IAPN
INSTITUTE OF
APPLIED PLANT NUTRITION

ANNUAL REPORT 2016

RESEARCH ON SUSTAINABLE PLANT NUTRITION

Imprint

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Pictures: Herwig, Jákli, Lingner, Tavakol, Tränkner

September 2017

Institute of Applied Plant Nutrition (IAPN)

at Georg-August-University of Göttingen

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Preface

Dear reader,

in front of you is the annual report 2016 that covers a prosperous and fruitful year at IAPN. 2016's great highlight was the completion period of the first generation of young scientists who either finalized their dissertation projects or submitted their PhD thesis for defence in 2017. In the course of these activities many scientific results were published in international scientific journals on plant nutrition.

Spreading knowledge and exchanging scientific concepts was also continued in the series of seminars 'IAPN in Dialogue' which in 2016 featured two very important crops. In June four experts reported on current challenges in growing and nourishing potato crops in different environments, emphasing tropical highlands such as in Kenia. In December, "IAPN in Dialogue" that usually addresses young scientists' research activities and experiences, deviated from its tradition by inviting two experts with a long-term standing as internationally renowned scientists, representing two research organizations and programs with global impact, namely CIMMYT and Harvest Plus. Focus was given to current issues in wheat breeding and activities to improve micro-nutrient supply of wheat for regions on earth with larges shares of wheat in human diets.

The research infrastructure at the Department of Crop Sciences of University of Göttingen and at IAPN made another step forward. With active support of IAPN scientists, DFG and Lower Saxony funding for two new walk-in plant growth chambers was acquired.

One of the key administrative activities was the revision and renewal of the IAPN's cooperation agreement with the University of Göttingen in order to eliminate employment burdens and allow appointing a new candidate for the IAPN junior professorship. Also for this professorship, the position announcement and initiation of assessment process was done in 2016.

This annual report provides an overview about IAPN's scientific activities that cover many aspects of the role of mineral nutrients in plant stress physiology and their functions in plant growth and stress responses. These research fields remained IAPN's prime focus and they aim at contributing to growing healthy crops that are robust towards unfavourable growing conditions and that provide healthy food and feedstuff in a healthy environment.

Before recommending further reading, words of thankfulness go to a number of international visiting scientists and students who worked with us at IAPN; most enduring and with countless contributions we thank Prof. Ismail Cakmak who spent another year at IAPN. He joined many activities in research and university teaching and he gave much to the well-focused scientific atmosphere among IAPN staff and in contact with students from Germany and from abroad. His support is greatly acknowledged.

Hoping that you'll find interesting 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.

In October 2016, the contract of cooperation between Göttingen University and K+S KALI GmbH was extended for another six years. To the end of the year three PhD Students finished their studies successfully.

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.

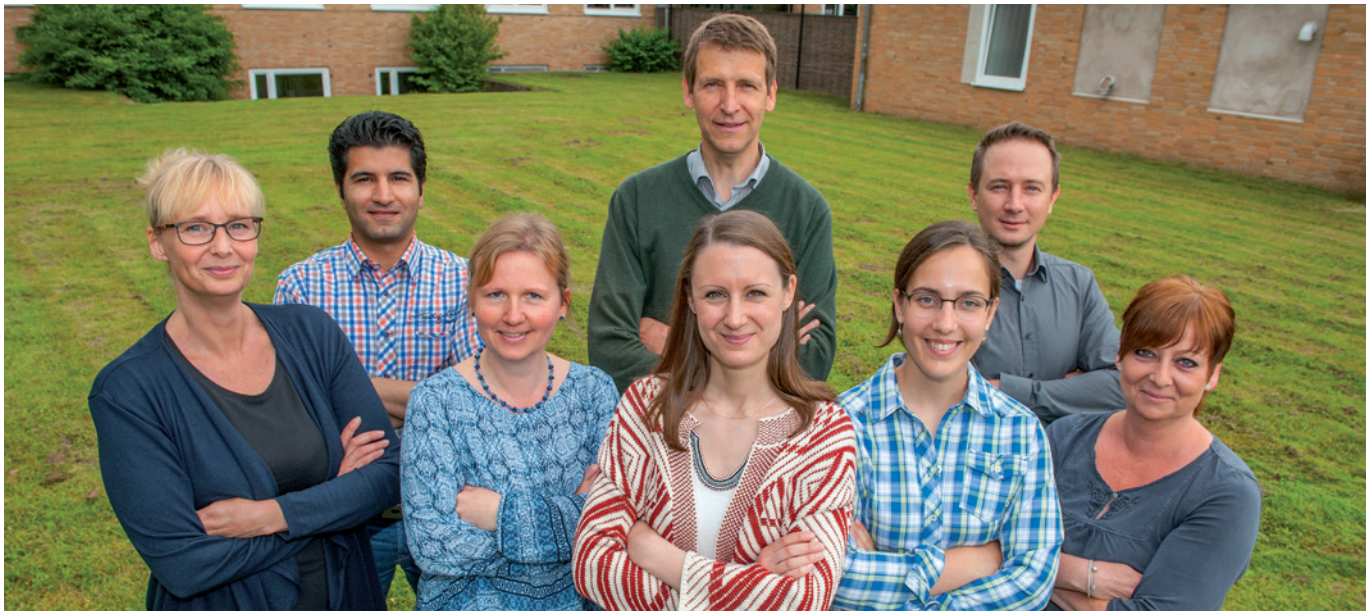
The IAPN Team

In 2016, 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.

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 ROS detoxifying enzymes.

In 2016, three PhD Students left the IAPN to the end of the year. Merle Tränkner, the first PhD student at IAPN, finalized her PhD studies and compiled her PhD thesis entitled "Magnesium, potassium and nitrogen deficiency-induced responses of crops and their impact on water-use efficiency – from protein to plant scale –". She successfully graduated in November 2016. Bálint Jákli also successfully graduated in November 2016 and published his PhD thesis, entitled "The relation between potassium nutrition and water-use efficiency of crop plants – Comparative studies from leaf to field scale", in December 2016. Ershad Tavakol has almost finished his PhD studies on "Physiological and molecular responses of contrasting barley cultivars to limitations of potassium and water availability" in 2016 and will be graduated in early 2017. Annika Lingner in the third 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.



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)

Good cooperation (left to right): Prof. Dr. Andreas Gransee, managing director of the IAPN, and Prof. Dr. Klaus Dittert, scientific director of the IAPN. (Photo: IAPN)

Punching of potato leave samples for the analysis of reactive oxygen species. (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.

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

IAPN Topics

Magnesium, potassium and nitrogen deficiency-induced responses of crops and their impact on water-use efficiency – from protein to plant scale – (PhD research project of Merle Tränkner, M.Sc.)

Introduction

Limitation of water is a worldwide constraint to crop production and thus improvements of water-use efficiency (WUE) are targeted by science and industry. Beside breeding efforts, plant nutrition management is an influential variable on WUE and different supply levels of plant nutrients can affect WUE. In this context, the PhD project of Merle Tränkner aimed at investigating the plant physiological reactions to Mg deficiency in barley and N deficiency in tobacco and the relation between WUE considering different levels of the plant, i.e. leaf-WUE (defined as the ratio between net CO_2 assimilation and stomatal conductance) and biomass-WUE (defined as plant dry matter production per unit of water loss via transpiration).

Experimental work on investigating water-use efficiency

In numerous experiments in which plants were cultivated in the greenhouse, parameters such as leaf gas exchange, whole plant transpiration and biomass production were measured and leaf-WUE and biomass-WUE calculated. The obtained results indicate a highly nutrient specific response of WUE as magnesium deficiency slightly increased leaf-WUE, but decreased biomass-WUE and contrastingly, N deficiency decreased leaf-WUE, but did not affect biomass-WUE.

Research on plant physiology and carbon partitioning influenced by magnesium fertilization

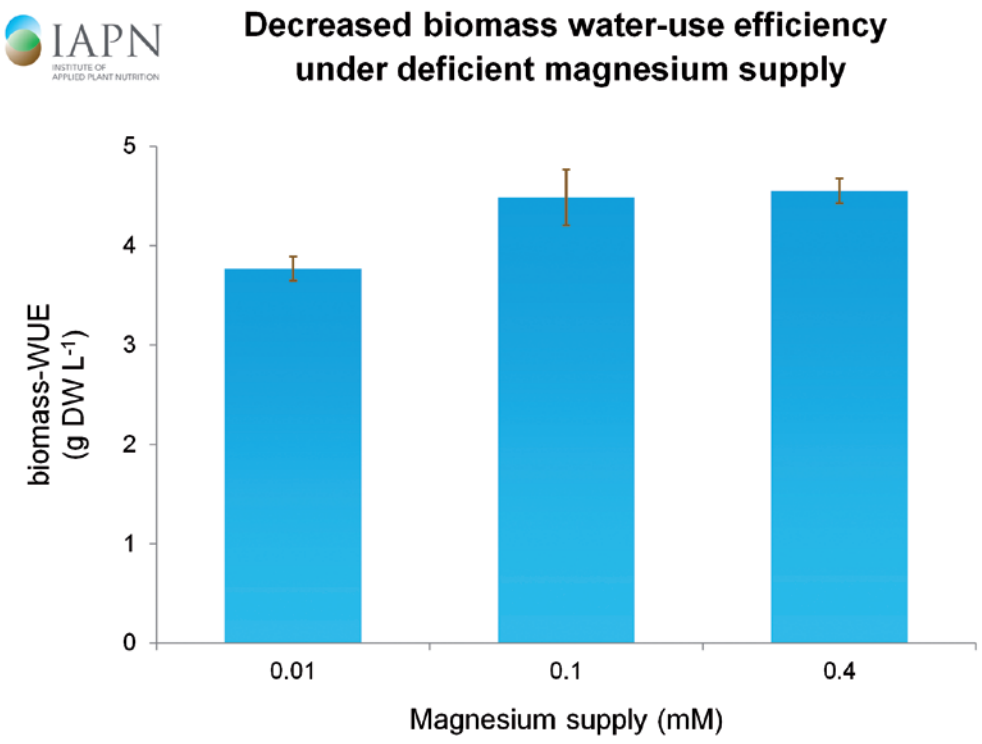
Beside these studies, Merle Tränkner analyzed the impact of magnesium deficiency on the level of oxidative stress in barley plants. Oxidative stress is characterized by the formation of reactive oxygen species, such as hydrogen peroxide, and enhanced antioxidant enzyme activity which were measured by intense laboratory studies. Magnesium deficiency remarkably increased the formation of ROS, although the activities of ROS antioxidant enzymes were highest. From this work, it can be concluded that severe magnesium deficiency exhausts the capacity of the antioxidative machinery to detoxify ROS and leads to severe oxidative stress in the plants.
It is well known that biomass production is reduced under Mg deficiency in numerous crops and that Mg deficiency negatively impact the translocation of assimilates (i.e. sugars) from leaves having a high rate of photosynthesis to young growing organs of the plant, but it is still under debate whether accumulation of sugars is the result of defective export from source leaves or limited carbohydrate use in sink leaves. Thus, a PhD project of Merle Tränkner investigated whether the inhibition of carbohydrate allocation under Mg deficiency originates from source leaves or from the sink tissues in sugar beet. A research cooperation of IAPN and the Section of Plant Nutrition at University Gießen, headed by Prof. Sven Schubert, was established at the end of 2014 and Merle Tränkner stayed for 1½ years as a guest PhD student in this working group to conduct the respective experiments and analyses.

Research on proteomic alterations under conditions of water-deficit and potassium deficiency

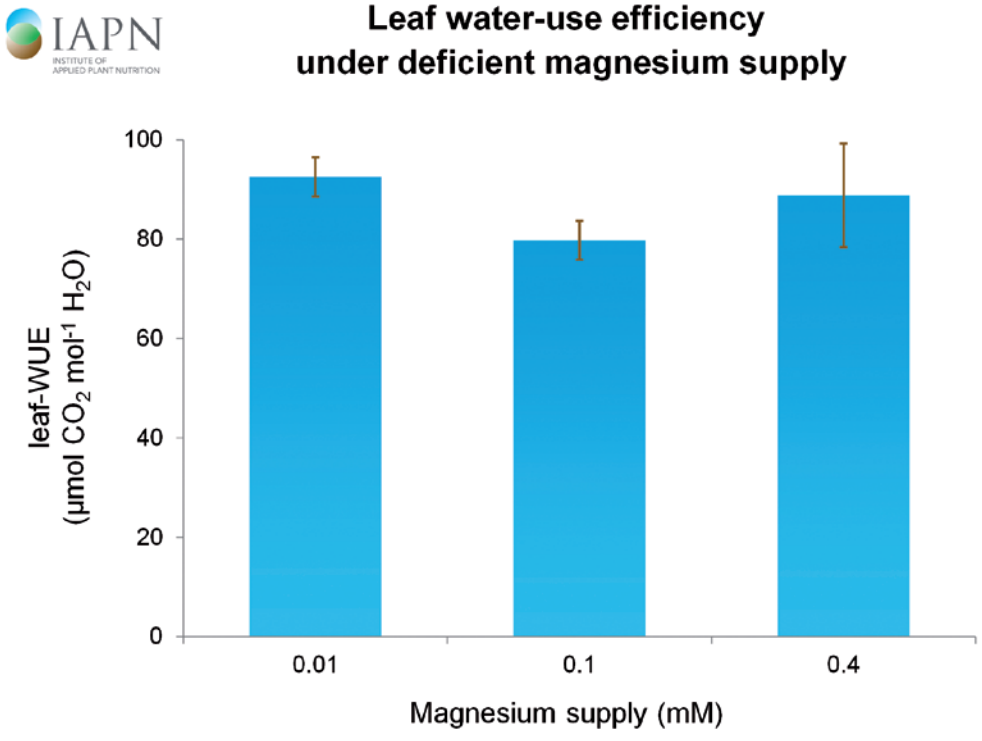
In a further PhD project, Merle Tränkner studied the proteomic alterations under conditions of water-deficit and potassium deficiency in roots of wheat to enhance the understanding of plant responses to drought and potassium deficiency. In this respect, she established the proteomic system in the laboratory of IAPN which allowed analyzing precisely the proteins after their extraction from wheat roots. The results showed that potassium deficiency and drought lead to changes in the expression of proteins which are involved general stress defense mechanisms. These studies were done in cooperation with Prof. Christian Zörb, head of the section of Quality of Plant Products at University Hohenheim.

Graduation

In 2016, Merle Tränkner finalized her PhD studies and compiled her PhD thesis, entitled "Magnesium, potassium and nitrogen deficiency-induced responses of crops and their impact on water-use efficiency – from protein to plant scale – ". She successfully graduated in November 2016.



Decreased biomass water-use efficiency under deficient magnesium supply. (Source: Tränkner, 2016)



Leaf water-use efficiency under deficient magnesium supply. (Source: Tränkner, 2016)

The relation between potassium nutrition and water-use efficiency of crop plants – Comparative studies from leaf to field scale

(PhD research project of Bálint Jákli, M.Sc.)

Introduction

The world's population presently experiences a period of unprecedented growth, increasing the need to further intensify agricultural production. At the same time, recent climate models predict shifting global precipitation patterns. Incidences and duration of drought periods will increase in many regions of the world, threatening agricultural productivity. Enhancing the water-use efficiency (WUE) of agricultural cropping systems is therefore a major research objective in water-limited environments. Generally, WUE is defined as the ratio of assimilated carbon to the amount of water lost by (evapo)transpiration and can be defined on the level of single leaves (WUE_L), individual plants (WUE_P), entire canopies (WUE_{Eco}) or, from an agronomic perspective, based on the harvested yield (WUE_{Yield}). Potassium (K), as one of the major mineral plant nutrients, is crucially involved in plant-water-relations and has the potential to enhance WUE. The impact of the amount of K that is available in the growth medium on crop WUE can substantially differ with respect to the spatio-temporal scale of its integration. In his PhD project, Bálint Jákli studied this multi-scale aspect and evaluated leaf to field scale WUE with respect to K nutrition. Particular focus was on the role of K in maintaining photosynthetic carbon assimilation.

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

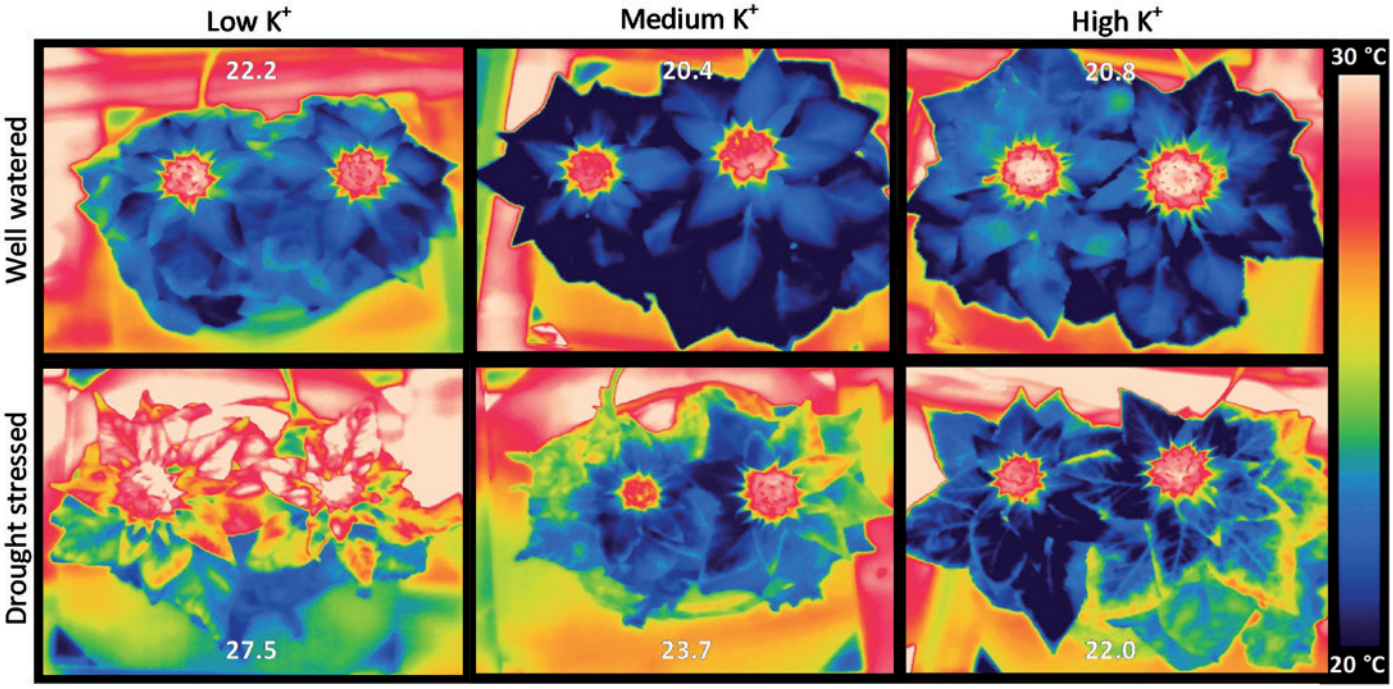
Research on water-use efficiency (WUE) considering different concepts of WUE

WUE_L was calculated from photosynthetic leaf gas exchange under greenhouse and field conditions or expressed as δ13C from the ratio of stable carbon isotopes in the dry matter of crops. WUE_P was calculated only for pot experiments as the ratio of dry matter accumulated to the amount of water used during the period of crop growth. Water use was therefore measured by continuous automated weighing of the pots. In field experiments, WUE_{Eco} was calculated from canopy gas exchange, which was measured using a mobile non-steady-state chamber system. Furthermore, WUE_{Yield} was determined by relating total biomass production or harvest yield to the amount of water lost from crop stands by evapotranspiration during the growing season.

Adequate K supply enhanced WUE_P of wheat (Triticum aestivum L. var. Sonett) and sunflower (Helianthus annuus L. var. Pacino) grown in nutrient solution up to 30 % and additionally up to 20 % under water deficit conditions (induced by addition of PEG 6000 to nutrient solutions), but had no effect on WUE_L.

Research on the limitation of photosynthetic CO_2 assimilation under potassium deficiency

A quantitative limitation analysis of photosynthetic CO_2 assimilation revealed that stomatal functioning was maintained under K deficiency and that, if water availability was not limiting, stomatal conductance was adjusted to meet the CO_2 demand of photosynthesis. The major limitation to assimilation was posed by CO_2 diffusion through the leaf mesophyll, which was drastically impaired in leaves of K deficient sunflower. On the field scale, K fertilization, relative to long-term omitted K fertilization, did not significantly alter net ecosystem exchange of CO_2, evapotranspiration and instantaneous WUE_{Eco} of sugar beet (Beta vulgaris L. var. Hannibal). However, K fertilization enhanced white sugar yield and therefore time-integrated WUE_{Yield}.



Thermal image of young sunflower plants. In the experiment, plants were grown hydroponically and subjected to different levels of potassium supply. Additionally, water deficit was induced by addition of PEG-6000. White numbers represent average leaf surface temperatures. (Source: Jákli, 2014, unpublished)

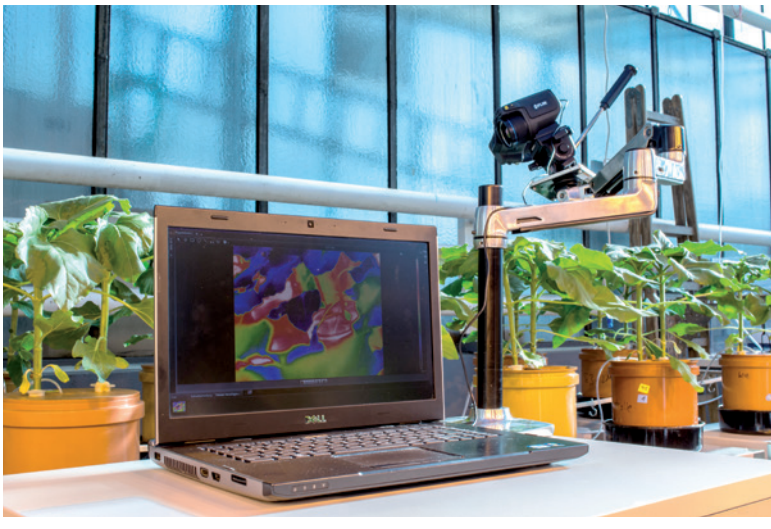
Major conclusions drawn from this project are that K deficiency triggers a reduction of mesophyll conductance to CO_2, most likely due to changes in leaf anatomy, which negatively affects carbon assimilation and causes the typical symptoms like oxidative stress, growth inhibition and reduced WUE_P. Differences between WUE_L and WUE_P arise from the fact that, in addition to photosynthetic leaf gas exchange, WUE_P also integrates water lost by transpiration during the night as well as dark respiration and root respiration. These factors can be substantially affected by K nutrition. Hence, leaf scale evaluations of WUE are not reliable in predicting WUE of crops suffering K deficiency on larger scales.

Final conclusion

It is finally concluded that WUE is determined by a vast number of interlinked (eco)physiological processes. K nutrition is only one of the many factors that can affect WUE and its potential to enhance the WUE of crop plants strongly depends on the scale of spatiotemporal integration.

Graduation

Bálint Jákli successfully graduated in November 2016 and published his PhD thesis, entitled "The relation between potassium nutrition and water-use efficiency of crop plants – Comparative studies from leaf to field scale", in December 2016.



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

Physiological and molecular responses of contrasting barley cultivars to limitations of potassium and water availability

(PhD research project of Ershad Tavakol, M.Sc.)

The concept

The world's climate is currently undergoing an era of rapid change, characterized by increased average temperatures and shifting precipitation patterns. Based on modelled predictions, there is an increasing risk of extreme drought incidences in many regions. Agriculture as the biggest consumer of water on this planet is therefore at high risk of losing productivity. The latter indicates that current agricultural practices are obliged to improve in order to keep up with the food demand in the future.

Plant drought stress responses affected by potassium nutrition

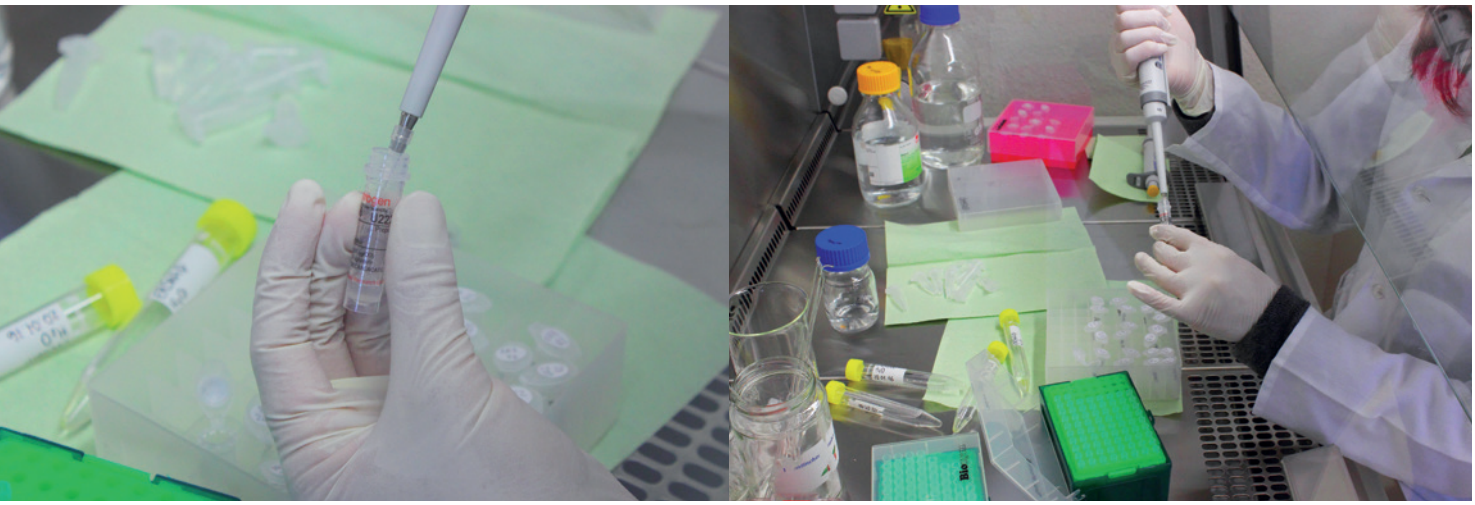
Studies show that plants try to cope with drought stress conditions by adjusting transpiration and simultaneously optimizing their carbon assimilation rates. In this context, the availability of nutrients to the plants is decisive for their performance. One of the necessary nutrients, which aids the osmoregulation in plants, is potassium (K). K is the most abundant cation in plants that plays a crucial role in stomata conductance, water-use efficiency (WUE) and assimilate translocation. However, physiological mechanisms underlying plant drought tolerance and improvement of water-use efficiency (WUE) by sufficient K supply are not completely understood. It is also known that there is high risk of photo-oxidation damage under drought stress initiated by toxic reactive oxygen species (ROS) which is mitigated by adequate K supply. However, the extent to which K supply can suppress ROS damage under drought stress is limitedly studied.

Studying the extent to which potassium can avoid or mitigate drought stress

In this context, the aim of the PhD study performed by Mr. Tavakol was to investigate the role of K supply on avoidance and defense measures taken by the plants to overcome drought stress and to elucidate these mechanisms from a molecular perspective. Additionally, his studied covered the role of K supply on plant growth characteristics. To this end, he applied multiple approaches comprised of studying plant water relations, ROS and antioxidant measurements and whole genome transcriptional profiling.

A multiple approach using biochemical assays, measurement of whole genome transcriptional responses and gas exchange analysis

In one of the most important experiments, Mr. Tavakol used two barley cultivars varying in drought tolerance (cv. Sahin-91 and cv. Milford). These plant material were treated with two K supply levels (0.04 and 0.8 mM K) and two osmotic stress conditions induced by polyethylene glycol 6000 (PEG) in the hydroponic culture. The direct effect of K supply and osmotic stress on a wide range of physiological characteristics such as kinetics of leaf area development, daily whole plant transpiration rate (DTR), stomatal conductance (g_s), assimilation (A_N), biomass and leaf water-use efficiency (WUE), abscisic acid (ABA) content, hydrogen peroxide (H_2O_2) concentration, super oxide (O_2^-) concentration, activities of ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), super oxide dismutase (SOD) and the respective gene expressions was studied. Based on the results of the mentioned measure-



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

ments, RNA of youngest fully expanded leaves was extracted and Massive Analysis of CDNA Ends (MACE) was performed to observe whole genomic transcriptional response of the selected treatments.

Potassium supply improves biomass water-use efficiency, avoids toxicity and enhances growth under osmotic stress conditions

The results showed that low K supply reduces dry matter (DM) by 53% and 66% in cv. Milford and Sahin-91 respectively, while drought induced PEG caused 47-51% reduction in DM of the respective cultivars. Overall, biomass-WUE under low K supply decreased significantly in both barley cultivars, being more pronounced under osmotic stress treatment. However, the experiment clearly showed that leaf-WUE was not affected by K supply. The study showed that leaf K content and ABA concentration were negatively correlated. ABA concentration was also negatively correlated with both leaf- and whole plant transpiration rates. This indicated that under osmotic stress conditions, potassium limitation increases ABA content and eventuates in reduced stomatal conductance and whole plant transpiration. H_2O_2 and O_2^- concentrations rose to 1.4 and 4.3 folds under low K supply respectively. However, limited antioxidant activity was observed under the latter conditions. Under PEG induced drought, there was a slight increase in antioxidant activity, nevertheless when PEG was combined with K deficient pots (low K +PEG), considerable augmentation of antioxidant activity was observed. This indicated that K supply under osmotic stress mitigates ROS damage mainly by avoiding its generation rather than improvement of antioxidant activity.

Sufficient K supplied plants respond to osmotic stress with less changes in the transcriptome level compared to low K treated ones

The whole genome transcriptional response showed that a considerable amount of entities were significantly up/down regulated under different K and PEG treatments. The highest amount of differentially expressed genes compared to control conditions (nearly 4000 entities) occurred under multiple stress (low K +PEG) conditions, which was nearly 3-4 times of the other two treatments (1-low K supply, 2-adequate K supply with PEG induced drought). This indicated that under osmotic stress, the deficiency of potassium causes severe stress to the plants and in order to survive, they have to suffer highest physiological changes compared to control conditions.

Expression of genes related to ABA biosynthesis and response to ABA under low potassium supply was negatively affected. In contrast, under osmotic stress conditions, a considerable upregulation in ABA biosynthesis was observed. Here, the expression of genes related to the light reactions of photosynthesis reduced proportionally according to the level of stress, being more affected by low K supply compared to sufficient K supplied plants. Therefore, it was suggested that under osmotic stress conditions, when plants are trying to avoid ROS production by avoiding energy absorption, optimized K supply allows them to absorb more light energy and properly consume it through improved photosynthesis. This eventuates in reduced ROS production under the latter conditions.

Overall, based on the results of the studies performed by Mr. Tavakol, he concluded that low biomass WUE under low K supply is not due to inefficient water loss through the stomata, but rather due to energy consumption for secondary compounds production. It was also hypothesized that increased respiration as well as changes in the leaf morphology could account for the reduced WUE under low K supply treatment. Additionally, it was concluded that under osmotic stress, switching low K supply to high K supply causes the plants to switch from a surviving strategy which is highly energy inefficient to a resistant strategy being highly energy efficient and aiding them in photosynthetic performance leading to limited yield losses.

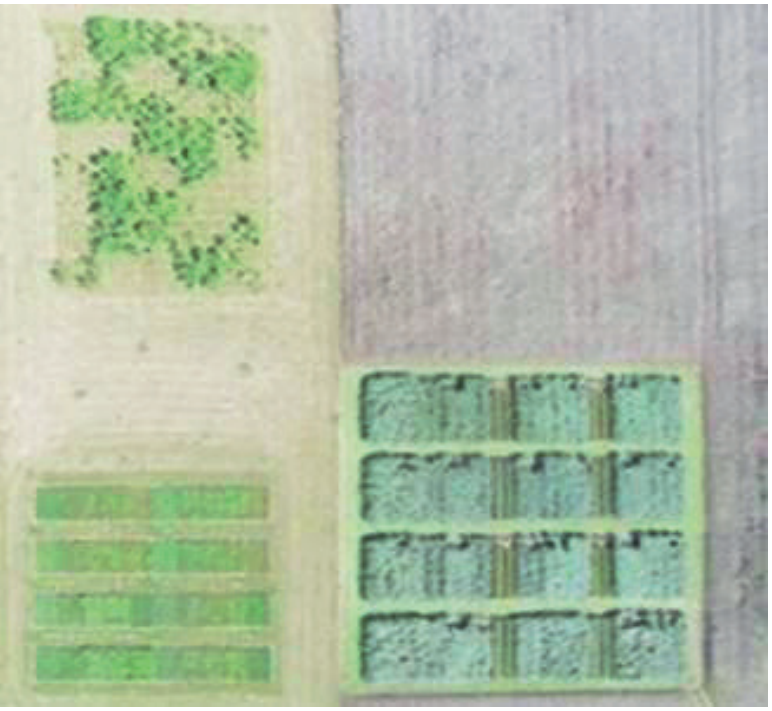
Mr. Tavakol has almost finished his PhD studies in 2016 and will be graduated in 2017.

Traits for water and nutrient use in mono and mix-cropping systems (PhD research project of Ms Annika Lingner, M.Sc.)

In future, there is a growing demand for improved concepts to ensure the productivity, sustainability, resource use efficiency and stress tolerance of agricultural systems. A promising option for arable systems is the development and investigation of alternate cropping systems such as the cultivation of mixed crop stands, where stand architecture and alternate rooting may increase the efficiency of both, light and water use as well as nutrient uptake. The intercropping of cereals with legumes is particularly common and introducing N_2-fixing legumes into cereal-based crop rotations may result in lower needs for mineral N fertilizer and reduced dependency on external inputs.

Improving water-use efficiency in mixed cropping

Thereby one of the major goals is the identification of genotypes that show superior performance in mixed crop stands. Simultaneously, knowledge of resource use efficiency (water, light and nutrients) is essential to understand the performance of mixed cropping systems which might lead to improved water-use efficiency. Also it is necessary to have a closer look at the physiological responses of plants under drought. In this framework, the implications of mixed crop stands on canopy water-use efficiency and drought tolerance are studied.



Field trials with legume-based mixed cropping in the land-use systems woodland (top left), grassland (bottom left) and arable land (right). (Photo: Lingner)

Remote sensing as useful tool

Within this context, mixtures of winter faba bean with winter wheat as well as white clover with ryegrass and cichory are compared to their respective pure stands in field experiments. For drone-based monitoring of these different crop stands in arable land and grassland new remote sensing methods were established. For the evaluation of important crop stand characteristics, a quadcopter (EagleLive Raptor, EagleLive Systems, Germany) was equipped with a multispectral camera system (ADC Micro, Tetracam Inc., California) which is able to image visible and near-infrared properties of the crop stands at high spatial resolution. The collected data allow evaluation of Normalized Difference Vegetation Indices (NDVIs) which provide information about biomass production und photosynthetic activity of different crop stands in the field within a short time frame. In parallel, a thermal camera (PI 400, optris, Germany) provides canopy surface temperature information for estimation of canopy water use.

The examination of crop stands throughout the growing cycle also focuses on identifying key indicators of tolerance to drought events. Therefore two separate approaches are used to measure the parameter water use efficiency (WUE) of each crop stand during the first two years of the field experiments. Stable isotope analysis (^{13}C) in plant tissues is used to measure intrinsic WUE in critical vegetation periods. In addition, net CO_2 exchange and evapotranspiration as assessed by gas exchange of the different crop stands are directly measured (GFS 3000, Heinz Walz GmbH, Germany) using a mobile canopy chamber.

Remote sensing of field trials via drone. (Photo: Herwig)

Winter faba bean and winter wheat in mixed stands under control conditions (left) and under water deficit (right). (Photo: Lingner)

Water deficit in the greenhouse

In order to identify genotype-specific physiological properties of stress adaptation and the tolerance of different winter faba been genotypes to temporal water deficit in more detail, additional experiments were conducted under controlled environmental conditions in the greenhouse. Various genotypes of winter faba bean (Vicia faba L.) were cultivated and subjected to drought stress. In a first set of experiments (Exp1) plants were grown in nutrient solution and water deficit was induced by adding PEG 6000 to the solutions. In a second set of experiments (Exp2) the performance of two of these genotypes (i.e., the most and the least tolerant) was tested in pure stands as well as in mixtures with winter wheat. Here, plants were grown in soil substrate and drought stress was induced by deficit irrigation.

Architecture of winter wheat and ryegrass determine correlation with NDVI

A first set of promising results was obtained in 2015. For this vegetation period it was shown by gas exchange measurements that in grassland, white clover was highest in net-photosynthesis and thus most efficient in water use while the mixture of white clover and ryegrass had lower water-use efficiency. Concurrently the arable crops had similar water-use efficiencies, only showing a tendency towards the end of the vegetation period that net-photosynthesis and therefore also water-use efficiency was higher in mixed cropping plots of winter faba bean and winter wheat.

Based on spectral screening of the crop stands via quadcopter the development of the vegetation was visualized. In arable crops during summer 2015 the NDVI images reflected lower values and thereby lower stand density in winter wheat while winter faba bean and their mixtures had significantly higher values and a later ripening. Correspondingly, confirming the hypothesis, the spectral indices of mixed stands in arable crops were markedly increased compared to the calculated theoretical mean of both pure stands. Grain yield correlation with NDVI of winter faba bean was restricted by a generally higher leaf area index: beyond a certain NDVI ceiling value (close to 1), the NDVI technology cannot distinguish differences in stands with very high biomasses. However, due to a generally lower leaf density in wheat stands compared to faba bean, NDVI values of winter wheat were reflecting grain yield the most. For 2016 there is a larger data set available to investigate the index development for the whole vegetation period during spring and summer showing an evolving curve starting from April, when soil cover is closed, to the ripening phase in July.

Also in grassland, mixtures of white clover and ryegrass had higher NDVI values than the calculated theoretical mean of monocultures. Still, after applying 240 kg N/ha to ryegrass highest NDVI values were obtained. Generally, the availability of nitrogen seems to have an important influence on the development of the spectral reflectance by the canopy. However, plant architecture plays another crucial role in the reflectance patterns. White clover, similar to winter faba bean, has horizontally orientated leaves which reduce the correlation effect of NDVI with dry matter yield. And, similar to winter wheat, ryegrass has erectophilic leaves which allow a higher correlation between NDVI and dry matter yield of fertilized and non-fertilized treatments.

Species mixtures promote biomass production

It was shown in the greenhouse Exp1 (conducted under controlled conditions in nutrient solution) that water deficit caused impaired production rates resulting in lower biomass and leaf area. Genotypes with highest and lowest biomass production were then tested for their performance in a mixed cropping system (Exp2). Here, one genotype showed higher biomass production in the mixture than in pure stands. Under deficit irrigation biomass was reduced in all treatments with no differences between mixed and pure stands. A detailed analysis of traits related to stress tolerance (e.g., physiology of leaf, and canopy gas exchange, water-use efficiency, oxidative stress) is currently performed.

Knowledge Transfer

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.

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 Göttingen agricultural sciences. (Photos: IAPN)

Completed Thesis in 2016

Jonas Lotze, BSc Thesis (2016):
Vergleich der Wassernutzungseffizienz von Reinsaaten und Gemengen in den Landnutzungssystemen Acker und Grasland

Johannes Meyer zur Müdehorst, MSc Thesis (2016):
K supply in sugar beet (Beta vulgaris L.) enhances yield formation, leaf area index and drought tolerance but did not affect leaf- or canopy-water-use efficiency in a long-term K depletion trial

Nick Nöhren, MSc Thesis (2016):
Einfluss von Blattgaswechsel und Atmungsprozessen auf die Wassernutzungseffizienz von Sonnenblumen und Weizen unter Kaliummangel und PEG-Stress

Vanessa Hanecke, BSc Thesis (2016):
TLS und digitale 3D Analyse von Sonnenblumen (Helianthus annuus) zur Untersuchung der Pflanzenarchitektur bei unterschiedlicher Kalium- und Wasserversorgung

Albert Bickert, BSc Thesis (2016):
Tageszeitliche und saisonale Dynamik der Wassernutzungseffizienz eines Gerstenbestandes unter differenzierter Kaliumversorgung

Astrid Christel Helga Jäger, BSc Thesis (2016):
Zusammenhang zwischen Infrarot-Thermografie und Intensitätswerten von TLS-Daten bei Sonnenblumen mit unterschiedlichen Wachstumsbedingungen

Sascha Braun, BSc Thesis (2016):
Physiologische Parameter der Trockenstresstoleranz von verschiedenen Genotypen der Winterackerbohne (Vicia faba L.)

Christian Wenthe, MSc Thesis (2016):
Remote sensing of legume based intercropping in arable land and grassland

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 practioners from around the world report about their projects. In 2016 two events of the series with international experts took place in Göttingen.

Potato Potentials in Africa

In June 2016 the event titled "Potato Potentials in Africa" and focused on the importance of potatoes as a means of fighting hunger and poverty in Africa. International lecturers met with students, scientists and other participants in order to discuss challenges such as the availability of know-how on potato-growing, access to means of production and the development of a stable value-added chain.

Florian Dieker introduced the topic by providing an overview of international potato cultivation, ranging from Ethiopian peasants to high-tech large-scale production in the US. Dieker, who earned his master's degree at the University of Göttingen, had embarked on what he termed his "Personal World Potato Tour" in 2013. "The challenges faced by potato farmers differ greatly from country to country, always depending on local conditions," said the potato-globetrotter. "There's a world of difference between the 47 tonnes on average per hectare harvested in the US, and the 11 tonnes on average harvested by an Ethiopian small farmer, whose situation is often exacerbated by extremely fluctuating yields."

Dr. Elmar Schulte-Geldermann from the Nairobi branch office of the International Potato Center (CIP) explained the relevance of potatoes for securing both food supply and income for African small farmers. In many African highland regions, potatoes are the second most important food after maize. In his talk, Schulte-Geldermann illustrated the importance of high-quality and regionally adapted seed potatoes and use of suitable varieties for improving potato cultivation. "Yield volume and quality largely depend on the quality and suitability of the seed potatoes used. The CIP's Seed Potato for Africa Program therefore aims at integrated measures in order to significantly raise seed quality in African potato cultivation. Without healthy seed potatoes other measures such as improved fertilization and harvesting techniques will not really take effect," Schulte-Geldermann explained.

The speakers and hosts (left to right): Elisabeth Morgen, Dr. Shamie Zingore, Dominik Fortenbacher, Prof. Dr. Klaus Dittert, Florian Dieker, Prof. Dr. Andreas Gransee, Dr. Elmar Schulte-Geldermann. (Photo: IAPN)

Caption: Dr. Shamie Zingore, IPNI. (Photo: IAPN)

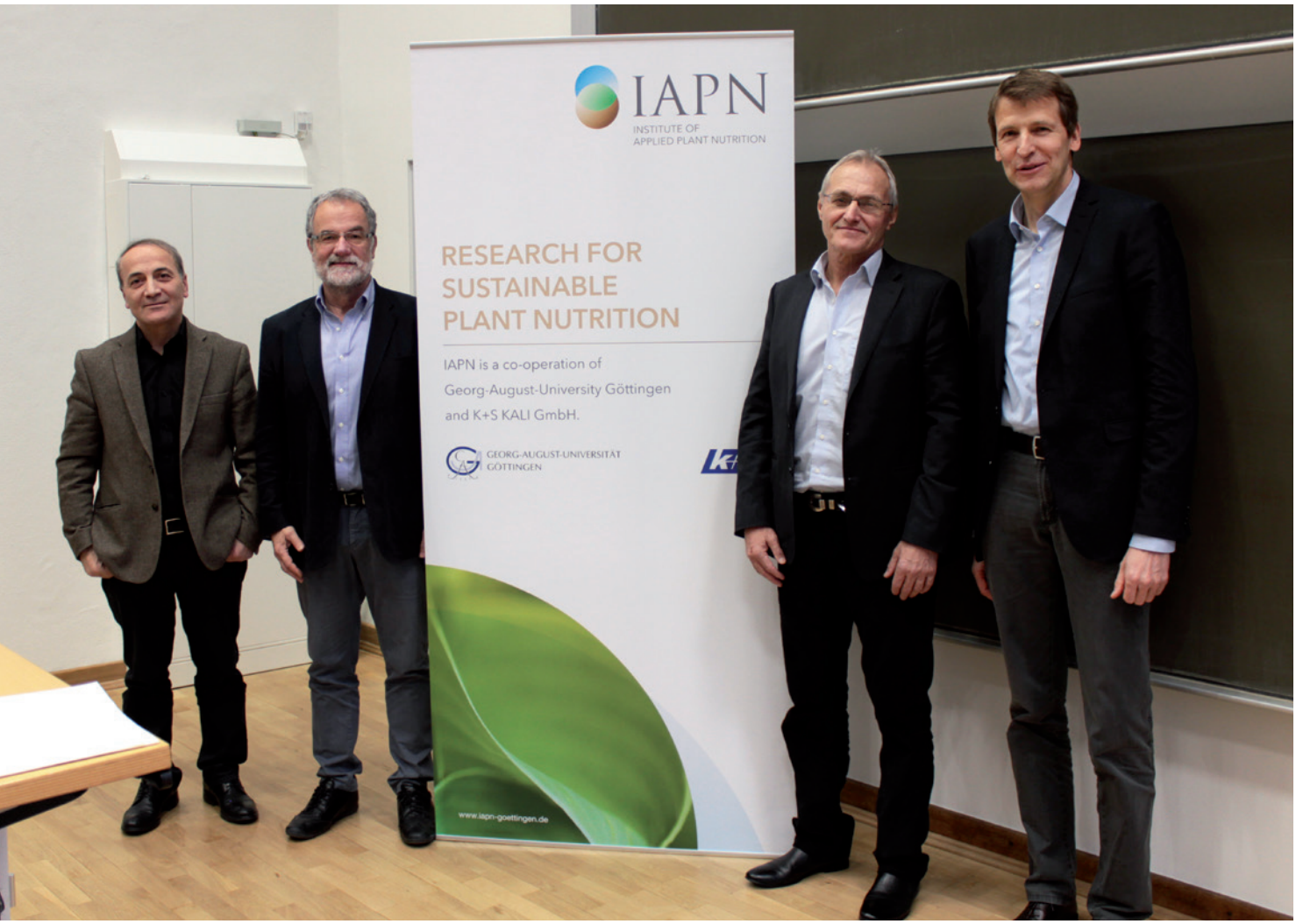
According to Dominik Fortenbacher from the Gesellschaft für Internationale Zusammenarbeit (GIZ) it is indispensable to look at the entire potato value-added chain, making improvements on a variety of levels. "There are several difficulties, beginning with deteriorating soil fertility and outdated cultivation techniques all the way to non-existing marketing standards. Regionally adapted solutions therefore need to address a great range of obstacles, and in order to do so need to bring together appropriate partners," Fortenbacher sums up his experience from many GIZ projects. "To develop networks together with stable public-private partnerships is not easy, but indispensable to international projects."

Corporate experience and the importance of a well-functioning nutrient supply for realizing the yield potential of potatoes were introduced by Prof. Dr. Andreas Gransee, Director of Innovation Lab Ag Tech & Nutrition of the K+S KALI GmbH. For a number of years the fertilizer manufacturer has supported the project "Growth for Uganda", focusing on the development of advisory and delivery infrastructure to serve Uganda's small-scale farmers. "In Uganda we've seen again and again just how important this so-called `last mile´ is to smallholders. This is just as true for know-how as it is for means of production," Gransee reports. This is all the more relevant as potatoes require a steady supply of nutrients. "Working together with local partners we have developed customized compound fertilizers in smaller packages. The mixtures are designed to for local soil conditions, and their smaller size makes them affordable to smallholders."

The relevance of a well-functioning knowledge transfer for realizing yield potentials and the experience made with various advisory systems in Ethiopia, Kenya, Zimbabwe and Mali were the topics of a contribution by Dr. Shamie Zingore. Born in Zimbabwe, Dr. Zingore now works as Regional Director for the Sub-Saharan Africa Program of the International Plant Nutrition Institute (IPNI). In his opinion, the lack of access to know-how on the side of small farmers is one of the greatest impediments to development. In order to alleviate this situation, the IPNI has come up with the "4R Nutrient Stewardship", with the intention of transferring to farmers the best practice cultivation methods for maize, rice, potatoes and millet. Participating farms showed yield increases of 20 – 60 per cent over three years. "Crucial for success is that research, advisory and practice communicate on a regular basis, and are willing to learn from each other. Experience therefore continuously flows into the further development of the 4R Nutrient Stewardship," says Zingore.

Wheat for Food Security and Health: The World Needs More

Two internationally recognized experts on global food and wheat production attended the sixth event of the series "IAPN in Dialogue" that took place on December 2016: Dr. Hans-Joachim Braun and Dr. Wolfgang H. Pfeiffer. The event was initiated by Prof. Dr. Ismail Cakmak, who was a guest researcher at the Institute of Applied Plant Nutrition in 2016, and was moderated by Prof. Dr. Klaus Dittert.



In dialogue (left to right): Prof. Dr. Ismail Cakmak, Dr. Hans-Joachim Braun, Dr. Wolfgang H. Pfeiffer and Prof. Dr. Klaus Dittert. (Photo: IAPN)

Global wheat production needs to increase by 50% according to the FAO to meet the demand of 9 billion people by 2050. This represents a huge challenge for breeders, agronomists and farmers, as the additional acreage that would be needed cannot be made available, and global warming, water shortage and new emerging cereal diseases make yield increases difficult. Dr. Hans-Joachim Braun, Director of the Global Wheat Program at CIMMYT (International Maize and Wheat Improvement Center) in Mexico presented the work of the Center on wheat yield improvements. He illustrated the way in which climate change can impact food supply with an impressive example: "We measured the influence of increasing night temperatures on the yield at a Mexican experimental site. An increase in the average night temperature by 1°C reduces the yield per hectare by around 700 kilograms." Brown made a strong case for making more resources available for agronomic consulting in developing countries, as this is the only way that advances in breeding will actually be applied in practice.

Fighting Hidden Hunger: Dr. Wolfgang Pfeiffer, Global Director of the International HarvestPlus Program in Colombia, talked about breeding and disseminating varieties enriched with micronutrients as a strategy to tackle the problem of hidden hunger. Today, more than two billion people suffer from nutritional deficiencies, and micronutrient malnutrition through a lack of e.g. zinc, iron, vitamin A and iodine is the most widespread issue. The problem is known as "hidden hunger", and is particularly common in countries in which there is high consumption of cereal-based foods, which are dense in energy, but low in micronutrients. Micronutrient deficiency is the cause of diverse diseases and developmental disorders, especially in children. These include a reduced immune system, higher susceptibility to general diseases, higher mortality, and impaired mental development. He also stressed the central importance of agronomic consulting for global food security. "Training smallholders in agronomic techniques is also giving people advice about diet and nutrition. We show in demonstrations how improved fertilization increases the zinc content in wheat and thus makes the wheat more valuable as a staple food for the family."

The two presentations and a statement by Prof. Cakmak were followed by intense discussion with the participants about various aspects of the talks. Dr. Brown pointed out in his concluding address that he looks forward to welcoming Göttingen students to CIMMYT and will be happy to answer any queries.

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 2016 two visiting researchers spent time at the IAPN:

- Prof. Dr. Ismail Cakmak from Turkey
- Recep Serdar Kara from Turkey

Prof. Ismail Cakmak is a worldwide acknowledged scientist. He worked in Göttingen 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 was engaged on joint research activities of IAPN und Sabanci University. He also strengthened the scientific connections between both of these institutions and for example the International Magnesium Institute, which was established in September 2016 as a public-private partnership by K+S KALI GmbH and the Chinese Fujian Agriculture and Forestry University (FAFU). The International Magnesium Institute will develop 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 scientific head of IAPN Professor Dittert, to teaching activities. He also assisted PhD students in developing their publications. During his visit at IAPN in 2016, Ismail Cakmak has given numerous lectures in Germany and abroad, and has written articles about recent topics of plant nutrition.

Recep Serdar Kara is a PhD student at the Department of Soil Science and Plant Nutrition at Ege University in Izmir, Turkey. His expertise lies, inter alia, in soil analysis, soil chemistry and physics, soil and water conservation, and carbon sequestration. Mr. Kara joined the working group of IAPN and Section of Plant Nutrition and Crop Physiology as an intern for 2 months. Within this time, Mr. Kara assisted PhD and Master students in their experiments which aimed at investigating the water-use efficiency and its enhancement by optimized fertilization. As a visiting scientist, his work served to deepen and to evaluate studies that had commenced during previous research at IAPN. Mr. Kara conducted an experiment in the greenhouse on sugar beet in which plant physiological responses to magnesium and potassium deficiency were sought to study and thereby could broaden his knowledge specifically on plant physiology affected by magnesium and potassium deficiency.

Publications

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

Avenhaus, U., Cabeza, R.A., Liese, R., Sulieman, S., Ligner, A., Dittert, K., Salinas-Riester, G., Pommerenke, C. and Schulze, J. (2016) Short-term molecular acclimation processes of legume nodules to increased external oxygen concentration. FRONT PLANT SCI 6: 1133.

Gong, X.Y., Giese, M., Dittert, K., Lin, S. and Taube, F. (2016) Topographic influences on shoot litter and root decomposition in semiarid hilly grasslands. GEODERMA 282: 112-119.

Jákli B. (2016) The relation between potassium nutrition and water-use efficiency of crop plants – Comparative studies from leaf to field scale. 1st ed. Cuvillier Verlag, Göttingen. ISBN 978-3-7369-9430-0. eISBN 978-3-7369-8430-1.

Jákli, B., Tränkner. M., Senbayram, M. and Dittert, K. (2016): Adequate supply of potassium improves plant water-use efficiency but not leaf water-use efficiency of spring wheat. J. Plant Nutr. Soil Sci. 179, 733-745.

Senbayram, M., Wenthe, C., Lingner, A., Isselstein, J., Steinmann, H., Kaya, C. and Köbke, S. (2016) Legume-based mixed intercropping systems may lower agricultural born N_2O emissions. Energy, Sustainability and Society 6:2.

Thiel, H. and Jákli, B. (2016) Kalium erhöht die Wassernutzungseffizienz pflanzlicher Systeme. Kali & Steinsalz 03/2016, 38-47.

Tränkner, M., Jákli, B., Tavakol, E., Geilfus, C.M., Cakmak, I., Dittert, K. and Senbayram, M. (2016) Magnesium deficiency decreases biomass water-use efficiency and increases leaf water-use efficiency and oxidative stress in barley plants. PLANT SOIL 406: 409-423.

Wiesler, F., Hund-Rinke, K., Gäth, S., George, E., Greef, J.M., Hölzle, F., Hülsbergen, K.J., Pfeil, R., Severin, K., Frede, H.G., Blum, B., Schenkel, H., Horst, W., Dittert, K., Ebertsseder, T., Osterburg, B., Philipp, W. and Pietsch, M. (2016) Use of organic fertilizers and organic wastes in agriculture. Berichte über Landwirtschaft – Zeitschrift für Agrarpolitik und Landwirtschaft 94: 1-25, doi: http://dx.doi.org/10.12767/buel.v94i1.124.g251

Conference Papers – Posters

Jákli, B., M. Senbayram, J. Meyer zur Müdehorst, M. Fuchs, F. Böttcher, F. Hertwig, A. Lingner and K. Dittert (2016) Drone-based remote screening of water-use efficiency. 75th Congress of the International Institute for Beet Research (IIRB), Brussels, Belgium, 16.–17. February 2016.

Lingner, A., K. Dittert and M. Senbayram (2016) Traits for water use in mixed cropping systems. The PLANT 2030 Status Seminar, Potsdam, 14.-16. March 2016.

Lingner, A., D. Siebrecht, M. Senbayram, W. Link and K. Dittert (2016) Productivity of legume-based mixed cropping systems as estimated by NDVI imaging. DGP-Conference 2016 - Ressourceneffizienz: von Modellpflanzen zu Nutzpflanzen und Agrarsystemen, Stuttgart-Hohenheim, 28.-30. September 2016.

Lingner, A., K. Dittert and M. Senbayram (2016) Water-use efficiency and drone-based spectral screening of productivity in mixed cropping systems. ILS2 Second International Legume Society Conference, Troia Resort, Portugal, 11.-14. October 2016.

Lingner, A. and K. Dittert (2016) Spectral screening of legume-based mixed cropping systems using NDVI imaging. Internationale Pflanzenbautagung "Die Rolle der Bodenmikroorganismen bei der Ernährung von Kulturpflanzen", Bernburg-Strenzfeld, 17.-18. November 2016.

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, Institut of Bio- und Geosciences Agrosphere (IBG-3)	Jülich, Germany
Hanninghof Research Station – Yara Int. ASA	Dülmen, 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 Analytik- und Forschungszentrum (AFZ)	Unterbreizbach, Germany
K+S KALI GmbH	Kassel, Germany
LUFA Nord-West, Institut für Düngemittel und Saatgut	Hameln, Germany
Poznań University of Life Sciences	Poznań, Poland
Sabanci University, Biological Sciences and Bioengineering Program	Istanbul, Turkey
Sasakawa Africa Association	Kampala, Uganda
SKW Stickstoffwerke Piesteritz GmbH	Lutherstadt Wittenberg, Germany
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 Peradeniya	Peradeniya, Sri Lanka

In Teaching

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

Prof. Andrea Carminati
Georg-August-University of Göttingen

Dr. Hendrik Führs
Landwirtschaftskammer Niedersachsen

Prof. Dr. Ismail Cakmak
Sabanci University, Istanbul, Turkey

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