IAPN
INSTITUTE OF
APPLIED PLANT NUTRITION

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RESEARCH ON SUSTAINABLE PLANT NUTRITION

Imprint

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Institute of Applied Plant Nutrition (IAPN)

at Georg-August-University of Göttingen

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Preface

What are the functions of mineral elements in drought stressed crop plants? Why is there reduced tolerance to oxidative stress in crop plants when there is nutrient deficiency? How to improve the use efficiency of water in crop plants? Which are the most promising tools to identify latent nutrient deficiency at early stages? Researchers and students at the Institute of Applied Plant Nutrition study questions like these and they aim at improving and disseminating the knowledge about resource use efficient and sustainable plant nutrition and also at developing new ideas for better growing crop plants in different environments.

The following report will introduce you to IAPN's science, the people behind, their projects, their methods and their motivations. We'd like to bring you in touch with applied research questions and scientific work that addresses basic questions. Studies contribute to basic knowledge about the role of minerals in plant stress response and about their functions in primary production through photosynthesis and in plant-water relationships, in particular plant transpiration. You may read about IAPN's university teaching and knowledge transfer and discussion activities.

We have compiled a flying visit across our activities and we offer you some glances behind IAPN's curtains, hoping that you will find it an interesting and inspiring reading.

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 and critically reflecting 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 established. In many respects there are no visible differences between IAPN activities and facilities and those of University departments. Researchers and students are busy on their projects and during teaching periods numerous students assist and 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.

2015 was a year of quite some change at IAPN. In early spring, the research project "Novel genotypes for mixed cropping allow for IMProved sustainable land use ACross arable land, grassland and woodland IMPAC³" went into action. Within this large research consortium at Göttingen University, the IAPN's subproject focusses on 'Traits for water and nutrient use in mono and mix-cropping systems'. Mrs. Annika Lingner was appointed as PhD student in this project and rapidly, she established new remote sensing methods for use in this project. In September 2015, IAPN co-organized the Annual Conference of the German Society of Plant Nutrition which addressed "Soil, Nutrients, Water – Research for Sustainable and Efficient Use of Resources".

A major change in 2015 took place in July. After three years of very successful research and teaching at IAPN, Junior Professor Dr. Senbayram followed a call to Harran University, Sanliurfa, Turkey. Here, very close to his personal roots, he has found a new basis to continue his university research and teaching career and to develop the Institute of Plant Nutrition and Soil Science. IAPN is very thankful to him and our farewell goes along with our best wishes for his personal and professional future.

In the IAPN greenhouse, plants are being grown in nutrient solution (left), which allows precise control of nutrients and water. Each pot is positioned on a set of scales, which allows scientists to precisely determine water usage. (Photo: Herwig)

IAPN's Objectives

IAPN's objectives are to conduct scientific research and to contribute to closing such 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. This transfer 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. IAPN receives a large number of inquiries for internships. However each year, some young colleagues with good potentials and backgrounds that match IAPN's expertise pass two to three months internships. Here they get involved with our research and discuss the needs of their own particular project.

The IAPN Team

In 2015, the team of IAPN consisted of eight members in administration, technical and laboratory assistance and scientific staff. The institute is headed by Professor Klaus Dittert and until July there was also Junior Professor Mehmet Senbayram at IAPN supervising his junior research group within IAPN. While his tight contacts and projects continue, Mehmet Senbayram himself left the IAPN in summer 2015 to follow a call to Harran University, Sanliurfa, Turkey.

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.

Dr. Birgit Pfeiffer, a specialist in soil microbiology, joined the IAPN team for a few months to investigate the role and diversity of microbial communities in cultivated soils which interact with growing plants and their nutritional status. Merle Tränkner, PhD student at IAPN, conducted an external research stay at Justus-Liebig-University Gießen, Section of Plant Nutrition in 2015, in which she complemented plant physiological studies that she had carried out in her first PhD years. Bálint Jákli and Ershad Tavakol, PhD students in the IAPN project "Potential for enhancing water use efficiency and drought-stress tolerance in agricultural crops through improved fertilizer management systems, with particular consideration of physicochemical soil processes", continued their research activities as detailed in later sections of this report. Annika Lingner in the second 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" brought forward her greenhouse and particularly her field experiments which will also be described in later sections.

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.

Successful partnership: Staff and visitors of the IAPN, dean and vice dean of the Faculty of Agricultural Sciences of the Georg-August-University and representatives of K+S KALI GmbH at a meeting in Göttingen. (Photo: Dach)

Team of the IAPN (left to right): Kirsten Fladung, Ershad Tavakol, Ulrike Kierbaum, Klaus Dittert, Merle Tränkner, Annika Lingner, Bálint Jákli, Martina Renneberg. (Photo: Herwig)

Professor Klaus Dittert and technical assistant Ulrike Kierbaum discuss a running experiment in the IAPN´s greenhouse. (Photo: Herwig)

Research at IAPN

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.

On this background, it is IAPN's mission to work at the interface of plant nutrition and plant-water relations. In the year 2000, at the Millennium Conference, Kofi Annan, Secretary General of the United Nations, explained that the 21st century must be the century of the blue revolution in agriculture and his words that, globally we need 'More Crop per Drop' reached every nations policy. Knowledge-based plant nutrition can make a significant contribution to this, and IAPN aims at providing and disseminating the plant physiological knowledge for it. There is solid evidence for nutrient effects on water use efficiency and drought resistance but, our research conducted in previous years also taught us that plants respond in different ways at different scales and similar to other responses in crop physiology, there are physiological compensation mechanisms that need to be considered. So there is some way to go. IAPN's team works at a range of different aspects from molecular changes at the sub-cellular level, e.g. anti-oxidant gene expression, to unmanned airborne vehicles that carry camera systems which look at crop plant stands throughout the growing cycle to identify key indicators and key periods of susceptibility or tolerance to drought. In many respects the projects are now quite advanced. The following pages will introduce you to some of our most interesting approaches and findings.

IAPN Topics

In late 2012/early 2013, Merle Tränkner, Ershad Tavakol and Bálint Jákli started their PhD projects at IAPN. Their research focuses on the effects of magnesium and potassium fertilization on water use efficiency and drought tolerance of crops. Since the concept of IAPN research comprises a systematic multiscale approach, the studies are conducted on eco- and plant physiological as well as on proteomic and genomic levels. In 2014, Annika Lingner started her PhD at IAPN within the multidisciplinary IMPAC^3 project. The following section will provide insight into their PhD research activities in 2015.

Physiological changes in response to magnesium deficiency in sugar beet
(Merle Tränkner, M.Sc.)

Introduction

Magnesium (Mg) nutrition is of major importance in agricultural plant production as magnesium is needed for an appropriate nutritional balance. Mg is one of the most abundant cations in the plant cell and functions as activator of numerous enzymes. It is also assumed to be involved in the translocation of assimilates. Assimilates such as sugars are mainly produced in leaves, characterized by a high rate of photosynthesis. These assimilates have to be transported into young, growing plant organs which is achieved by a process called phloem loading, i.e. sugars are translocated into the phloem to facilitate their translocation within the plant. Phloem loading involves the activity of the enzyme ATPase, which requires Mg for its activation. Under conditions of Mg deficiency, phloem loading might be impaired and thus, sugars accumulate in leaves and are not available in the young, growing parts of the plant. While it is well known that crop biomass production is reduced under Mg deficiency, there is little knowledge about the physiological effects related to assimilate translocation and specifically ATPase activity.

Research activities in 2015

In order to study the possible Mg effects, a research cooperation of IAPN and the Section of Plant Nutrition at the University of Gießen, headed by Prof. Sven Schubert, was established at the end of 2014 and Merle Tränkner was hosted as a visiting PhD student in Gießen since the beginning of 2015. In this context, two experiments were conducted with sugar beet. The first experiment aimed at defining the critical time point when first physiological changes occur in progressing Mg deficiency. The second experiment was focused on changes of ATPase expression patterns. For this purpose, sugar beet plants were cultivated under Mg deficiency and harvested in 3-day intervals. Several physiological and agronomical parameters, such as biomass production and chlorophyll concentrations, were assessed. This approach allowed a dynamic overview on the chronological responses within the respective parameter as well as across the different parameters. After having defined the critical time point based on the obtained dataset, a second experiment was established. Sugar beet plants were cultivated under the same conditions as before and differences in the expression of ATPase isoforms were studied. RNA was extracted from plant tissue samples of three different plant organs. Analysis of ATPase expression differences was done by qPCR. This work is continued in 2016.

Symptoms of Mg deficiency on a specimen of the 2nd leaf pair of sugar beet after 25 days of Mg deficiency. (Photo: Tränkner)

Sugar beet cultivation in the climate chamber at Gießen University. (Photo: Tränkner)

The importance of magnesium and potassium in plant-water relations

Drought stress leads to enormous yield reductions and in many situations this might be partly compensated by proper fertilizer management. In this respect, adequate magnesium (Mg) and potassium (K) fertilization are indispensable since they are two essential macro nutrients for plants. Especially in drought situations, physiological changes might occur as plants adapt to varying environmental conditions. For instance, potassium uptake is achieved by K+ channels and K+ co-transporters in the root and, the root system is the first plant organ sensing drought. Hence, adaptation responses in the root due to drought and potassium deficiency are likely to occur.

Achievements in 2014 and activities in 2015

One of the main research targets in 2014 was to elucidate the adaptation of roots to drought and potassium deficiency by altering the protein content and composition, the so called "proteome". To this end, wheat was grown in nutrient solution under various levels of K supply and either drought or non-drought treated. Subsequently, the root proteome was separated by means of 2-dimensional-electrophoresis. In 2015, the obtained data were analysed in a specific proteomics analysis software and detection of significantly affected proteins was performed. These studies were done in cooperation with Prof. Christian Zörb, head of the section of Quality of Plant Products at University Hohenheim.

Another important target in the research year 2014 was the examination of changes in the water use efficiency (WUE) as influenced by a variation in Mg supply and to identify causes of eventual changes. For this purpose, an experiment with barley was conducted to test the influence of Mg fertilization on water use efficiency and physiological parameters reflecting photosynthetic capacity. Barley plants were supplied with different Mg levels ranging from highly deficient to adequate supply. Data analysis was finished in 2015 and a report paper was submitted for publication. Parts of the results were presented at the annual meeting of the German Society of Plant Nutrition.

Effects of potassium nutrition on crop water use efficiency – a line of ecophysiological studies addressing their scale dependency

(Bálint Jákli, M.Sc.)

The importance of potassium in plant-water relations

The potassium cation (K+) is the most abundant inorganic osmolyte in plants. It plays a crucial role in plant-water relations and facilitates the adaptation of plants to environmental stress. Potassium also has important functions in maintaining optimal rates of photosynthesis and in the translocation of photo-assimilates and metabolites from source organs to the growing tissue. Water use efficiency (WUE) as the ratio of biomass production to water consumption is therefore positively affected by an adequate K availability in soils. Mild K deficiency might not show any visible symptoms under optimal environmental conditions, but will reduce crop yield under stress conditions like drought.

The role of potassium in photosynthesis

The beneficial effect of K on photosynthesis has been studied intensively throughout the recent decades. However, the associated physiological and biochemical mechanisms are complex and not yet completely identified. In 2014/15, a series of experiments were conducted in the IAPN greenhouse, where sunflower plants were grown under varying K supply. The aim of these studies was to investigate whether K nutrition is directly affecting photosynthesis, or whether beneficial effects of K on photosynthesis are indirect (e.g. by facilitating the diffusion of CO_2 from the atmosphere into the leaf and further into the chloroplasts, where photosynthesis is taking place).

Plant carbon losses reduce effective water use efficiency

First studies in 2013 indicated that the WUE of a single leaf (i.e., leaf-WUE) is not necessarily reflecting WUE of the entire plant (plant-WUE). Leaf-WUE is calculated as the instantaneous ratio of carbon assimilation to transpiration during photosynthetic leaf gas exchange. During normal metabolic operation, plants also release carbon as CO_2, a process called respiration. Major sources of plants' CO_2 release are not included in calculations of leaf-WUE. This applies for example to respiration during the night, root respiration and exudation of organic compounds from the root system. The question arises, whether K deficiency promotes respiration. Enhanced respiration reduces plant-WUE, but cannot be detected by leaf-scale measurements during the day. To answer this, experiments were carried out in cooperation with Elsa Martineau (INRA Centre de Bordeaux Aquitaine, Bordeaux, France) at the IAPN facilities. The effects of K nutrition on daily patterns of photosynthesis, nocturnal respiration, root respiration and root exudation where studied in detail on two contrasting crop plants (sunflower and wheat). In the course of this cooperation, much experimental and analytical work was done by Nick Nöhren (B.Sc.), who – based on these experiments – compiled his master thesis in Agricultural Sciences at the University of Göttingen in this project.

Measurement of leaf gas exchange (GFS 3000, Walz, Germany) of sunflower grown in the IAPN greenhouse. (Photo: Jákli)

Measuring canopy water use efficiency using a custom-built chamber in combination with the GFS-3000 gas flux analyser (Walz, Germany) of field-grown sugar beet at the SKW Piesteritz experimental site in Cunnersdorf, Saxony. (Photo: Meyer zur Müdehorst)

Assessing WUE in the field

The systematic approach of WUE studies done at IAPN, aims at revealing fundamental physiological processes that are affected by K nutrition. Therefore, during initial experiments, plants were grown in nutrient solution in the greenhouse. These very simplified systems allow a precise control of environmental conditions and, therefore, a straight-forward interpretation of the results obtained. However, most of our crops are commercially grown under field conditions where K fertilization is only a single aspect within the plant-soil-atmosphere system. New technologies facilitate systematic studies that take into account the complexity of interactions within crop canopies. To evaluate effects of K fertilization on WUE in the field (i.e., canopy-WUE), a field trial was carried out at Cunnersdorf Experimental Station, Cunnersdorf, Saxony. The experimental site is managed by SKW Piesteritz and a long-term fertilizer experiment was established 25 years ago with four levels of K input (0, 60, 120, 180 kg ha^{-1}) based on a 4-year crop rotation (spring barley – potato – winter wheat – sugar beet). In 2014 and 2015, trials were conducted on wheat and sugar beet in close cooperation with Falk Böttcher of Germany's National Meteorological Service (Deutscher Wetter Dienst, DWD, Leipzig). In 2015, remote sensing of crop productivity (as measured by the NDVI index) and canopy transpiration (estimated by thermal imaging) was performed using a high-end quadrocopter (EagleLive Systems GmbH, Germany). To validate remote sensing data, canopy CO_2 uptake and evapotranspiration were measured on eight days during the vegetation period with a mobile non-steady-state chamber system. Additionally, soil water dynamics where monitored by soil sampling in weekly intervals. The practical work for the thesis of Johannes Meyer zur Müdehorst, master student of Agricultural Science at the University of Göttingen, was included in this project.

Non-destructive evaluation of sunflower leaf temperature by thermal imaging (T640, FLIR, USA) in the IAPN greenhouse. (Photo: Jákli)

Outlook for 2016

The methods for qualitative and quantitative studies on WUE that have been successfully established at IAPN during the recent years allowed the systematic investigation of the effects of K on WUE across temporal and spatial scales. The most prominent task remaining is the publication of the main findings in peer-reviewed scientific journals. A first manuscript ("Adequate supply of potassium improves plant water use efficiency but not leaf water use efficiency of spring wheat") has been submitted in October 2015.

Physiological and molecular responses of crop plants to potassium deficiency and drought stress (Ershad Tavakol, M.Sc.)

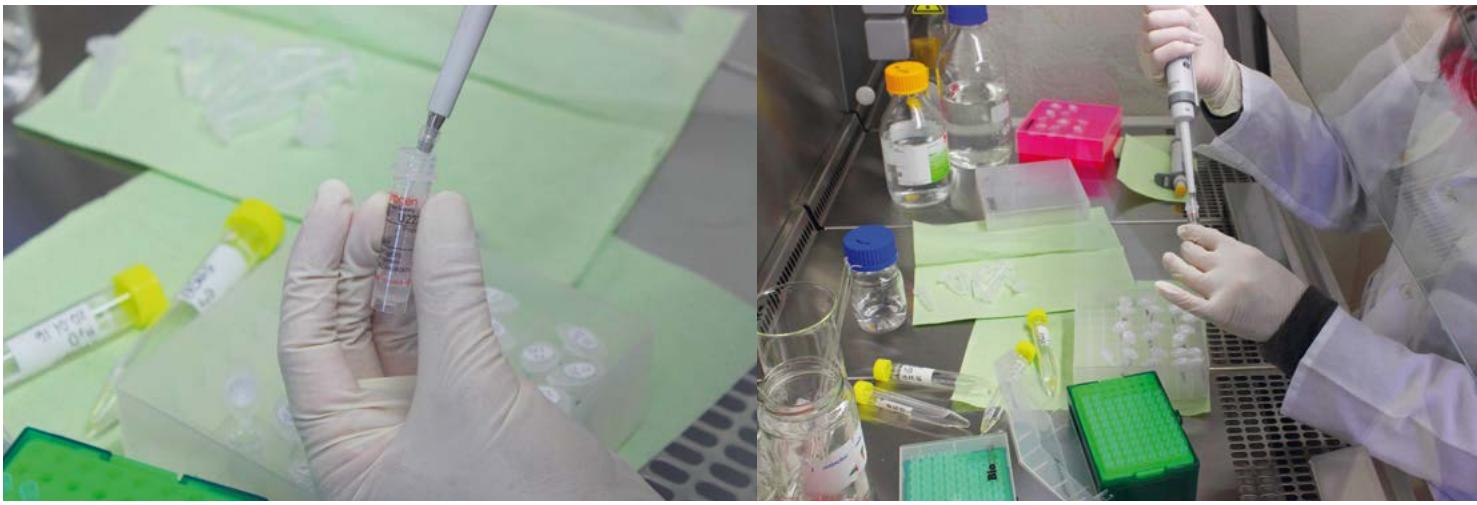
Introduction

Complementary to the eco-physiological studies of Bálint Jákli on the relation between potassium (K) nutrition and the adaption of crops to unfavourable environmental conditions, Ershad Tavakol's research targets the identification of molecular and genetic processes relevant for stress adaptation of crops. In this context, the fundamental role of adequate K nutrition in crucial processes like enzyme activation, the balancing of plant-water relations and the mitigation of oxidative stress are studied in detail.

Under a wide range of environmental stress conditions the formation of toxic compounds like reactive oxygen species (ROS) impedes the physiological functioning of the plant metabolism. These compounds are formed under conditions where the primary energy source of plants, i.e. the light emitted by the sun, cannot be sufficiently utilized during photosynthesis. ROS will react with cell membranes, cause degradation of chlorophyll and eventually cell death. Plants have developed numerous mechanisms to help in such situations. Among the most important are (i) to avoid excess formation of ROS by dissipating absorbed light energy by a process called non-photochemical quenching (NPQ) and (ii) to re-transform ROS to non-toxic compounds by enhancing the activity of enzymes involved in the detoxification process. The efficiency of these processes is highly affected by the K nutritional status. Since many stress reactions and adaptations are triggered on the genomic level, a major aim of these studies is the identification of gene expression levels specific to nature of combined K deficiency and drought stress.

Achievements in 2013 and 2014

The scientific evaluation of the dynamics and external influences on ROS formation and antioxidant activity requires the development of laboratory protocols based on spectrophotometry. In 2013, we established the required methodology with which the impact of different levels of K availability on the concentrations of the most important ROS (i.e. H_2O_2) as well as the main antioxidants were evaluated in a number of greenhouse experiments on wheat, barley, sugar beet and sunflower. It was shown that the amount of H_2O_2 was drastically enhanced under deficient K supply. Additional drought stress intensified the production of ROS. Under these adverse conditions, antioxidant activity increased to ensure plant survival but, under limited K supply, this strategy proved not efficient in the long-term and chlorosis symptoms appeared indicating severe chloroplast degradation. In 2014, additional experiments were performed on sunflower, field grown wheat and barley. In the case of barley intensive studies were conducted on two contrasting cultivars. In this project, the impact of a broad range of K supply levels in combination with drought stress on the dynamics of ROS production and the corresponding antioxidant activities were studied as well as the production of specific phytohormones related to stress adaptation. Furthermore, the beneficial effect of adequate K supply on drought signalling and adaptation as well as its role in enhancing plant water use efficiency was shown in the early stages of this study.



Preparation of RNA samples and PCR primers in order to confirm the activity of certain genes by real time PCR. (Photos: Tavakol)

Progress in 2015

Based on the observed differences in the physiological responses of the barley cultivars, a high-throughput RNA sequencing method was performed to reveal differences in the genetic responses of plants under different levels of K supply and additional drought stress. The rates of gene expression of numerous stress responding genes was shown to be significantly affected under these contrasting growth conditions. With drought, many genes related to photosynthesis appeared to be down-regulated while only a few were upregulated. In general, the changes in these expression levels contribute to the survival of the chloroplast and therefore ensure carbon assimilation and plant growth. On the other hand potassium transporters and signallers were highly affected under drought indicating that drought adaptation requires an improvement of the plant-water balance by enhancing absorption, transport and allocation of K.

Outlook for 2016

To promote a deeper understanding of the genomic response under the contrasting growth conditions, a comprehensive investigation of the results obtained from RNA sequencing is required. A systematic approach will help to identify novel genes which respond specifically to drought stress and K deprivation. Furthermore, visualization of the differentially expressed genes using state-of-the-art software will facilitate the interpretation of the genomic responses in barley. Following that, the expression of some targeted genes should be confirmed by real time PCR measurements which will help to verify the biochemical pathways and processes responsible for the specific genomic response under varying combinations of K supply and drought.

Water use efficiency and drought tolerance in mixed cropping systems (Annika Lingner, M.Sc.)

Introduction

Facing an ever growing world population, agricultural production has to keep pace with only limited options to extend the area under cultivation. Additionally, in the context of global change, regional precipitation patterns are predicted to undergo drastic changes. Thus in future, innovative concepts are needed to ensure the sustainability, resource efficiency and stress tolerance of agricultural systems.

While still being challenged for a number of reasons, a promising option for arable systems is the development and investigation of alternate cropping systems such as the cultivation of mixed crop stands. This approach implies the integration of multiple crops into a single canopy, where alternate rooting and stand architecture may increase the efficiency of both light and water use as well as nutrient uptake. It may furthermore reduce the incidence of pest and disease infestations. So as a result, lower needs for e.g. fertilizer and pesticide inputs are anticipated.

Faba bean, var. Hiverna, subject to one week with no, with mild, with medium or with severe water limitation (from left to right) after grown in nutrient solution (simulated water-limitation using PEG). (Photo: Lingner)

The IMPAC³ multidisciplinary project

In order to investigate the complexity of mixed cropping in different agricultural systems, a large field experiment was established in fall 2014 as a collaborative project with scientists of the faculties of Agriculture, Forestry and Biology at the University of Göttingen as well as with researchers from external plant breeding companies (**IMPAC³**: "Novel genotypes for mixed cropping allow for **IMP**roved sustainable land use **AC**ross arable land, grassland and woodland"). One

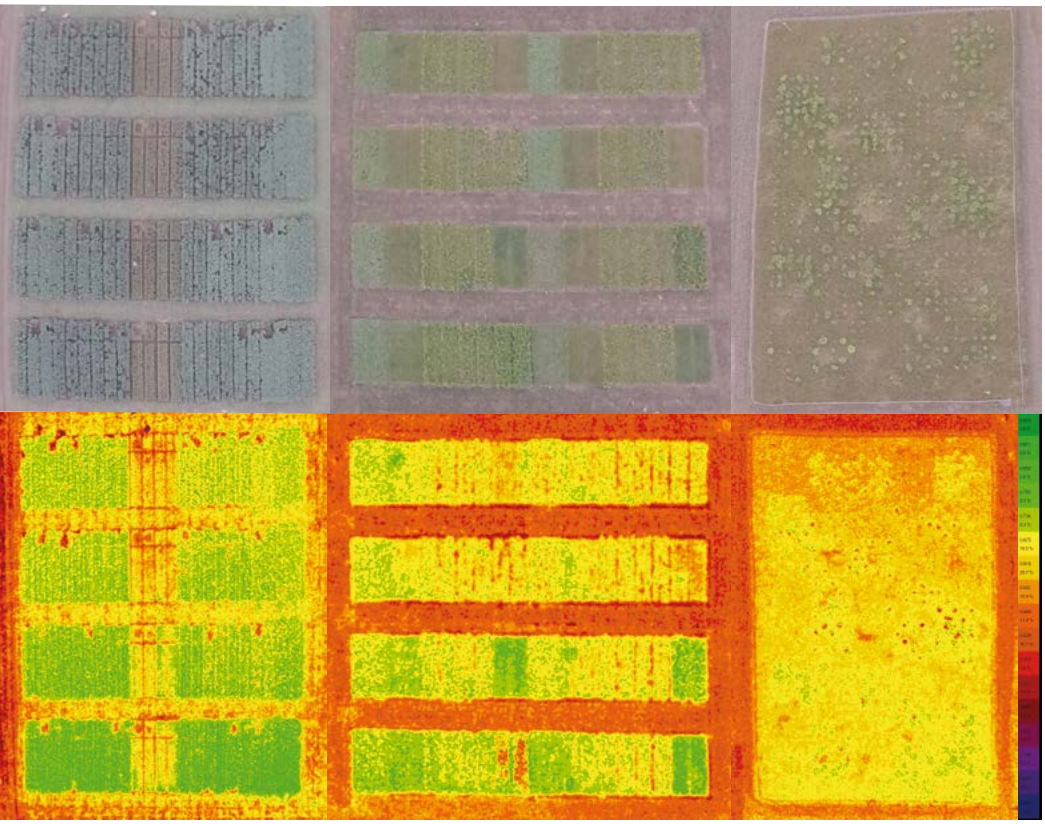
of the major goals is the identification of genotypes that show superior performance in mixed crop stands. In this framework, Annika Lingner studies the implications of mixed crop stands on canopy water use efficiency and drought tolerance.

Water use efficiency and drought tolerance in mixed cropping systems

For the evaluation of important crop stand characteristics, a quadrocopter (EagleLive Raptor, EagleLive Systems, Germany) was equipped with a multispectral camera system which is able to image visible and near-infrared properties of the crop stands at high spatial resolution. The collected data provide high-resolution Normalized Difference Vegetation Indices (NDVIs) which allow evaluation of biomass production und photosynthetic activity of different genotype combinations at the plot-scale. A thermal camera provides canopy surface temperature information for estimation of canopy water use. In addition, net CO_2 exchange, evapotranspiration and water use efficiency of the different crop stands are directly measured using a mobile canopy chamber. A first set of promising results were obtained in 2015.

Identification of stress tolerant genotypes

In order to identify genotype-specific physiological properties of stress adaptation, additional experiments were conducted in the IAPN greenhouse. Various genotypes of winter faba bean (Vicia faba L.) were cultivated and subject to mild, medium and severe drought stress. Genotype-specific quantification of CO_2 assimilation, transpiration and water use efficiency on the level of single leaves as well as chlorophyll fluorescence-based studies on the integrity of the photosynthetic apparatus were important research aims. Additionally, detailed studies on the expression of specific genes related to drought stress tolerance are scheduled for 2016.



Example of quadrocopter-based imagery (digital image above, NDVI below) of IMPAC³-experimental blocks comprising arable land, grassland and woodland (from left to right). Greener colors represent higher productivity. (Photo: Lingner)

Quadrocopter (EaglelLive Raptor, EagleLive Systems GmbH, Germany) for remote imaging of crop development and stress tolerance. (Photo: Lingner)

Knowledge Transfer

Teaching at the Georg-August-University of 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.

One of the topics available during the winter semester is the postgraduate module "Plant-Water-Nutrient Relations in Semi-arid and Arid Agriculture". In this module, students learn about water-shortage problems in crop cultivation (seasonal and temporary drought), CO_2 assimilation and transpiration in C3 and C4 plant species, nutrient cycles in semi-arid and arid climates and the influence of plant-water-nutrient relations on water usage efficiency. In the module's exercises, students become familiar with analysis methods for determining water-usage efficiency, gas exchange, thermography, chlorophyll fluorescence and working with stable isotopes or multi-spectral image analysis for water use efficiency research.

Of course, students have the option of doing their dissertations at the IAPN, at undergraduate, Master's and PhD level.

Completed Thesis in 2015

Tim Schaare, BSc Thesis (2015):
Einfluss pyrolytisch und hydrothermal veränderter Biomasse auf die Kohlenstoffdioxid- und Lachgasemissionen landwirtschaftlicher Böden

Haitao Wang, MSc Thesis (2015):
Einfluss der N- und C-Verfügbarkeit auf die N_2O-Emissionen nach Raps im Winter

Matthias Böldt, MSc Thesis (2015):
N_2O-Emissionen beim Rapsanbau in Abhängigkeit von N-Düngung und Strohapplikation – Ein Nachernteversuch auf einem südniedersächsischen Lössstandort

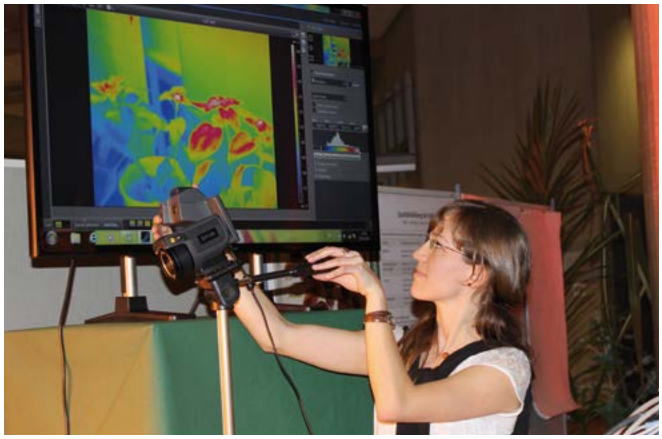
Junior Professor Dr. Mehmet Senbayram and MSc students discuss experiment results and the role of magnesium in sunflowers experiencing drought stress in pot experiments. (Photo: Schröder)

PhD student Ershad Tavakol and teaching assistant Ulrike Kierbaum demonstrate for MSc students how to measure hydrogen peroxide concentrations in damaged sunflower plant tissue. (Photo: Schröder)

Curious minds of all ages: IAPN Junior Professor Mehmet Senbayram explains his research on the nutrient supply of sunflowers. (Photo: IAPN)

IAPN joined Night of Knowledge on Göttingen Campus

On 17 January 2015 the 2nd Night of Knowledge was held on the Göttingen campus. The Institute of Applied Plant Nutrition joined in and provided exciting insights into its scientific work. "Without potassium sunflowers catch cold" was the motto of former IAPN Junior Professor Dr. Mehmet Senbayram and doctoral candidate Merle Tränkner when they offered glimpses into their research on the water use efficiency of crops. Using a thermal camera they displayed images of sunflowers especially raised for the Night of Knowledge. Sunflowers that were grown with low levels of potassium impressively showed lower leaf-surface-temperatures than plants with a good supply of potassium. In his well-attended presentation "Laughing Gas and Agriculture – Nothing to Laugh at" on the relevance and processes of nitrous oxide emissions from the soil, Prof. Dr. Klaus Dittert went into environmental impacts and agricultural management practices that influence the microbial soil processes producing this climate-relevant trace gas.



The colorful image on the screen is created by a thermal imaging camera, which translates the different leaf temperatures into different shades. (Photo: IAPN)

Not only plants have different temperatures: This is what the screen shows when the camera is directed at visitors. (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 June 2015 Falk Böttcher from the Deutscher Wetterdienst (DWD, "German Meteorological Service") visited IAPN. He described changes in the past and projected hydrological data and discussed their consequences for agriculture with participants at the event. In his presentation he covered extensive exploration of recent and long-term data on precipitation, soil moisture and evaporation.

Focusing on the Göttingen region, there are observations showing that there are significant increases in pre-summer aridity, which is leading to a significant reduction in soil moisture levels. This is because the measured evaporation from the crops examined (winter wheat and sugar beet) has hardly changed. This development is also expected to continue in the future, but the climate model does not show significant changes until the middle of the century.

"Keep calm and carry on" was Böttcher's answer to the question of what farmers in the Göttingen region should be preparing for. "It's too early to already be thinking about radical measures like installing irrigation equipment – that can be left to the next generation." However, farmers do need to be gearing up for more volatile precipitation patterns. He also said it was worth considering planting intercrops and a careful spreading of risk across the types of crops planted, or across different varieties of each crop.

Prof. Dr. Klaus Dittert introduces Falk Böttcher, agrometeorological specialist at the German Meteorological Service, as he begins his presentation. (Photo: Dach)

Falk Böttcher presents the differences between observed and predicted climate change. (Photo: Dach)

Agricultural research faces worldwide challenges: German Society for Plant Nutrition met at Göttingen University

From 15 to 18 September 2015 the 127th annual meeting of the Association of German Agricultural Analytic and Research Institutes (VDLUFA) was held at the University of Göttingen, preceding the 2015 annual meeting of the German Society for Plant Nutrition (DGP e.V.). The novelty in this case was that both events were linked by a joint workshop, headlined "Challenges and Synergies". Being the organizer of the 2015 annual meeting of the DGP and at the same time one of the initiators of the joint workshop with the VDLUFA, Prof. Dr. Klaus Dittert, Scientific Director of the IAPN and head of the Department of Crop Sciences at the Georg-August-University of Göttingen was glad to host these events. "We developed the idea of a joint workshop together with our colleagues at VDLUFA aiming to create a forum for participants of the two institutions to get to know each other, and to promote cooperation between basic sciences and VDLUFA", he explains. "The workshop therefore focused on the challenges that international agricultural research is facing today."

The challenges and requirements on plant nutrition, agricultural exploration and research in a globalized world were at the focus of a lecture by Prof. Dr. Bürkert, University of Kassel, Witzenhausen. In his presentation he clearly showed that increasing frequencies of extreme weather events and the deteriorating state of agricultural soils impose urgent demands on worldwide agricultural production as well as on applied research. Prof. Dr. Nicolaus von Wirén, Leibniz-Institute of Plant Genetics and Crop Plant Research, Gatersleben, outlined future challenges on crop plant research from a plant nutritionist's point of view, and he presented new options for improving nutrient use efficiency by applying novel plant breeding technologies. Prof. Dr. Christof Engels, Humboldt University of Berlin, emphasized the necessity of a "turn in the use of mineral matters" in plant production. Much greater efforts are needed in maintaining and increasing soil fertility, into sustainable growth of productivity and quality of plant products as well as minimizing leakage of minerals into the environment. Prof. Dr. Frank Wiesler, President of VDLUFA, provided an overview of VDLUFA activities. Based on a cooperative project on fertilization in Rhineland-Palatinate vegetable cultivation he went on to exemplify the manifold benefits of improved cooperation between universities and VDLUFA.

Opening event at the 2015 annual meeting of the DGP: the joint workshop with VDLUFA. (Photo: IAPN)

Bálint Jákli, doctoral researcher at IAPN, explained the relevance of potassium to optimizing water use efficiency and to drought adaption in plants. (Photo: IAPN)

One more important part of IAPN´s knowledge transfer activities: the International Symposium on Magnesium in Crop Production, Food Quality and Human Health

The first international symposium on the role of magnesium as a mineral crop nutrient for improving the quality of food products and for human health was held from 8-9 May 2012, and drew more than 120 participants from 30 countries. The conference was hosted by the Institute of Applied Plant Nutrition (IAPN) at the Georg-August-University of Göttingen. The symposium was intended to kick off an intense interdisciplinary discourse by internationally leading magnesium researchers.

Participants of the 1st International Symposium on Magnesium 2012 in Göttingen. (Photo: Herwig)

Participants of the 2nd International Symposium on Magnesium 2014 in São Paulo, Brazil. (Photo: IAPN)

The organizing team of the 2014 Magnesium Symposium: Luís Prochnow, Ismail Cakmak, Andrea Rosanoff, Klaus Dittert, Andreas Gransee (from left to right). (Photo: IAPN)

The interdisciplinary dialogue continues

At the 2nd International Symposium on Magnesium held with approximately 100 people in São Paulo, the importance of the element magnesium for the health of humans, animals and plants was discussed intensively for the first time in Brazil. Fertilization with magnesium has not as yet been customary in Brazilian agriculture, but so far, there is much evidence that the element's importance for soil fertility and the quality of the crops in Brazil is not adequately recognized. "The current situation in Brazil was an important reason for us to organize the second symposium on magnesium in Brazil", said Prof. Klaus Dittert, scientific director of the IAPN and co-organizer of the symposium. "With the symposium, we were able to initiate a dialogue together with our Brazilian research partners on the importance of magnesium in agriculture. It is very important to put the already available knowledge about magnesium fertilization into practice more intensively, but also to formulate open research questions jointly with national and local practitioners and scientists."

Guests at IAPN

The transfer of knowledge and building up of worldwide networks in the area of plant nutrition are important tasks of the IAPN. Visiting scientists and visiting students are therefore very welcome at the institute.

In 2015 five students spent time at IAPN for an internship:

- Selin Meral from Turkey
- Vilde Kaldhusdal from Norway
- Alaa Al-Lahham from Israel
- Mensah Kwabena Agyei from Ghana
- Petar Jovanovic from Serbia

Visiting researchers in 2015 were:

- Yasemin Ceylan from Turkey
- Di Wu from China
- Prof. Jehad Abbadi from Israel
- Elsa Martineau from France
- James Mugo from Kenya

Prof. Jehad Abbadi stayed at IAPN for the third time. He is an Associate Professor of Biology at the Al-Quds University in East Jerusalem, Palestine. Sponsored by the Al-Quds University, he conducted research at the IAPN for three months in summer 2015. As a visiting scientist, his work served to deepen and to evaluate studies that he had commenced within the scope of his previous research visits, which had been sponsored by the DAAD, on the effects of potassium on safflower and sunflower. In semi-arid regions, both of these plants are important oil crops. Due to their substantial demand for potassium, soil availability of K may not suffice to adequately nourish sunflowers and safflower – in particular when water gets short.

James Mugo works at the International Potato Center (CIP), Nairobi Branch, Kenya. He visited the IAPN for three months in winter 2015, in order to learn more about plant nutrition, fertilizer blend formation and on soil and plant analysis methods. Using these methods, he can identify the limiting nutrients on the farmers' fields and develop more demand-oriented fertilizer blends for highland regions. His work is part of the International Agricultural Research Development Program "Improved Soil Fertility Management for Sustainable Intensification in Potato Based Systems in Ethiopia and Kenya".

Publications

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

Cabeza, R.A., Liese, R., Fischinger, S.A., Sulieman, S., Avenhaus, U., Lingner, A., Hein, H., Koester, B., Baumgarten, V., Dittert, K. and Schulze, J. (2015) Long-term non-invasive and continuous measurements of legume nodule activity. Plant Journal 81, 637-648.

Geilfus, C.M., Niehaus, K., Godde, V., Hasler, M., Zörb, C., Gorzolka, K., Jezek, M., Senbayram, M., Ludwig-Müller, J. and Mühling, K.H. (2015) Fast responses of metabolites in Vicia faba L. to moderate NaCl stress. Plant Physiology and Biochemistry 92, 19-29.

Gong, X.Y., Fanselow, N., Dittert, K., Taube, F. and Lin, S. (2015) Response of primary production and biomass allocation to nitrogen and water supplementation along a grazing intensity gradient in semiarid grassland. Eur. J. Agron. 63, 27-35.

Köster, J.R., Cardenas, L., Bol, R., Lewicka-Szczebak, D., Senbayram, M., Well, R., Giesemann, A. and Dittert, K. (2015) Anaerobic digestates lower N_2O emissions compared to cattle slurry by affecting rate and product stoichiometry of denitrification – an N_2O isotopomer case study. Soil Biology & Biochemistry 84, 65-74.

Senbayram, M., Bol, R., Dixon, L., Fisher, A., Stevens, C., Quinton, J. and Fangueiro, D. (2015) Potential use of rare earth oxides as tracers of organic matter in grassland. J. Plant Nutr. Soil Sci. 178, 288-296.

Senbayram, M., Gransee, A., Wahle, V. and Thiel, H. (2015) Role of magnesium fertilisers in agriculture: plant-soil continuum. Crop & Pasture Science 66, 1219-1229.

Senbayram, M., Tränkner, M., Dittert, K. and Brück, H. (2015) Daytime leaf water use efficiency does not explain the relationship between plant N status and biomass water use efficiency of tobacco under non-limiting water supply. J. Plant Nutr. Soil Sci. 178, 682-692.

Tao, Y., Zhang, Y., Jin, X., Saiz, G., Jing, R., Guo, L., Liu, M., Shi, J., Zuo, Q., Tao, H., Butterbach-Bahl, K., Dittert, K. and Lin, S. (2015) More rice with less water – evaluation of yield and resource use efficiency in ground cover rice production system with transplanting. Eur. J. Agron. 68, 13-21.

Xiao, Q.Y., De Gernier, H., Kupcsik, L., De Pessemier, J., Dittert, K., Fladung, K., Verbruggen, N. and Hermans, C. (2015) Natural genetic variation of Arabidopsis thaliana root morphological response to magnesium supply. Crop & Pasture Science 66, 1249-1258.

Conference Papers – Posters

Claassen, N., W. Römer and K. Dittert (2015) Der Entwurf zur Novellierung der Düngeverordnung (DüV) trägt kaum dazu bei, die P-Belastung der Umwelt zu mindern. 127. VDLUFA-Congress, Göttingen, 15. – 18. September 2015.

Jákli, B. (2015) The role of potassium in optimizing water use efficiency and drought adaptation – from single leaves to whole plants. 45th Annual Conference 2015 "Ecology for a Sustainable Future" of the Ecological Society of Germany, Austria and Switzerland, Göttingen, 31. August – 4. September 2015.

Jákli, B. (2015) Der Einfluss von Kalium auf die Wassernutzungseffizienz von Weizen – vom einzelnen Blatt zur gesamten Pflanze. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Köbke, S., M. Senbayram, H. Hegewald, O. Christen and K. Dittert (2015) Ernteresiduen von Winterraps haben keinen Einfluss auf die Nachernte – N_2O-Emissionen im Bioenergie-Rapsanbau. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Lingner, A., K. Dittert, H. Steinmann, J. Isselstein, W. Link and M. Senbayram (2015) Traits for water and nutrient use in mixed cropping systems. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Rekate, F., M. Senbayram and K. Dittert (2015) HTC-Biokohlen als Bodenverbesserer – Einfluss variierter Prozesstemperaturen auf die Abgabe klimarelevanter Gase und die Stickstoffdynamik im Boden. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Rekate, F., J. Niemeyer, H. Wackerbarth and K. Dittert (2015) Raman-spektroskopische Analyse von pyrolytischen Biokohlen und deren Wechselwirkung mit Rinderserum-Albumin und Wyoming-Montmorillonit. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Römer, W., R. Hilmer, N. Claassen, N. Nöhren and K. Dittert (2015) Einfluss einer langjährigen P-Düngung auf Erträge und Dynamik der CAL-P-Gehalte in einem Lösslehmboden. 127. VDLUFA-Congress, Göttingen, 15. – 18. September 2015.

Tavakol, E. (2015) Physiological and molecular responses of barley to potassium deficiency and drought stress. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Tränkner, M., E. Tavakol, K. Dittert and M. Senbayram (2015) Photoprotective reactions of Mg deficient barley plants. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Yang, L., B. Steingrobe and K. Dittert (2015) Exudation of organic acids by sugar beet and implications on phosphorus availability. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Yueyue, T., S. Lin and K. Dittert (2015) Growth and photosynthetic activity of lowland rice as affected by nitrogen form and manganese availability. "DGP-Conference 2015 – Soils, nutrients, water – research on more sustainable and efficient use of resources" of the German Society of Plant Nutrition (DGP), Göttingen, 17. – 18. September 2015.

Cooperation

In Science

Partner	Location
Al-Quds Open University	Jerusalem, Palestine
Bodengesundheitsdienst	Ochsenfurt, Germany
Bordeaux Sciences Agro – INRA	Bordeaux, France
CIP International Potato Center, Central Africa Branch	Nairobi, Kenya
Deutsche Landwirtschafts-Gesellschaft (DLG)	Frankfurt/Bernburg, Germany
Ege University, Department of Soil Science and Plant Nutrition	Izmir/Turkey
Forschungszentrum Jülich, Institut für Bio- und Geowissenschaften, Agrosphere	Jülich, Germany
Harran University, Department of Soil Science and Plant Nutrition	Sanliurfa, Turkey
Institute of Sugar Beet Research (IfZ)	Göttingen, Germany
International Plant Nutrition Institute	George Town, Malaysia
K+S KALI GmbH	Kassel, Germany
K+S Analytik- und Forschungszentrum (AFZ)	Unterbreizbach, Germany
KWS SAAT SE	Einbeck, Germany
Land-Data GmbH	Visselhövede, Germany
Leuphana University of Lüneburg – Nachhaltige Landwirtschaft in der Region	Lüneburg, Germany
LUFA Nord-West, Institut für Düngemittel und Saatgut	Hameln, Germany
Norwegian University of Life Sciences, Nitrogen Group	As, Norway
Rothamsted Research, Sustainable Soils and Grassland Systems	North Wyke, UK
Sabanci University, Biological Sciences and Bioengineering Program at Sabanci University	Istanbul, Turkey
Sasakawa Africa Association	Kampala, Uganda
Thünen-Institute – Institute of Climate-Smart Agriculture	Braunschweig, Germany
University of Gießen, Institute of Plant Nutrition	Gießen, Germany
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 Verona, Department of Biotechnology	Verona, Italy
University of Western Australia, School of Plant Biology	Perth, Australia
Hanninghof Research Station – Yara Int. ASA	Dülmen, Germany

In Teaching

Prof. Holger Brück
YARA GmbH & Co. KG, Dülmen

Prof. Andrea Carminati
Georg-August-University of Göttingen

Dr. Hendrik Führs
Landwirtschaftskammer Niedersachsen

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