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Agricultural Sciences – Current topics of research at ETH Zürich

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Text and figures of this manuscript have been approved by all professors mentioned in Figure 1.

1. Introduction

Research in Agricultural Sciences has been performed at ETH Zürich since 1869, when the seventh department of ETH was founded. Research topics have always depended on current challenges and on the structure and core interests of the professorships. Today, ETH is structured in 16 Departments. One of them is the Department for Environmental Systems Science (in German: Umweltsystemwissenschaften; D-USYS). D-USYS is one of the largest departments and the home of six institutes; one of them is the Institute of Agricultural Sciences (IAS). Currently, ten professorships out of the total number of ca. 500 professors at ETH and ca. 45 at D-USYS, are members of IAS. Two further professorships are closely associated to IAS and dedicate their teaching activities to the study program in Agricultural Sciences (see Fig. 1). The professorship in Agricultural and Resource Economics is currently still open. Overall, the activities of the above mentioned professorships cover the full spectrum of agricultural research at ETH, but other professorships at D-USYS and in other departments also perform research on topics of relevance for Agricultural Sciences. All professors at ETH Zürich enjoy a high degree of freedom with respect to their choice of research topics – and the departments also are quite free when they define topics for new professorships before and during the search process. Time and university rankings have shown that these liberties – together with the substantial basic financial support, grant application possibilities and other factors – stimulate excellence in research and allow for maximum flexibility of core topics to be dealt with in research. Focussing as a group on a certain catalogue of core agricultural research interests is assured by checks and balances in the professorial search process, by the necessity to sustain the existing teaching program from within the department, and by the result of an international evaluation every six to seven years. Such a 'bottom-up' process of the definition of research topics is not self-evident for the field of Agricultural Sciences. In many countries across all continents, the teaching curriculum in Agricultural Sciences is defined by ministries and also the choice of research topics is by far more restricted. Also in Switzerland, research topics are initiated by the federal administration – but this is implemented mostly via the federal research institution Agroscope that hosts a far higher number of researchers in Agricultural Sciences compared to ETH Zürich. Academic liberty of the choice of research topics is a high value of ETH and since ETH is the only university in Switzerland that hosts an Agricultural Sciences study program and the required spectrum of professors, the liberty of research topic choice is a precious and non-endangered good for all professors in Agricultural Sciences. The success of this process of research definition is also mirrored in the teaching curriculum, which was rewarded recently in a tri-national survey (Germany, Switzerland, Austria) to deliver the best education with respect to a later career in academic research in the field of Agricultural Sciences.

Today, agricultural research at ETH Zürich covers a lot of aspects from Swiss to global relevance. Research is done in the three major fields that also form the focal points of the study program: Agricultural Economics, Plant Sciences and Animal Sciences. Seven of the above mentioned twelve professorships (see Fig. 1) have been installed during the previous five years; a thirteenth professorship has recently been advertised but is still vacant. Due to an acute shortage in teaching in Animal Sciences a few years ago, two independent teaching units have been installed in addition to the professorships, but they are being integrated into the professorships again – only one still exists. One overarching feature that unites the research activities of all professorships is that their research is dedicated to an increase in the sustainability of agricultural activities. Some of the professorships have strong ties to organic agriculture, some have strong ties to industry, but for all professorships

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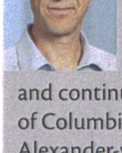

Achim Walter, Dr. rer. nat., has been Professor of Crop Science at ETH Zürich since 2010. He studied and has degrees in physics (diploma in 1995) and biology (diploma in 1997). Studies were conducted at Heidelberg University, Germany and at ETH Zürich. He received a doctoral degree in plant ecophysiology in 2001 from University Heidelberg and continued his scientific career with a postdoc at Biosphere 2 Center of Columbia University New York, USA as Feodor-Lynen-Fellow of the Alexander-von-Humboldt-Foundation between 2002 and 2003. He has been research group leader and later on deputy institute director at the Institute for Phytosphere Research at Forschungszentrum Jülich, Germany, between 2003 and 2010.

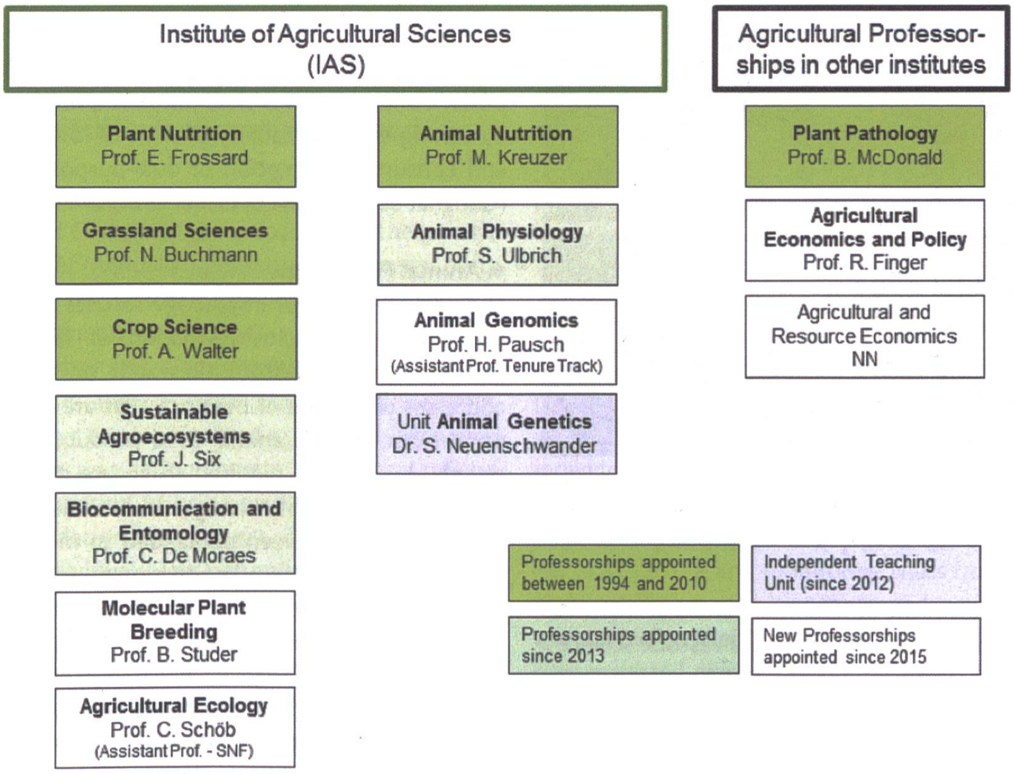

***Fig. 1.** Overview on professorships with a focus on Agricultural Sciences at ETH Zürich.*

the sustainability of agriculture with a reduction of detrimental side-effects on natural ecosystems and wide social and societal acceptance is a premise in their research efforts. The subsequent sections will highlight some of the most relevant research efforts of the professorships.

2. Agricultural Economics and Policy

The group of Agricultural Economics and Policy has been installed in 2016. The research of the group improves the understanding of linkages between policies and production and risk management decisions taken in the agricultural and food sector. The group's research is highly interdisciplinary and has direct policy implications. A good example for this is their research in the field of the economics and policy of pesticide use. Innovative research approaches are developed to open novel pathways to understand farmers' pesticide use decisions and to develop policy instruments for a sustainable agricultural development. Reducing the risks for the environmental and human health caused by pesticide application is on the top of political agendas all over Europe. This research has opened new perspectives on the potential of pesticide taxation as well as potential implications of ban of glyphosate (e.g. Böcker (2018)). Research in the field of weather index insurances is another important topic of the group. These insurances are not based on direct compensation of yield losses but compensate the farmer if facing extreme weather events such as droughts. The group has been the first to i) coherently design weather index insurances towards a focus on the reduction of downside risks, i.e. extreme losses (Conradt *et al.*, 2015a), ii) to propose the use of flexible periods to specify weather indices such that they reflect crop growth phases (Conradt *et al.*, 2015b; Dalhaus and Finger, 2016) and iii) to illustrate the high potential of new data sources to remove geographical basis risks (Dalhaus *et al.*, 2018). Furthermore, bio-economic, agent based and econometric modelling approaches are used in the group to evaluate outcomes of agricultural policies but also investigate effects of new market and climatic conditions (Huber *et al.*, 2017). Such models form the basis to analyse the effects of new policy instruments or scenarios and are therefore important elements to establish new agricultural policy measures, such as the currently existing model of 'direct payments' given to Swiss farmers that are balanced according to a wide set of defined criteria. In currently ongoing research projects of the group, a particular focus is given to the role of risk and uncertainty in farmers' uptake and investment decisions for new technologies related to the digitalization of agriculture and to the processing of big data on the farm (Walter *et al.*, 2017).

3. Animal Nutrition

The current group of Animal Nutrition has been installed at ETH 24 years ago. After helping to initiate the process, it has contributed to the establishment of an animal research facility over the last decade. The

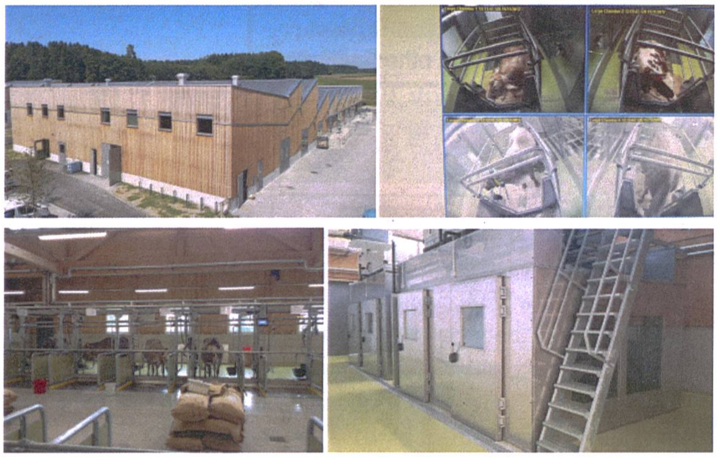

Fig. 2. Metabolic Center of AgroVet-Strickhof. Top left: building; bottom left: facility for balance experiments; top right: respiration chambers stocked with dairy cows; bottom right: outside view of four medium-sized respiration chambers.

facility allows for the development and assessment of new technologies in the realm of livestock sciences: The research platform AgroVet-Strickhof (see Fig. 2). This entity is operated since 2017 collaboratively by ETH Zürich, University of Zürich and the Cantonal Vocational School Strickhof. The core element is the metabolic center, where high-throughput data can be acquired in digestive and metabolic studies, generating in-depth insights on various key indicators of, among others, nutritional efficiency and low greenhouse gas emission strategies. This will enormously strengthen the output of the group e.g. in the field of sustainable feeding, nutrition physiology and quality of food; linking nutritional approaches with quality of meat and milk. Experiments in this field cover the range from basic nutrition experiments to controlled studies in complex landscapes. Tools include fine analysis of feeds and foods as well as sensory evaluations. In recent years, the group could show positive effects of physical activitiy and of secondary compounds on meat and milk quality e.g. (Gangnat *et al.*, 2017). Other research activities of the group focus on digestion, metabolism and environment. Here, functional traits such as degradability, fermentation or methane production are analyzed. These analyses revealed novel effective feed supplements, mechanisms as well as interactions that affect the (manipulated) symbiosis between the ruminant host and its microorganisms e.g. (Staerfl *et al.*, 2012). Research was also conducted with partners of tropical and subtropical countries, focusing on problems of dry season feed scarcity and sustainable use of tropical rangelands. The group experimentally described adaptation of livestock to different environments (from remote Himalaya to Chaco dry forests to African savannahs) and assessed effects of browsing on the vegetation e.g. (Barsila *et al.*, 2014). Finally, ethical and world nutrition related aspects of poultry nutrition and poultry systems have also been intensively dealt with. The group identified possibilities to valorize spent hen meat and quantified the comparative performance of novel dual-purpose poultry types by testing the applicability of diets of lower quality and consumer perception of dual-purpose poultry (Gangnat *et al.*, 2018; Loetscher *et al.*, 2014).

4. Animal Physiology

The group of Animal Physiology focuses on understanding the complex regulation of health and performance in livestock. Research of the group addresses challenges of livestock that are of utmost importance for the animal food production chain. Healthy livestock is required to ensure global food security. Considerable changes in livestock production have recently been demanded to mitigate the contribution of livestock production to environmental problems. Endocrine disrupting chemicals affecting both humans and livestock are among the global environmental challenges to which livestock production needs to react. Already trace concentrations of these very potent chemicals in the environment can lead to long-lasting, irreversibly negative effects in exposed organisms that can affect the production of healthy foodstuff markedly and for more than one generation. Estrogens as such are natural steroid hormones that govern sexual reproduction and development in vertebrates. The group recently elucidated the effects of an in-utero exposure of low-dose estradiol-17b in the pig as large animal model and found that a perturbation of the uterine milieu can induce an epigenetic imprint in preimplantation embryos that can be linked to a later subtle adverse phenotype in offspring (Flöter *et al.*, 2016; Kradolfer *et al.*, 2016; Pistek *et al.*, 2013). The findings show that the effect level of estrogenic endocrine disrupting chemicals is at much lower concentration than currently presumed and propose epigenetics as a sensitive novel parameter for risk assessment. In general, livestock and wildlife, namely cows, pigs, sheep as well as roe deer, are assessed as large animal model systems. Animal welfare is addressed including both physical and mental health based on principal physiological, behavioural and cognitive ethological studies. Specifically, vocal expression and the communication of emotions have been measured by studies of valence (negative versus positive) and arousal (calm versus excited) (Briefer *et al.*, 2015; Briefer, 2018). The current core topic of the group of Animal Physiology is to study the role of extracellular vesicles in the mammary gland during lactation. This research addresses basic strategies to increase dairy health and reduce the need for antibiotic treatment. The group applies sensitive methods to determine environmental effects on exposed animals such as genomewide deep sequencing of the mRNA and (iso)miRNA transcriptome and of the DNA methylome (van der Weijden *et al.*, 2017). Research possibilities at AgroVet-Strickhof are of great importance for the group for the future experimental research approaches in livestock.

5. Animal Genomics

The Animal Genomics group focuses on the genetic dissection of Mendelian phenotypes, complex traits and diseases in livestock. They use high-throughput DNA sequencing technologies, statistical genomics approaches and bioinformatics tools to collect, process and analyze large amounts of genomic data in order to pinpoint trait-associated DNA variants. Using population-genetic approaches allows genomic variation to be assessed within and across entire populations that consist of hundreds of thousands of individuals. This rich collection of data facilitates generating knowledge for more sustainable, personalized, and efficient animal breeding. Cattle are the main «targets» of research within the Animal Genomics group. The research projects address the genetic diversity of livestock populations, statistical genomics and the identification and management of inherited disorders. The genetic diversity in livestock is characterized within and across livestock populations at base-pair resolution. It is of particular interest in this research field to develop approaches that exploit high-throughput sequencing and high-performance computing to assess genomic variation in thousands of individuals simultaneously (Daetwyler *et al.*, 2014; Pausch *et al.*, 2017a). Moreover, statistical genomics approaches are applied to characterize the genetic architecture of complex traits. The group uses genotype imputation to infer sequence variant genotypes for large mapping populations and carries out genome-wide association studies between sequence variant genotypes and quantitative traits to identify trait-associated sequence variants (Pausch *et al.*, 2016, 2017b). Finally, the identification of inherited disorders in several cattle breeds is possible based on large scale sequencing and genotyping data. This helps to characterize biological consequences associated with such variants and prevents the birth of animals with severe diseases(Pausch *et al.*, 2014; Schwarzenbacher *et al.*, 2016). The group collaborates with breeding and farmers associations to transfer their findings into practice, e.g., by contributing to the development of new genotyping arrays that allow for monitoring trait-associated genetic variants in populations.

6. Crop Science

The group of Crop Science mainly establishes and applies crop phenotyping technologies. This means that they create novel ways to elucidate the performance of crops such as wheat and soybean via image-based analyses of shoots and roots in the lab and in the field throughout time intervals from minutes to seasons. Image-based parameters such as height, growth, time to flowering are used to extract information relevant to understand the physiology of the plant, to advance crop management and crop breeding (Walter *et al.*, 2015). The group has established methods that allow for analysis of root system growth under controlled conditions either on germination paper (via optical monitoring; (Le Marié *et al.*, 2016)) or in soil-filled pots (via x-ray computed tomography; (Colombi *et al.*, 2017). In the field, platforms were established that facilitate leaf growth analysis in individual plants in response to temperature change, monitoring of multiple traits of canopies in small plots of breeding populations [see Fig. 3; (Kirchgessner *et al.*, 2017)] and monitoring traits from moving aerial platforms such as unmanned aerial vehicles and Zeppelins. Applications of these methods have demonstrated differences in growth response of different wheat genotypes towards changing temperatures (Grieder *et al.*, 2015) or of root growth under the effect of the plant hormone strigolactone. First results demonstrate the power of these approaches also for improving precision agriculture related field management with respect to treatment of pests and diseases as well as to fertilizer use (Lottes *et al.*, 2017). In numerous discussion panels, public seminars, blog entries and opinion articles (Walter *et al.*, 2017), several group members provided important contributions to the public debate on the future of agricultural sciences and of our agricultural systems in general. Appropriate use of digitalization and big data; new plant breeding tools and the transdisciplinary

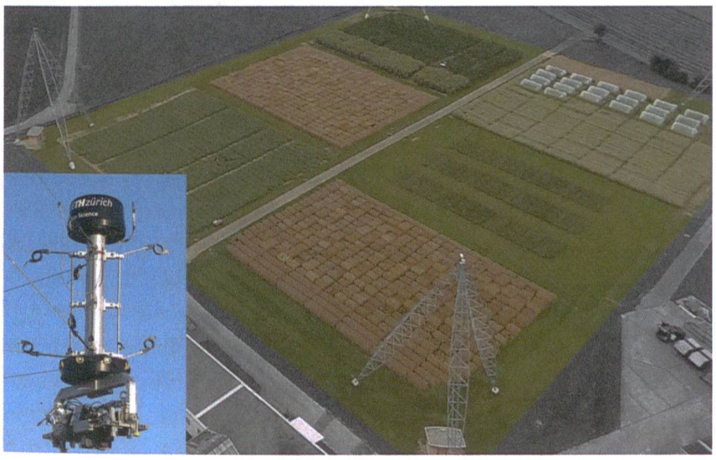

Fig. 3. *Field Phenotyping Platform FIP of ETH Zürich. The field site of 1 ha is managed with a crop rotation of forage crops, wheat, soybean, buckwheat and in some years maize, sunflower or oilseed rape. The inset shows the sensor head carrying multiple camera systems. The sensor head is attached to eight ropes guided over the top of the four 24-m-masts in the corners of the field. The length of the ropes is controlled by winches at the bottom of the mast, thereby allowing for precise positioning of the sensor head over the canopy.*

dialogue between scientists, companies, farmers, consumers and other stakeholders of the agro-food chain have been the core topics of these activities.

7. Molecular Plant Breeding

The group of Molecular Plant Breeding is a joint professorship of ETH Zürich and Agroscope. The main aim of the group is to develop genetic and genomic tools that can assist and accelerate plant breeding. This is being achieved by taking advantage of recent technical advancements, not only in genome sequencing and genotyping technologies, but also in a variety of disciplines connected to plant breeding such as molecular biology, statistical modeling, bioinformatics and crop phenotyping, to understand the composition of agriculturaly important traits in crop species. Ultimately, this will help to efficently realize genetic gain for these traits by breeding. Methodological research comprise the assessment of the genetic diversity per se, approaches to accelerate the breeding cycle, methods to increase the selection efficiency and tools of bioinformatics. For example, characterizing the genetic constitution of plants that form the basis for a breeding program requires state of the art genotyping technologies, such as genotyping by sequencing (GBS) or the modified GBS-approach 'genome wide allele frequency fingerprints' (GWAFF). Currently, genomic tools used to monitor gene diversity changes in relation to time and management practices in grasslands are being develped. Another main reserch area of the group encompasses methods such as the detection of quantitative trait loci (QTL) and genome-wide association studies (GWAS) as well as more efficent approaches of family-based mapping to unravel and improve complex crop traits by single marker-based or genome-wide selection strategies. Using such methods, partly in cooperation with other research groups at and beyond ETH, the group has studied the genetic constitution of crop traits such as disease resistance, drought tolerance, water use efficiency, quality (e.g. leaf starch content) in forage crops (Ruckle *et al.*, 2017), wheat, common bean (Keller *et al.*, 2015) and buckwheat. Moreover, novel bioinformatics approaches have been developed (e.g. Pfeifer *et al.* (2013)) that allow to connect data from different crop species and/or from different regulatory levels of the plant (such as genetic, metabolic or protein-based characterization of the variety of the constitution of differences between crops). Finally, research approaches have been developed that allow to characterize and utilize biological mechanisms in forage grasses to control pollination, which can e.g. be exploited in breeding schemes facilitating hybrid vigour (Do Canto *et al.*, 2017), an important mechanism to increase yield and quality in crops by careful selection of parental plants, which is currently applied for the establishment of lots of modern cultivars of the currently used crop species.

8. Plant Pathology

The main aims of the Plant Pathology Group are to i) understand the evolutionary processes affecting plant pathogens in their interactions with host plants in order to make more effective use of genetic resistance and other control strategies; to ii) understand the mechanisms governing biological control of plant diseases in order to develop more effective biological control strategies and to iii) develop and implement new technologies for better control of plant diseases in a sustainable way. Research activities of the group are focused on delivery of fundamental knowledge in key areas of plant pathology while maintaining an orientation toward problem-solving, innovative research. Therefore, the group is associated to the institute of integrative biology facilitating a close interaction with biologists and ecologists also on a day-to-day basis. Pathogen evolutionary ecology is the group's most prominent research topic. This includes the population genetics and evolutionary biology of plant pathogens, pathogen origins and phylogeography, pathogen-plant coevolution, experimental evolution, resistance gene conservation and utilization, and resistance breeding (e.g. Stukenbrock *et al.*, (2011); McDonald *et al.*, (2013)). Research projects include the correlation between diversity for ecologically relevant quantitative traits and diversity for DNA-based genetic marker systems as well as using population genomics (QTL mapping, GWAS, genome scans) to identify genes involved in virulence, fungicide resistance, stress tolerance and thermal adaptation. Major experimental systems comprise the wheat diseases Septoria tritici blotch caused by *Zymoseptoria tritici* (Lendenmann *et al.*, 2016; Stewart *et al.*, 2018), Stagonospora nodorum blotch caused by *Parastagonospora nodorum*, wheat blast caused by *Pyricularia graminis-tritici*, and the barley scald disease caused by *Rhynchosporium commune*. Topics such as biological control, diseases of apples, grapes and potato have also been intensively studied. Recently, mapping of QTL and GWAS enabled identification and cloning of genes that have a significant effect on pathogen quantitative traits. This led directly to the functional validation of three avirulence effector genes in *Z. tritici*, including *AvrStb6* (Zhong *et al.*, 2017), which had eluded cloning for 20 years. Moreover, automated imaging-based phenotyping tools enabled acquisition of 11 million phenotype measurements. This amount of big data facilitated genetic separation of plant resistance components affecting host damage from resistance components affecting pathogen reproduction. Such procedures will dramatically improve the efficiency of breeding for resistance against dangerous diseases in wheat, reducing the pressure to apply pesticides. Finally, the group has explored the use of plant-beneficial *Pseudomonas* bacteria to improve plant health in agricultural systems by controlling soil-dwelling insect pests for which no satisfactory control methods currently exist (Flury *et al.*, 2017).

9. Plant Nutrition

The Group of Plant Nutrition addresses through its research the challenge of how to improve nutrient efficiency in productive agricultural systems. Its mission is to: i) understand the biotic and abiotic processes controlling the release of nutrients from the soil solid phase or fertiliser to the soil solution and to the plant; ii) develop concepts and tools for characterizing the chemical nature of nutrients in soils and fertilisers and quantify nutrient fluxes in the soil/fertiliser/plant system and iii) develop integrated nutrient management schemes that are relevant to ecologically efficient agricultural systems in order to preserve and enhance the natural resource base and contribute to national and global food security. The group focuses its research on phosphorus (P), nitrogen (N), zinc (Zn) and cadmium (Cd). In particular, the group has a strong expertise with the use of radioactive and stable isotopes, spectroscopy, and a variety of physical, chemical, biochemical and molecular methods. The research is done under controlled laboratory and glasshouse conditions and in field experiments managed either by scientists or by farmers in various regions of the world (see Fig. 4). In addition, research of the group includes the study of "semi-natural" systems (forests, extensive grasslands) as models to understand the effect of climate and parent material on the chemical nature and dynamics of nutrients at ecosystem level. In the last decades the group could provide new information on the dynamic of inorganic and organic P forms in agricultural and semi natural systems. The research results show the relative importance of different drivers of the P cycle, and suggest a more important role of biological processes than previously thought (Jarosch *et al.*, 2015; Tamburini *et al.*, 2012). This fundamental knowledge was also used to assess the agronomic impact of recycling P fertilizers for sustaining the P nutrition of crops, which is a central topic in circular economy (Nanzer *et al.*, 2014). The group could further show that the addition of N rich plant residues to soil could lead to a large release of soil Zn that was subsequently taken up by the plant and tranported to the grain, contributing the biofortification of cereals (Aghili *et al.*, 2014). Finally the group leads the inter- and transdisciplinary YAMSYS project, which aims to develop technologies that are biophysically,

Fig. 4. Research activities of ETH Zürich also comprise field research with smallholder farmers in Africa.

economically and institutionally acceptable to sustainably improve yam tuber yields, food security and income of actors along the yam value chain in West Africa (Frossard *et al.*, 2017).

10. Biocommunication and Entomology

The Biocommunication and Entomology research program explores the complex role of chemistry in mediating interactions among plants, insects, and other organisms. Work in the group addresses diverse phenomena at scales ranging from the molecular and biochemical bases of plant defense responses to the community-level effects of chemical signaling, to the chemical ecology of vector-borne disease transmission. The research activities of the group are particularly focused in the ecological functions of plant-derived olfactory cues, and some of the group's most significant findings have documented previously unexpected levels of informational complexity in plant volatile emissions and elucidated the sophisticated ways in which insects and other organisms interpret and respond to these information-rich cues (De Moraes *et al.*, 1998, 2001; Helms *et al.*, 2017; Mauck *et al.*, 2010; Mescher *et al.*, 2015; Runyon *et al.*, 2006). This research focus addresses important basic science questions that also have applied relevance for sustainable agriculture, ecological conservation, and human health. In addition to investigating the role of plant volatiles as sources of ecological information for other organisms, the group's research has played a key role in elaborating the ways in which plants themselves perceive and respond to olfactory cues (Helms *et al.*, 2017; Runyon *et al.*, 2006). For example, the discovery that plant odors serve as host-location and host-discrimination cues for parasitic plants documented an entirely new class of volatile-mediated ecological interactions6. Similarly, the demonstration that the anti-herbivore defenses of tall goldenrod plants (Solidago Altissima) are primed by exposure to the putative sex pheromone of a specialist herbivore, the gall-inducing fly Eurosta solidaginous (Helms *et al.*, 2017), provided the first example of plant response to an animal-derived olfactory cue. Research from the group has also made important contributions to the emerging field of disease chemical ecology through work on both plant and human pathosystems. For example, some of the groups recent work has explored how pathogen-induced changes in host-plant chemistry, including volatile emissions, influence interactions between plants and insect disease vectors and suggests that variation in virus transmission mechanisms may be an important factor shaping pathogen effects on plant-vector interactions (Mauck *et al.*, 2010). The group is also exploring how human pathogens (specifically malaria) can alter host odors in ways that influence vector behavior, and the implications of such effects for disease diagnosis as well as for efforts to disrupt transmission by vectors (Moraes *et al.*, 2014).

11. Grassland Sciences

The multidisciplinary research of the Grassland Sciences group focuses on the process- and system-oriented understanding of functional plant diversity and biogeochemistry in agroecosystems and forests (Adams *et al.*, 2016; Reichstein *et al.*, 2013). In particular, the biospheric-atmospheric greenhouse gas exchange, both in response to human and biophysical drivers and across spatial and temporal scales, is the main subject of many research projects of the group. For this research, classical ecological methods are used, but also innovative tools such as stable isotope applications and micrometeorological measurements of trace gases are developed and applied in observational and experimental studies. A prominent example for the group's approaches is the 'Swiss FluxNet' that has been established in the last decade (see Fig. 5). The Swiss FluxNet combines all ecosystem-scale CO_2 and H_2O vapour (at some sites also CH_4 and N_2O; (Merbold *et al.*, 2014)) eddy-covariance flux measurement sites in Switzerland. It currently encompasses eight long-term ecosystem sites, six run by the group, covering the major land-use types in Switzerland. The high frequency, long-term measurements of greenhouse gas fluxes allow determination of greenhouse gas budgets and of reactions to climate extremes as well as management. Thus, they built the base for climate-smart agriculture and forestry. In the meantime, 87 site-years of open-access flux measurement data have been generated across the three land use types of grassland, cropland and forest. Carbon sinks and sources have been quantified; effects of weather and management regimes have been identified, and fluxes were linked to plant ecophysiology and remote sensing proxies such as sun-induced fluorescence (Guanter *et al.*, 2014). Another major group of achievements relates to functional plant diversity: With the group's long-standing contributions to Europe's largest grass-

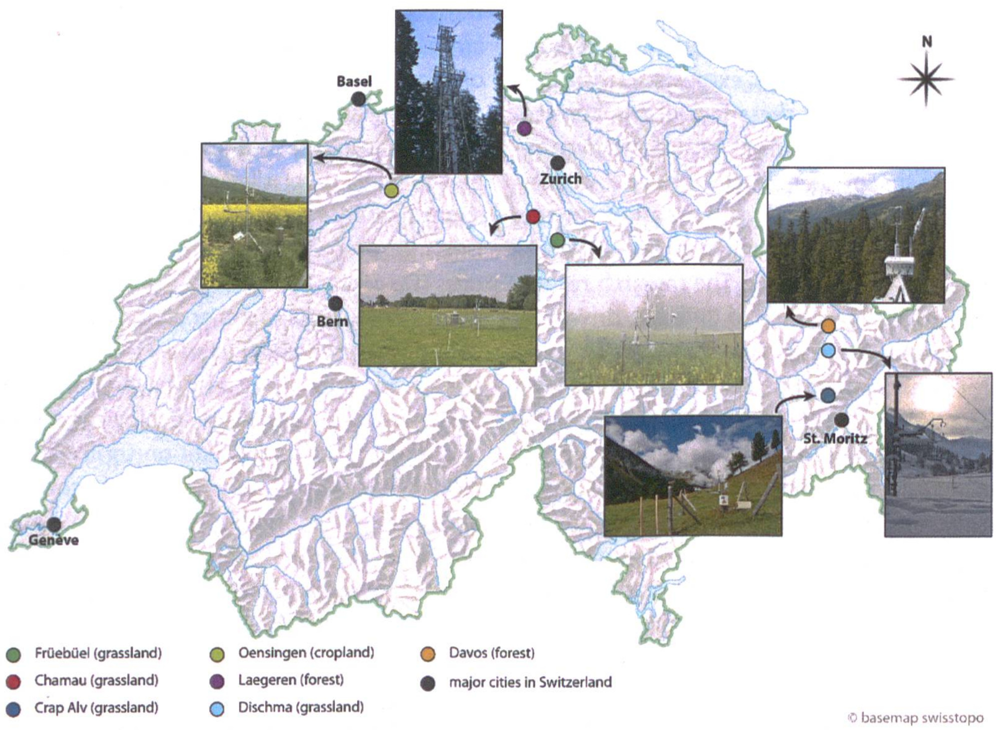

Fig. 5. Swiss Fluxnet. Measurement sites to determine greenhouse gas fluxes from different sites with different land use, distributed throughout Switzerland.

land biodiversity study – the Jena Experiment – the group was able to show experimentally that resource niche complementarity is less widespread than previously hypothesized and that species redundancy does not exist if multiple ecosystem services are to be maintained (Weisser *et al.*, 2017). Finally, some of the group's current projects have direct policy relevance, e.g. to validate national greenhouse gas budgets or to assess the economic value of biodiversity and ecosystem services in grasslands (Finger and Buchmann, 2015).

12. Sustainable Agroecosystems

Research by the group of Sustainable Agroecosystems focuses on the feedbacks between agroecosystem management options (such as tillage, cover cropping, green manuring, sustainable farming and grazing), global change (e.g. elevated CO_2 and climate change) and biogeochemical cycling. More specifically, the group studies the complex interactions between plants, soil, soil biota and nutrient (C, N, P) cycles in agroecosystems. Their general approach is to integrate field sampling, laboratory analyses and mathematical modeling to investigate whole system dynamics under current and future environmental conditions. The project sites span from small growers' fields to intensively-farmed production systems to agricultural research stations and the group is involved in a suite of international research projects in Africa, Europe, North America, Asia, and Central and South America. Research projects can be grouped in five classes: i) soil biota and nutrient cycling, ii) nitrogen cycling and isotopes, iii) diverse agroecosystems, iv) biogeochemical modeling and v) food systems. A recent major achievment is the establishment of a network of projects addressing the resilience of food systems around the world. Food systems are increasingly exposed and affected by various types of shocks (natural, economic and social) and stresses (population growth, land-use changes, etc.) (Tendall *et al.*, 2015). The group has adopted a mix of transdisciplinary and interdisciplinary research techniques to holistically analyze the relevant drivers that define the ability of different actors in food value chains to deal with shocks and stresses by building resilience in the food systems. Working closely with key stakeholders of food systems enables them to bridge the gap between research and action. In the past four years, the group has established six sub-projects that cover a total of ten food value chains in six different countries. The group also conducted several on-farm studies on the influence of incorporating shade trees into cocoa plantations in Ghana and Indonesia. They found that shade trees can have several benefits for cocoa systems such as reduced disease pressure, reduced temperature stress and increased biodiversity. The group has conducted several highly cited meta-analyses on the productivity limits and potentials of the principles of conservation agriculture (Pittelkow *et al.*, 2015), N_2O emissions in reduced tillage systems (van Kessel *et al.*, 2013) and the control of soil carbon storage by interactions between geochemistry and climate (Doetterl *et al.*, 2015). Recently, activities of the group have focused on soil property prediction based on analyses performed via soil diffuse reflectance infrared fourier transform spectroscopy and other techniques. Based on newly generated soil databases with regional resolution, biogeochemical models will be used to evaluate field-scale and regional effects of fertilization, tillage, soil cover and crop rotation on soil nutrient dynamics.

13. Agricultural Ecology

The group of Agricultural Ecology has most recently been installed as an SNF assistant professorship, providing the grant holder with the opportunity to establish an independent research group on this topic within a time frame of four (plus maximum two more) years. This opportunity is often used to consolidate the role of the awardee in the scientific research arena and to boost his or her future career. In this particular case, the professorship is hosted by the group of Sustainable Agroecosystems because of the close fit of the core research topics. The group of Agricultural Ecology takes a community ecological perspective on crop systems and studies the potential of biodiversity in agriculture, in particular through intercropping. Intercropping adapts plant diversity in natural communities to an agricultural setting through the cultivation of more than one species or cultivar at a time on a given piece of land. Such mixed cropping can benefit from beneficial interactions among genotypes or species that result in more and improved agroecosystem functioning. In this line of research, the group studies the benefits of mixed cropping compared to monocropping on a range of agroecosystem services such as food production and sheds light on the key processes involved in these beneficial interactions (Brooker *et al.*, 2018). Another line of research elucidates the effects of biodiversity on ecosystem functioning. Here, the group studies natural ecosystems that provide useful insights for agroecosystems; but also 'hybrid' agroecological experiments are conducted that follow an ecological design but use an agricultural environment (e.g. species or ecosystems) to better understand the mechanisms of such positive biodiversity effects (Schöb *et al.*, 2017a). Also, direct plant-plant interactions (Kikvidze *et al.*, 2015; Schöb *et al.*, 2017b). and the effect of plant traits on the environment are assessed in mechanistic detail (Li *et al.*, 2017)

14. Conclusions

Agricultural research at ETH Zürich covers a wide range of topics. Often, groups have used their resources to a large part to install unique methodologies ranging from physical measurement tools to complex socioeconomic modeling approaches. Application of these unique methodological toolboxes then often allows for unique research opportunities that can elucidate novel mechanisms governing plant or animal performance or the inner workings of agroecosystems or socioeconomic systems. Some of the research topics are closely linked to direct applications on farms, whereas others generate new perspectives for basic science. Interaction with project partners is usually facilitated in a specific way that is defined often by the institutions, which fund this research (such as the European Union, the Swiss National Science Foundation or partners from the private sector). Yet, also within ETH, multiple coordinative bodies and activities are present that allow for a frequent exchange of ideas and to deal efficiently with administrative necessities: Professors are members of D-USYS committees such as the departmental or professorial conference; they interact on issues of finances and experimental possibilities in the 'resource commission' and in the institute's assembly. Most professors are also members of ETH's 'World Food System Center' and of the Basel-Zürich 'Plant Science Center' – competence centers that offer independent teaching activities such as summer schools, but that also provide joint contact to private partners and other stakeholders that allow for joint research projects project funding. ■

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