dr. Thomas Oberthür, Dr. Beate Deuker, Dr. Joachim Milz, Dr. Rolf Härdter, Prof. Klaus Dittert, Dr. Hsiao-Hang Tao and Jun.-Prof. Merle Tränkner. (Photo: IAPN)

Dr. Rolf Härdter illustrated the many uses of palm oil as ingredient. (Photo: IAPN)

A vital constituent in many products

Palm oil is a vital constituent of many products of daily use. Its versatile application as ingredient of a variety of products ranging from food, feed, soap, washing detergents, industrial oils to biodiesel etc. has caused that palm oil is globally the number one vegetable oil consumed nowadays.

Dr. Rolf Härdter, Head of Agronomy & Advisory of K+S KALI GmbH, gave an introduction to palm oil production and its use from an industrial point of view. Oil palm has by far the greatest potential in producing vegetable oil, explained Dr. Rolf Härdter. Nevertheless yield gaps in oil palm production are still widespread and need to be overcome by improved management. From his point of view, nutrient management is a key factor for closing yield gaps. "We have to raise the yields per acre to reduce the pressure on land", Härdter emphasised.

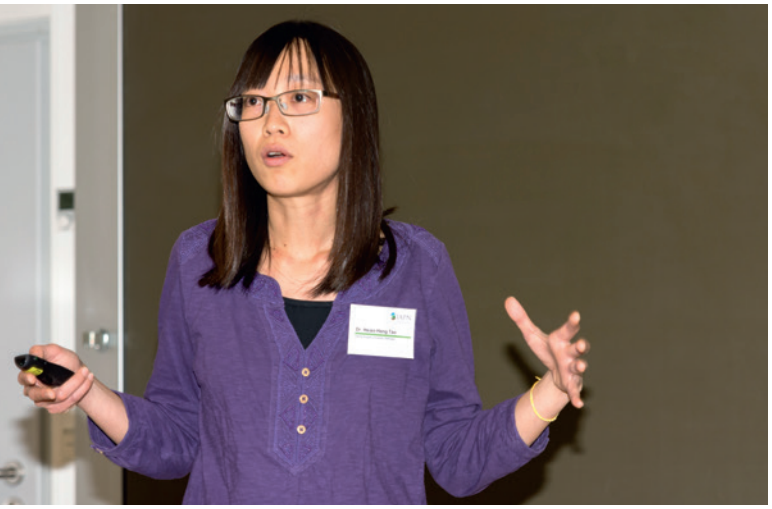
Insights in experiences in Southeast Asia

Dr. Thomas Oberthür, Director at International Plant Nutrition Institute, talked about research and development requirements in Southeast Asian oil palm plantation systems, using the example of potassium. He introduced the magnitude of nutrient requirements and highlighted the importance of responsible crop nutrition in plantations for sustainable oil palm intensification. Finally, he showed selected key issues that crop nutrition research needs to solve to support the responsible development of oil palm production systems.

Nutrient management for oil palms

Dr. Hsiao-Hang Tao showed selected results of trials on sustainable palm oil nutrient management in her speech. She spent a one-year postdoctoral fellow period at the Section of Tropical Plant Production and Agricultural Systems Modelling of the Department of Crop Sciences of Göttingen University and at IAPN. The International Plant Nutrition Institute provided the university with data and information for analyses from its trial network in Southeast Asia.

The results show that applying best management practices in Indonesia for four years enhanced oil palm dry matter production and fruit production efficiency. The effects of best management practices on oil palm growth were stronger at study sites with higher annual rainfall. "Improved management practices for oil palm cultivation have a high potential to enhance its sustainable development", Tao summarized.



Dr. Hsiao-Hang Tao presented results on trials on oil palm nutrient management. (Photo: IAPN)

Dr. Thomas Oberthür, expert for oil palm production in Southeast Asia. (Photo: IAPN)

Dr. Joachim Milz talked about alternatives in oil palm production. (Photo: IAPN)

A critical view

A critical view on industrialised oil palm production was given by Dr. Joachim Milz, Director of ECOTOP consult from La Paz, Bolivia. He represented a systemic point of view and pointed out alternative production systems, such as dynamic agroforestry, as really sustainable solution. Imitating how nature works, he considers the optimal approach. "Large scale mono cropping represents the driving force for destruction of landscapes and habitats", so Milz. "Today´s oil palm production is contributing considerably to destruction of tropical forests, depletion of soils, contamination of water resources, regional climate change and social imbalance." He is convinced that oil palm is a wonderful crop which should be produced as close as possible to its natural eco-physiological requirement.

The four presentations were followed by intense discussion with the participants in which direction further development has to go in order to fulfil the needs for vegetable oil of a growing population in future. "We have seen different approaches to sustainable oil palm cultivation and heard about the challenges associated with it. Further efforts are needed to implement farming practices which meet the global demand for palm oil, but at the same time are sustainable. We as agronomists, scientists or consumers can contribute to achieving this", stated Merle Tränkner at the end of the afternoon.

Guests at IAPN

The transfer of knowledge and establishing international networks in the field of plant nutrition are important tasks of the IAPN. Visiting scientists and visiting students are therefore very welcome at the institute.

In 2017 Prof. Dr. Ismail Cakmak from Turkey spent time at the IAPN as a visiting researcher. He is a worldwide acknowledged scientist in the field of plant nutrition and human trace element nutrition being primarily based at Sabanci University, Istanbul, Turkey. Now for a number of years, he spends much of his time at the IAPN and also at the Department of Crop Sciences, in the Section of Plant Nutrition and Crop Physiology at the Georg-August-University. He is and was engaged in joint research activities of IAPN und Sabanci University. He also makes very valuable contributions to the strengthening of scientific connections between both institutions and for example the International Magnesium Institute, which was opened in September 2017 as a public-private partnership by K+S KALI GmbH and the Fujian Agriculture and Forestry University (FAFU) located in Fuzhou, China. The International Magnesium Institute aims at developing scientific know-how for application of the plant nutrient magnesium in agriculture in Asia; also by means of research projects, new knowledge for plant nutrition will be developed and improved application recommendations worked out for fertilizers containing magnesium. Additionally, Professor Cakmak contributed, alongside to IAPN Professor Dittert and Junior Professor 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.

Publications

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

Chen, Q., Hooper, D.U., Li, H., Gong, X.Y., Peng, F., Wang, H., Dittert, K. and Lin, S. (2017) Effects of resource addition on recovery of production and plant functional composition in degraded semiarid grasslands. Oecologia 184, 13–24.

Dittert, K. and Bürkert, A. (2017) Spezielle Probleme der Düngung. In Ökologische Landwirtschaft. Eds. M. Wachendorf, A. Bürkert and R. Graß. pp. 338–351. Verlag Eugen Ulmer, Stuttgart, Germany.

Jákli, B., Tavakol, E., Tränkner, M., Senbayram, M. and Dittert, K. (2017) Quantitative limitations to photosynthesis in K deficient sunflower and their implications on water-use efficiency. Journal of Plant Physiology 209, 20–30.

Ruser, R., Fuss, R., Andres, M., Hegewald, H., Kesenheimer, K., Köbke, S., Rabiger, T., Quinones, T.S., Augustin, J., Christen, O., Dittert, K., Kage, H., Lewandowski, I., Prochnow, A., Stichnothe, H. and Flessa, H. (2017) Nitrous oxide emissions from winter oilseed rape cultivation. Agriculture, Ecosystems & Environment 249, 57–69.

Tränkner, M. (2017): Magnesium, potassium and nitrogen deficiency-induced responses of crops and their impact on water-use efficiency. 1st ed. Cuvillier Verlag, Göttingen. ISBN 978-3-7369-9536-9. eISBN 978-3-7369-8536-0.

Wu, D., Senbayram, M., Well, R., Brüggemann, N., Pfeiffer, B., Loick, N., Stempfhuber, B., Dittert, K. and Bol, R. (2017) Nitrification inhibitors mitigate N_2O emissions more effectively under straw-induced conditions favoring denitrification. Soil Biology & Biochemistry 104, 197–207.

Conference Papers – Posters

Albers, J. and M. Tränkner (2017): Is *Beta vulgaris* able to fully recover from Mg deficiency in young growth stages after resupply? XVIII. International Plant Nutrition Colloquium (IPNC), Copenhagen, Denmark, 21.–24. August 2017.

Jákli, B. and F. Hertwig (2017) Kaliumdüngung verbessert die Wassernutzungseffizienz – Ertrag, Evapotranspiration und Skalenabhängigkeit. Deutscher Wetterdienst (DWD), 13. Tag der Agrarmeteorologie, Leipzig, Germany, 11. January 2017.

Jákli, B., E. Tavakol, M. Tränkner and K. Dittert (2017) Restricted CO_2 diffusion through the leaf mesophyll and not stomatal regulation limits photosynthesis in K deficient sunflower. XVIII. International Plant Nutrition Colloquium (IPNC), Copenhagen, Denmark, 21.–24. August 2017.

Jákli, B., M. Tränkner; E. Tavakol and K. Dittert (2017) Restricted CO_2 diffusion through the leaf mesophyll and not stomatal regulation limits photosynthesis in K deficient crop plants. Frontiers of Potassium Science Conference, Rome, Italy, 25.–27. January 2017.

Lingner, A. and K. Dittert (2017) Remote sensing of productivity and water use in legume-based mixed cropping systems. 60. Tagung der Gesellschaft für Pflanzenbauwissenschaften, Witzenhausen, Germany, 26.–28. September 2017.

Lingner, A., B. Pfeiffer and K. Dittert (2017) Winter faba bean growth in pure and mixed stands under water deficit conditions in the greenhouse. Plant 2030 Status Seminar, Potsdam, Germany, 20.–22. February 2017.

Lingner, A., B. Pfeiffer and K. Dittert (2017) Performance and drought stress response of winter faba bean genotypes in mixed cropping with winter wheat. XVIII. International Plant Nutrition Colloquium (IPNC), Copenhagen, Denmark, 21.–24. August 2017.

Tränkner, M., M. Senbayram, B. Jákli, S. Halicki, K. Dittert and C. Zörb (2017) Comparative study on proteome changes in response to potassium deficiency and drought in *Triticum aestivum* roots. Frontiers of Potassium Science Conference, Rome, Italy, 25.–27. January 2017.

Tränkner, M., E. Tavakol, B. Jákli and K. Dittert (2017): Photoprotective responses and PSII functionality under Mg deficiency. XVIII. International Plant Nutrition Colloquium (IPNC), Copenhagen, Denmark, 21.–24. August 2017.

Cooperation

In Science

Partner	Location
Al-Quds Open University	Jerusalem, Palestine
Bodengesundheitsdienst	Ochsenfurt, Germany
Bordeaux Sciences Agro – INRA	Bordeaux, France
Chamber of Agriculture	Hannover and Oldenburg, Germany
China Agricultural University	Beijing, China
CIP International Potato Center, Central Africa Branch	Nairobi, Kenya
Deutsche Landwirtschafts-Gesellschaft (DLG)	Frankfurt/Bernburg, Germany
Deutscher Wetterdienst	Leipzig, Germany
Ege University, Department of Soil Science and Plant Nutrition	Izmir/Turkey
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
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