Deutsche Forschungsgemeinschaft

Perspektiven der agrarwissenschaftlichen Forschung

Future Perspectives of Agricultural Science and Research

Denkschrift
Memorandum

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Future Perspectives of Agricultural Science and Research
DFG, Deutsche Forschungsgemeinschaft

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*At present, agriculture is able to feed the majority of humans.
But scientists are becoming very concerned that this will not be the case
when we have eight billion people on the planet in about 20 years' time.
Failure to feed eight billion people in a sustainable way
will lead to enormous environmental damage,
social dislocation, and reduced economic growth
that will affect the whole world.*

Declaration of Hamburg, 2000
International Crop Science Congress

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Foreword

With its "Denkschrift zur Lage der Landbauwissenschaft" [Memorandum on the State of Agricultural Science] published in 1957, the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for the first time informed the public about the state of, and need to expand, agricultural and horticultural science.

Constantly changing demands in society have prompted the DFG, nearly 50 years later, to present a new memorandum on the outlook for agricultural science, which has been drawn up by the "Senate Commission on Substances and Resources in Agriculture". The new memorandum makes specific recommendations for research in agricultural science as a systems science and suggestions for its further development, in particular in the agricultural research departments of universities. It addresses both the scientific community in agriculture and related disciplines and at decision-makers in universities, research institutions, politics and administration.

A particular concern of the DFG is to put forward ideas on the positioning of agricultural science within the research landscape. Future fields of research in the international context and the training of young postgraduate scientists form an essential foundation for this.

At the universities, in particular, the fields of research in agricultural science, which are also of social importance, can be bolstered only by establishing appropriate framework conditions. The memorandum therefore also makes suggestions in respect of structural aspects of agricultural science.

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I am grateful to the authors and to the many others who have participated in this dialogue and have helped with their suggestions.

Bonn, April 2005

Prof. Dr. Ernst-Ludwig Winnacker
President of the Deutsche Forschungsgemeinschaft

Summary

Almost 50 years after the publication of the first memorandum on the state of agricultural science, the DFG has been prompted by changing demands in society to publish a new memorandum on the way ahead for agricultural science. It follows intensive discussions both within the scientific community and with decision-makers at federal and state level as well as in various bodies within the DFG, in particular the Senate Commission on Substances and Resources in Agriculture and the Review Board on "Agricultural and Forestry Science, Horticulture and Veterinary Medicine".

By defining important fields of research, the new memorandum identifies future strategies for agricultural science and puts forward ideas for further development of both its content and institutional structure. With its recommendations, the memorandum is aimed at the scientific community in this field, in particular at agricultural faculties and departments, as well as at related scientific disciplines. It also addresses decision-makers in the universities and research institutions, those in positions of responsibility in politics and administration as well as the German Science Council.

Agricultural research is of global significance and is not confined to national or regional areas. The problems to be solved have not diminished in the context of worldwide population growth, global climate change, the globalisation and liberalisation of world trade and the changes in preferences in society. They have also shifted in content, which confronts agricultural science with new challenges. It must therefore organise its work along international lines. Agricultural science comprises different disciplines and methods which are concerned with the biotic and abiotic natural environment. Key fields of re-

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search which are handled jointly by departments in interdisciplinary approaches are global food security, environmental standards, quality assurance as well as agricultural landscape research. Agricultural science is well equipped to tackle the global dimension of these topics since it has traditionally been strongly committed to international cooperative research projects, and thanks to its experience and networks is already making an important contribution towards solving these problems. However, these research fields can only be handled successfully if the capabilities that exist in agricultural science play a major supporting role in the subject areas to be handled through interdisciplinary cooperation.

The subject areas require further development both in terms of content and methodology, particularly for capturing the dynamics and interaction between the various system elements. The memorandum therefore also provides examples of how scientific methods can be developed further in order to bridge the gap between reductionist and holistic approaches. Of particular importance are research initiatives that transcend disciplinary boundaries; besides multidisciplinary initiatives, interdisciplinary and transdisciplinary potential must be utilised more fully.

The memorandum highlights the fact that agricultural science is system- and process-oriented. It differs from its related disciplines with which it has close relations in that it includes mankind as an active player in, and integral component of, the research approach. Taking the multifunctionality of agriculture as its starting point, agricultural research is concerned with the clarification and practical implementation of scientific, economic and ecological processes. Its goal is the qualitative and quantitative optimisation of crop and animal production and socio-economic processes. The subjects examined in agricultural research are the natural, biological and technical resources of man-made landscapes.

The scope of agricultural research extends from basic research to applied research of distinctly practical relevance. As a systems science, agricultural science uses both the methodological and theoretical instruments as well as the empirical knowledge of various related disciplines. It has, however, to a large extent developed its own methodology and autonomous theories, in particular in the areas of soil science, plant science and animal science, in engineering as well as in economics and the social sciences. Here, the advancements of agricultural science and the development of related disciplines stand in a close dialectic relationship.

In order to assess agricultural science as a problem-oriented systems science, not only research achievements but also collaboration between the agricultural science disciplines and the transfer of innovation into practice must be taken into account as significant criteria. Agricultural research has to be measured according to these criteria. However, the memorandum also provides guidelines on how agricultural science must be equipped institutionally and structurally in order to fulfil its scientific and social requirements.

Agricultural science forms its own scientific community. Its interdisciplinary and system-oriented research approach calls for close cooperation between the various subdisciplines which can best be provided within independent institutions such as university faculties with an appropriate strategic orientation.

In addition to specialists, covering the research fields requires scientists who possess technical knowledge from several disciplines. Institutional independence is therefore indispensable for the qualified training of young scientists and for teaching across disciplinary boundaries. At the present time, cross-departmental and cross-faculty centres of an increasingly interdisciplinary character are emerging both in Germany and abroad with the goal of integrating more closely with other scientific disciplines. It is particularly important here that despite difficult general financial conditions the full spectrum of the subject area has to be covered in order to comply appropriately with the holistic approach. To this end, specialist capabilities are required not only in the areas of soil science, plant science and animal science but also in engineering and in economics and the social sciences as cross-sectional disciplines.

What is important for the strategic and organisational re-orientation is raising the profile at the individual universities as well as collaboration between locations, institutions and departments. Co-operative projects between universities and non-university institutions should be further expanded, which is why appropriate framework conditions have to be established so that discernible benefits can be derived from the collaboration. In relation to research, appropriate funding instruments are available at the DFG to enable collaboration between both locations and institutions.

The training of junior scientists is of particular importance in agricultural science. Support must commence before the actual scientific work starts and should include career planning at the various phases of training. Structured postgraduate training, graduate schools, the Emmy Noether Programme or fellowships including funding specially intended to encourage scientists to return to Germany, all these are opportunities for providing improved support for young scientists. Furthermore, the discrepancy between the specialisation of future university lecturers and the concern to represent the subject fully across the board will have to be counteracted.

The social challenges give evidence of the considerable responsibility of agricultural science both in the national and in the international context. It must therefore be developed consistently and systematically both in terms of content and organisation. Only adequate framework conditions, particularly at the universities, can enable agricultural research to deal with the subject areas that are of long-term significance to society. The current uncoordinated cuts in capacity must be viewed as particularly critical for the preservation of agricultural science. In order to do justice to the international dimension of agricultural research, the performance of the locations must be strengthened.

1 Motives and Concerns

In 1957, the DFG published its "Denkschrift zur Lage der Landbauwissenschaft" [Memorandum on the State of Agricultural Science] (v. Massow 1957). Besides reviewing the contemporary situation, this memorandum contained recommendations as to how the agricultural and horticultural sciences could – under the general economic and social conditions prevailing at that time – keep abreast of international scientific developments. Since that time, the DFG has contributed substantially through its funding of Priority Programmes, Collaborative Research Centres, Research Training Groups and individual projects to improving the scientific basis of the subject area. As a result, agricultural research groups in Germany have made important contributions to the clarification of scientific, ecological and socio-economic interconnections and to the qualitative and quantitative improvement of procedures and their orientation towards sustainability in the production of food of vegetable and animal origin. Agricultural science expertise is much in demand in national and international commissions and organisations.

Changed conditions require a reorientation of agricultural research.

Notwithstanding these successes, it is noted that since the last memorandum the situation and conditions have changed substantially for agricultural science, yielding consequences for the principal focus of research. Some of the conventional areas of responsibility have decreased in significance, while new ones have been added and still others will play a decisive role in determining the direction of research in future. The shift of focus of research will be accompanied by continuing methodological advances, for example through the use of molecular-biological and bio-mathematical methods. Developments in terms of both content and methods must be viewed in

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the context of changed demands in society, and these are confronting agricultural research with major challenges.

The DFG's Senate Commission on Substances and Resources in Agriculture has taken these challenges as an opportunity to draw up a memorandum on the future perspectives of agricultural research. The aim of this memorandum is to define the key features and specific characteristics of agricultural research, to document its interaction with other disciplines and, by describing important fields of research, to indicate its future way ahead and to provide impetus for the further development of its content and institutional organisation. At the heart of the considerations will be Germany's universities and their integration within the national and international research environment.

The drawing up of the memorandum was accompanied by intensive discussions in the Senate Commission and by three additional events: the first of these took place in October 2003 at the Walberberg conference centre. The aim of this event, in which sixty scientists from agricultural science and related disciplines took part, was to take stock of current DFG funding, to analyse any shortcomings and above all to identify promising fields for future research in agricultural science. A second event was held in December 2003 in Bonn. One of the aims of these round-table talks was to discuss the key contents of the memorandum with potential addressees and in particular with decision-makers in order to inform them about the initiative and to take suggestions into consideration as early as possible. Representatives of federal and state ministries, the European Union and the German Science Council discussed requirements and brought forward valuable suggestions for the memorandum. Finally, in March 2004 a workshop was conducted in Bonn at which the intended content of the memorandum was discussed with about forty scientists from agricultural science and its related disciplines. This event also produced some important suggestions, which have been included in the text of the present publication.

A memorandum which deals with the future outlook for the subject area addresses by its very nature first and foremost its own scientific community. In this sense, it sees itself as a position statement for the subject area which is at the same time intended to provide food for thought and suggestions for the future direction of agricultural research. The authors hope that the discussions held in the course of drawing up this memorandum and the publication itself will result in new research initiatives, particularly as part of the Coordinated Programmes of the DFG, by means of which the status of agricultural science can be consolidated and enhanced both in Germany and internationally.

In addition, the memorandum also addresses the related scientific disciplines and decision-makers in universities and research institutions, as well as in politics and administration. Here, the intention is to improve the perception of the subject as a science which is still innovative and highly relevant to society and which has its own characteristics and strengths but of course also its weaknesses – as does ultimately every other discipline. With regard to the related fields, the publication aims to point out interfaces and complementarities so as to strengthen collaboration across disciplines.

One of the bodies at whom it is addressed is the German Science Council, which at intervals carries out cross-sectional reviews of major fields of research. In early 2004, the German Science Council set up a working group to prepare recommendations for its further development in terms of content, structure and institutional organisation using an inventory of agricultural research as a basis. With its concrete proposals, which principally relate to agricultural science at universities, but which also pick up on structural aspects, this memorandum aims to help shape the process of the further development of agricultural research as the DFG sees it.

Although efforts have been made, particularly where the recommendations are concerned, to be as concrete as possible, this publication aims to remain precisely what its name indicates: a memorandum whose prime function is to provide food for thought and by this means to set further developments in motion. The recommendations, which consequently do not yet constitute immediately implementable instructions, should also be interpreted in this spirit. In publishing this document, the authors hope that their proposals and ideas will be taken up and, as part of an ongoing discussion process, developed into concrete strategies.

2 Starting Situation

2.1 Definition and Delimitation

In the memorandum of 1957 mentioned in the introduction, the scope of agricultural science ("Landbauwissenschaft" as it was then called in German) is outlined as follows: "Agricultural science is concerned with the investigation of circumstances, processes and interdependencies in the field of agriculture which are amenable to scientific methods. Based on the natural sciences and on economics and the social sciences, it seeks to deepen and broaden knowledge of the interdependencies in its field through research and teaching" (v. Massow 1957). In principle, this description of the tasks it has to perform still applies today, although the range of functions ascribed to agriculture has expanded considerably since the end of the 1950s. Thus, according to a 1991 policy statement on the Common Agricultural Policy by the EC Commission, agriculture has not only functions as a producer of food but also has functions devolved to it in respect of the production of raw materials for industry and energy generation, the preservation of agricultural landscapes and the maintenance of the social structure in rural areas (EC Commission 1991). In the meantime, the term "multifunctionality" of agriculture, which was created in this context, has become a common term in agricultural policy.

In line with this expansion, the scope of agricultural science has also broadened considerably. It extends today to the sustainable use and shaping of the landscape and, in this context, also extends across the whole chain of food production, processing and marketing, including the factors determining food consumption. Modern agricultural research is today concerned with the clarification and

The multifunctionality of agriculture has broadened the remit of agricultural science.

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practical implementation of scientific, economic and ecological processes aimed at the qualitative and quantitative optimisation of plant and animal production as well as socio-economic processes. The natural, biological and technical resources of man-made landscapes form the subject matter investigated in agricultural research. The research includes a number of different disciplines and methods, all of which are concerned with the biotic and abiotic natural environment.

Agricultural science deals with the basic necessities of human life.

In this sense, agricultural science must be seen as a phenomenological science where the issues it deals with arise from the subject matter it refers to. It deals with the basic natural necessities of human life, in particular food production. Consequently, in all its observations of the natural biotic and abiotic environment, mankind is always seen as an active player and an integral part of the research approach. This reference to humans as active players on the one hand gives agricultural science a distinct process orientation and on the other distinguishes it from its related disciplines, for example biology or the geosciences, to which it nonetheless has close links.

In the present memorandum, agricultural research is to be understood within the meaning of this definition. Its content will firstly be delimited on the basis of the different land use options: the subject matter of agricultural scientific research is primarily agricultural (including horticultural) use, while less attention is paid to forestry and settlement use. The second delimitation is made with regard to the food chain. Here, the analysis begins with agricultural production and ends with the factors determining food consumption. These form the boundary with nutritional science, which deals primarily with the scientific and medical aspects of nutrition.

2.2 Institutions of Agricultural Research

There are a large number of institutions conducting agricultural research in Germany. This is partly due to the federal division of responsibilities and partly to the comparatively strong position of research-intensive companies, in particular in the fields of agrochemicals, seed production and agricultural engineering, operating worldwide. A comprehensive listing of the research-sponsoring organisations can be found in Lienemann and Knura (2004).

The universities continue to be the leading actors in government funded agricultural research. Through teaching and research at ten universities with agricultural and/or horticultural faculties, they form the basis in terms of personnel and finance of the multi-layered German research system. Universities of applied science offering courses of study in agricultural science and/or horticultural science, whose priority lies in applied teaching, also carry out research and development functions to varying degrees; there are currently thirteen such institutions.

Agricultural research is carried out at a large number of different institutions.

The federal ministries, in particular the Federal Ministry for Consumer Protection, Food and Agriculture (Bundesministerium für Verbraucherschutz, Ernährung und Landwirtschaft, BMVEL) and the Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF), are important sponsors of research. The BMVEL is currently responsible for seven research institutes. The principal function of these research institutes is to draw up basic scientific principles to be used to assist in policymaking in the areas of consumer protection, food and agriculture. The research institutions of the federal authorities are in principle required to adhere primarily to current policy stipulations.

The institutes of the Leibniz Association of German Research Centres (Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz, WGL) are financed jointly by the federal and state governments and are required to conduct applied basic research in the medium and long term. Out of the total of eighty WGL institutes, six fall under the jurisdiction of the BMVEL. Besides these, there are a number of others concerned with agriculture-related research. In addition, agricultural science issues are also tackled at a number of institutes run by the Max Planck Society and the Helmholtz Association of National Research Centres.

Besides the institutes of the federal government, the states also fund agricultural research. Similar rules apply to these with regard to the direction of research and the commitment of funds to institutions as at the federal government level. The functions of these research departments are more strongly oriented towards assisting administrative and hand-on decision-making in the states and towards the acquisition of knowledge to benefit agriculture and rural areas, in order to stimulate technological progress and to ensure sustainability.

While the aforementioned public institutions for agricultural research provide first and foremost the basic resources, project research is largely financed through third-party funds from public and private donors. Available internal university comparisons, the DFG's funding ranking (DFG 2003) and individually conducted evaluations show that agricultural research is characterised by a comparatively high volume of third-party funding, with funds attracted from the European Union taking up a constantly growing proportion.

2.3 Relevance of Agricultural Research to Society

Agricultural science strives to improve the basic necessities of people's lives. In this respect, it has scored major successes in the past. Significant advances in knowledge made in the early days of the discipline are associated with names such as Albrecht Thaer (1752–1828), Johann Heinrich von Thünen (1783–1850), Justus von Liebig (1803–1873) or Eilhard Alfred Mitscherlich (1874–1956)[1]. In the second half of the twentieth century, agricultural research provided the basis for the *green revolution*, for which Norman Borlaug, who is considered to have been its founder, was awarded the Nobel Peace Prize in 1970 (cf. Borlaug 1970; Brown 1970).

In 1974, the American nutritionist Jean Mayer[2] and his son André wrote in an article entitled *Agriculture, the Island Empire* that was to become famous: "Few scientists think of agriculture as the chief, or model science. Many, indeed, do not consider it a science at all. Yet, it was the first science – the mother of sciences; it remains the science which makes human life possible...".

[1] cf. Thaer (1809), Thünen (1826), Liebig (1840), Mitscherlich (1909).

[2] Jean Mayer was for a long time President of Tufts University in Medford, MA (USA); the USDA's Human Nutrition Research Center on Aging (HNRCA) is named after him.

The social relevance of agricultural research remains high.

This quotation, like the distinction awarded to Norman Borlaug, ascribes enormous social significance to agricultural science at that time. That this is still the view today is shown by the recently published findings of the *Copenhagen Consensus Project*[3]. An expert group of leading economists, including four Nobel Prize laureates, set out a priority listing of the most important challenges facing humanity. Among the eight topics accorded the highest priority, four are from agricultural science: the elimination of malnutrition, the development and introduction of new technologies in agriculture in general, the development and introduction, in particular, of irrigation techniques for peasants and, finally, research on the efficiency of water use in food production.

This shows that the subject matter of agricultural research cannot be restricted to national or regional contexts but is rather of global significance. It is therefore also in the intrinsic interest of agricultural research to orient its research activities internationally and to give them international prominence. In this regard, agricultural science in Germany can point to notable successes. Thus, the internationally oriented Collaborative Research Centres, Research Units and Research Training Groups[4] funded by the DFG are gaining worldwide recognition.

[3] Information on the Copenhagen Consensus Project can be found on the Internet at: http://www.copenhagenconsensus.com

[4] Notable amongst these are the Collaborative Research Centre 564 “Nachhaltige Landnutzung und ländliche Entwicklung in den Bergregionen Südostasiens” [Sustainable Land Use and Rural Development in the Mountainous Regions of South-East Asia], the Research Units “Protected Cultivation – An Approach to Sustainable Vegetable Production in the Humid Tropics” (Research Unit 431), “Strukturwandel und Transformation im Agrarbereich” [Structural Change and Transformation in the Agricultural Sector] (Research Unit 497), “Matter Fluxes in Grasslands of Inner Mongolia as Influenced by Stocking Rate” (Research Unit 536) and the International Research Training Group “Modellierung von Stoffflüssen und Produktionssystemen für eine nachhaltige Ressourcennutzung in intensiven Acker- und Gemüsebausystemen der Nordchinesischen Tiefebene” [Modelling of Matter Fluxes and Production Systems for Sustainable Resource Use in Intensive Arable and Vegetable Gardening Systems of North China Plain] (Research Training Group 1070).

Image 1: Typical land use system in mountainous regions of Vietnam (Collaborative Research Centre 564 "Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia")

Agricultural research is internationally prominent and enjoys worldwide recognition.

The international relevance of German agricultural research is also reflected in the attention paid to it by publications, as can be seen from a bibliometric study in Nature, in which the scientific performances of seven countries are compared across forty-seven disciplines, including "agriculture" as a discrete analytical category: measured against the "Relative Citation Index (RCI)" as an indicator of research impact, German agricultural science comes in fourth place among the seven countries included in the comparison, behind the USA, the UK and Australia and ahead of Canada, France and Japan. It can thus be seen that only English-speaking countries, which have a "natural" advantage with regard to the international prominence of publications are better placed. According to this study, agricultural science constitutes one of the particular strengths of the German research environment. Its research impact lies significantly above the average for all disciplines. It ranks in second place behind applied mathematics and ahead of physics and electrical engineering (Adams 1998).

Thus, while agricultural research finds a level of recognition among experts that accords with its continued high degree of relevance, this is not at all the case as far as its public perception is concerned. This may in part be due to the fact that people, particularly in the developed world, have become accustomed to a plentiful supply of high-quality food. Added to this is certainly also the fact that the individual findings of agricultural science usually tend to be rather unspectacular and rarely make the headlines. Only in the context of the system as a whole can the success of agricultural research be clearly discerned, as the example of the *green revolution* strikingly shows.

Modern agricultural research, as previously defined, is heavily influenced by national parameters such as laws and regulations at state or federal level. The subject matter of research as such cannot, however, be restricted to any particular national or regional areas, but is rather of global significance. It must therefore also be in the intrinsic interest of agricultural science to orient its research activities internationally and to give them international prominence. The observations in this memorandum must be interpreted accordingly.

3 Characteristics of Agricultural Research

3.1 Agricultural Research as Problem-oriented Systems Research

"Even in oral traditions, agriculture has always been perceived as a system... More than ever, the science of agriculture stands at the centre of a broader system integrating human society and its physical environment". This quotation from André and Jean Mayer (1974) characterises agricultural research as *systems research*. The subjects of its investigations are complex natural, technical and social systems.

Agricultural science is a systems science.

The systems approach proceeds from the basic idea that many phenomena and processes can in reality be recorded and explained only inadequately using the classical monocausal scheme. It is instead necessary to develop more comprehensive concepts which simultaneously consider a larger number of causal relationships. The isolated view under *ceteris paribus* assumptions is replaced by the holistic or systems approach. This concept is closely related to the name of the biologist Ludwig von Bertalanffy, who saw in a general systems theory the opportunity to promote collaboration between separate disciplines and to discover regularities which are beyond the scope of individual sciences. He emphasised the openness of biological systems to influences from their environment and the principles of self-regulation (homeostasis) and of equilibrium (cf. v. Bertalanffy 1968).

Agricultural research deals with agricultural ecosystems and with the socio-technical and socio-economic circumsystems and supersystems which influence them. Fig. 1 describes the system studied by agricultural science,

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which comprises the agroecosystem, containing the subsystems "soil", "plants" and "animals" as well as humans in their dual role as parts of the system itself and as control agents of the whole system. This is what constitutes the special feature agricultural-type ecological systems. As control variable, humans exert influence on inputs as well as outputs and interactions within the system. With humans functioning as an interface, the areas of technology, economy and society act upon the overall system.

System dynamics and interactions between system elements are incorporated in quantitative models.

The key feature of this approach is that it captures the dynamics and interactions between the various elements of the system, with particular emphasis on the nonlinear relationships which are typical for most biological systems and which result in extraordinarily complex behaviours. Examples include the investigation of nutrient dynamics and plant growth, the development of concepts and strategies for integrated plant protection, studies of the acceptance and adoption of new production techniques and the analysis of the economic and ecological implications of changes in economic and agricultural policy conditions, e.g. globalisation. In many cases, quantitative models are employed which have been developed by agricultural science itself or adapted for its particular purposes.

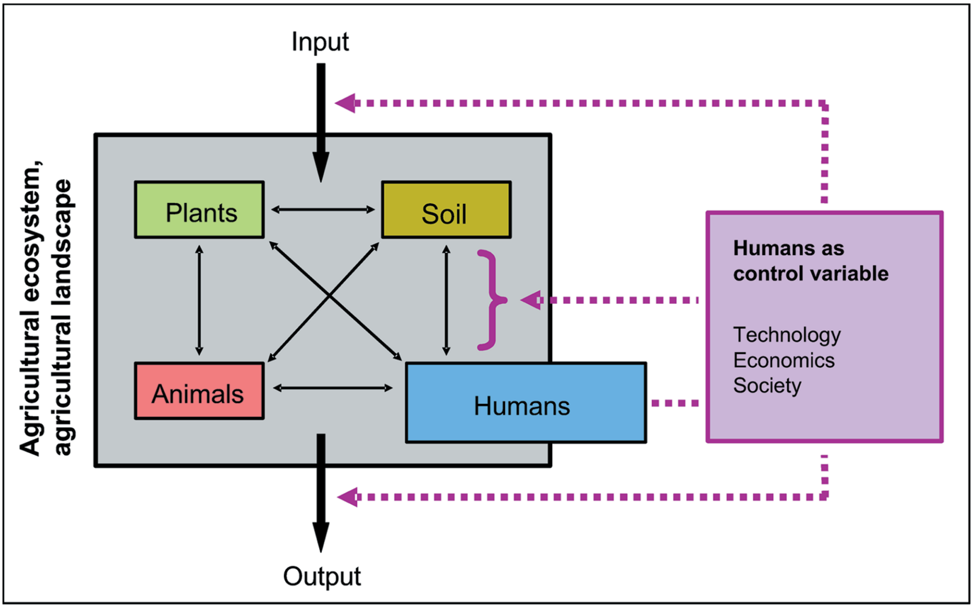

Figure 1: System studied by agricultural science.

Thus, a range of computer-simulation models now exists which are capable of representing the growth dynamics of plant crops depending on weather variables and nutrient and soil conditions (cf. Diekkrüger et al. 1995). These simulation models are based on pioneering studies by De Wit in Wageningen in the 1960s and contributions by other agricultural research institutes (Bouman et al. 1996). They originally pursued the goal of integrating and quantifying the interaction of various biophysical processes in order to achieve a better understanding of the observed yield variations. More recent areas of application lie in land use planning, climate impact research, *decision support* systems and GIS- and GPS-assisted *precision agriculture* (GIS = *Geographic Information System*, GPS = *Global Positioning System*). They increasingly serve as heuristic tools in scientific research and training, land use planning and the study of the ecological and environmental effects of land use. Finally, they will in future also be used in order to gain an improved understanding of genetic regulation of the actual and potential performance of plants (Hammer et al. 2002).

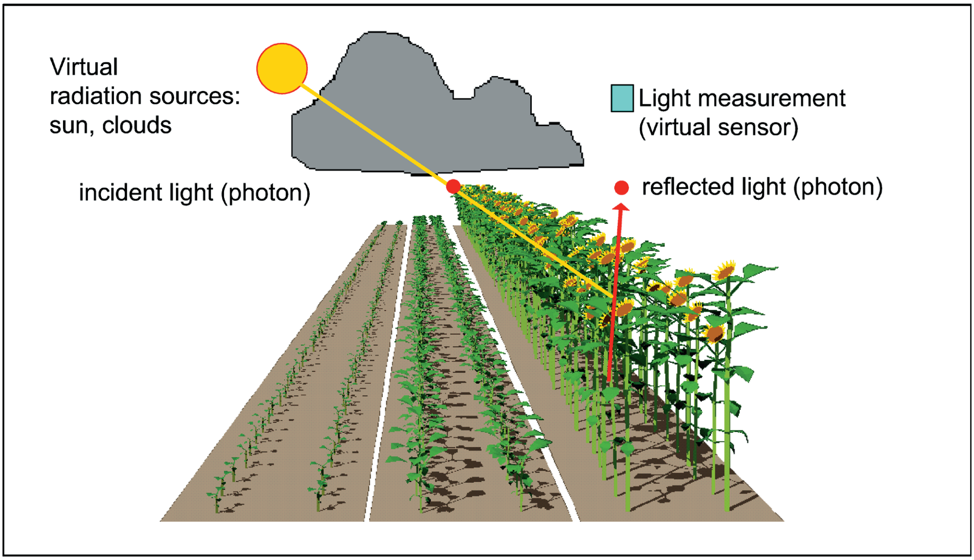

Image 2: Virtual plants: quantification and visualisation of the development conditions and radiation regime (reflection, light and shade) of a crop by means of computer simulation (Research Unit 472 "Virtual Crops – Architecture and Process-oriented Modelling and Visualisation of Crop Stands").

One of the most widely recognised models in livestock science is the model of population genetics which was described by Falconer (1960). Breeding success with farm animals in recent decades has been based essentially on the implementation and further development of this model within the framework of breeding planning and the development of breeding programmes. It will be extended in future by the inclusion of molecular-genetic information.

Single-farm (Zander & Kächele 1999) and spatially based (Balmann 2001; Fohrer et al. 2002; Kuhlmann et al. 2002) models have also been developed and used in order to quantify the economic and ecological effects of changes in agricultural structure and land use. Scientific and technological principles also form the basis of sectoral approaches for analysing the impact of changes in general conditions in the economy and agricultural policy, e.g. as a result of the latest expansion of the European Union (cf. Heckelei et al. 2001). Modelling concepts have also found their way into the teaching of agricultural science courses.

Quantitative models also form the nucleus of many projects funded by the DFG, beginning around 1980 with the Collaborative Research Centre 110 "Basic Data and Structures of Bio-economic Models for Energy and Labour Saving Technologies in Horticultural production" (cf. Krug and Liebig 1989). Besides numerous individual projects, the DFG currently funds a series of Coordinated Programmes in which modelling is a central element[5].

These examples characterise the approach to research in agricultural science which is oriented towards solving problems of relevance to society and which for this purpose develops scientific methods that make it possible to build bridges between reductionist and holistic approaches.

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[5] Noteworthy examples include the Collaborative Research Centre 299 "Land Use Options for Peripheral Regions", the Research Units "Virtual Crops – Architectural and Process-oriented Modelling and Visualisation of Crop Stands" (Research Unit 472), "Information System Site Specific Crop Management – Dürnast" (Research Unit 473) and the Research Training Groups "Strategies for Preventing the Emission of Climate-relevant Gases and Environmentally Toxic Substances from Agriculture and Land Use" (Research Training Group 259) and "Use of Information Technologies for Precision Crop Protection" (Research Training Group 722).

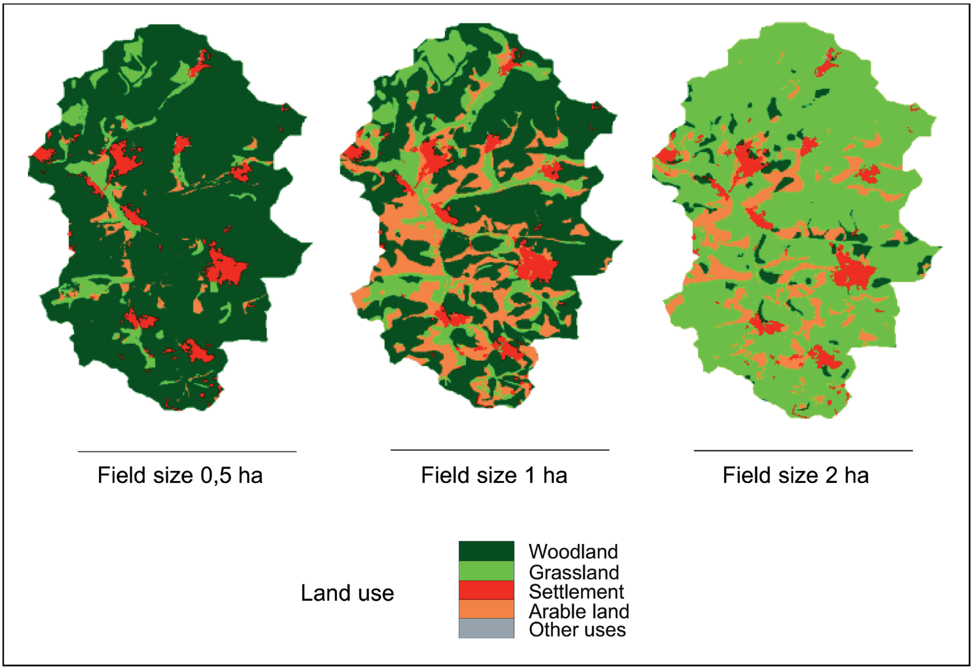

Image 3: Distribution of land use according to plot size. Analysis of complex ecosystems using process-based models, based on the example of ProLand scenarios for the Aar region (Collaborative Research Centre 299 "Land Use Options for Peripheral Regions").

3.2 Agricultural Research as Cross-disciplinary Research

Problem-oriented research is in essence always cross-disciplinary, since important problems in the real world always contain aspects which transcend the boundaries of individual sciences (Klir 1991). It should also be noted "that it is less and less the case that new scientific knowledge is generated exclusively within the context of a single discipline and from there transferred to wider areas of application in society as a basis for innovative products and services" (Wissenschaftsrat 2002a).

Agricultural science issues always have a scientific, a technological and a socio-economic dimension.

Both aspects apply in a particular way to agricultural research. On the one hand, agricultural science issues – for example questions regarding the sustainability of land use – always include scientific, technological and socio-economic dimensions, which can be examined only on the basis of interdisciplinary research concepts. This explains the fact that agricultural research sees itself as systems research. In order for its research objectives to be achieved, it must therefore be ensured that the different specialist fields of agricultural science such as crop science, livestock science, ecology, economic and social sciences, technological sciences and soil science are adequately represented.

On the other hand, it is essential, in order to be able to comply with the requirements of a problem-oriented science and to maintain the innovative potential of agricultural research, that a link be guaranteed between basic research and applied research. This is shown, for example, by research in the field of precision agriculture which extends from basic research to practical application and in this way gives rise to innovative products. In many cases, the transfer into practice can be achieved through transdisciplinary research. Of all the areas of research, agricultural research is the one which has implemented the most impressive projects in the area of transdisciplinary research in recent years, for example the project on "Approaches towards Sustainable Environmentally Sound Agricultural Production: the Model Region North-East Germany (GRANO)" and the project "Man-made Landscape of Hohenlohe" (Hagedorn et al. 2002; Müller et al. 2002; Kirchner-Heßler et al. 2004).

Agricultural science is a multidisciplinary science.

In order to be able to meet the requirements of problem-oriented systems research, agricultural research sees itself as a multidisciplinary science which, depending on the research subject, also implements interdisciplinary and transdisciplinary projects[6]. Agricultural research is a multidisciplinary science by virtue of the complexity of its subject area, which demands the collaboration of natural sciences and engineering sciences with the social and cultural sciences. Without such collaboration, which has to cover the entire spectrum of agriculture, it is not possible to manage the interdisciplinary issues typical of agri-

[6] Regarding the meanings of the terms multidisciplinarity, interdisciplinarity and transdisciplinarity cf. Kocka (1987), Mittelstraß (1987).

cultural research. For example, sustainable land use concepts can be developed only with the involvement of the various specialist agricultural science disciplines. It is only through the merging of the knowledge, methods, theories and research results of the specialist disciplines that a comprehensive picture emerges, which matches the heterogeneity of the real phenomenon.

Many research questions call for interdisciplinary and transdisciplinary approaches.

For many research issues, a multidisciplinary approach to research is not sufficient. This is particularly true where complex relationships of cause and effect, such as the impact of livestock management systems on animal physiology (animal behaviour), are examined. Interdisciplinary collaboration is required in such cases. In agricultural research, this takes place in two ways. Firstly, two or more specialist disciplines conduct research jointly in order to produce methods or results which lie on the boundary between the disciplines and which can be put to joint use. In recent years, for example, interdisciplinary collaboration with various basic sciences has taken place in the borderline areas between immunology and disease-resistance research. Secondly, different specialist disciplines cooperate on issues which are to be researched jointly so that the complexity of the real-life sequences of events can be taken into account. This type of research includes, for example, investigations into the consequences of structural changes in rural areas.

As already emphasised, agricultural research is also characterised by transdisciplinary research approaches, i.e. the integration of practical knowledge, the solution of problems, taking into account non-scientific developments, and an iterative research process. This research approach is always advisable if the "local players" are not only the subject matter of the research but are also involved in enhancing the practical relevance of the research results. An example of this is the *International Farm Comparison Network (IFCN),* launched by the Federal Agricultural Research Centre (Bundesforschungsanstalt für Landwirtschaft, FAL), the goal of which is to analyse the impact of economic, technological and political developments, with the involvement of members of panels created specifically for that purpose (Hemme et al. 1999).

Despite many successes with interdisciplinarity and transdisciplinarity, it can nevertheless be stated that agricultural research is not yet utilising its multidisciplinary potential to the full. Often, agricultural research appears

Image 4: Participatory field research with farmers in Thailand (Collaborative Research Centre 564 “Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia”).

to have only inadequate interdisciplinary links. One reason for this is that the subdisciplines within agricultural science, for example agronomy, are substantially more broadly based than is typically the case in the basic disciplines of natural science. Consequently research issues within a subdiscipline of agricultural science can in many cases already be termed interdisciplinary. Another reason is the fact that interdisciplinary and transdisciplinary research, although called for by science policy, is funded, recognised and rewarded only inadequately. Finally, in some cases the various specialist areas of agricultural science have already been so heavily cut that they no longer have adequate resources to invest capacity into interdisciplinary and transdisciplinary research as well as to preserve their specialist disciplinary expertise.

3.3 Scope of Agricultural Research

Agricultural research extends from basic research to applied research.

The problem-oriented approach of agricultural research also means that the key point of reference is the real system to which the respective research issue relates. Research questions therefore cannot be tackled solely in model systems or in laboratory trials, rather translation to the real system in the sense of field research or field trials is required in order to move towards solving a problem. Thus, the remit of agricultural research extends across various scale levels from problems of basic research to applied research with distinct practical relevance. The systems approach is characterised by the integration in the research chain of "laboratory research", "controlled experiments at experimental stations" and "practical field research". An example of this is plant breeding, where the combination of molecular genetic results and phenomenological results from controlled but practically relevant trials at experimental stations provides the basis for breeding advances.

The logical consequence of the broad scope of research, ranging from disciplinary to interdisciplinary or transdisciplinary and from basic to applied research, is that the level of expertise and knowledge of the subject area also heads to cover this area comprehensively. The scientific community in agricultural science thus inevitably comprises both "specialists" from the various basic disciplines and "generalists" who, in addition to focusing on one discipline, also have broader expertise. It is only intensive cooperation between them that creates the conditions for being able to successfully process and solve the complex problems of agricultural research.

3.4 Interactions between Agricultural Science and its Related Disciplines

Agricultural science has always been closely interrelated with a large number of other scientific disciplines (Fig. 2). The diversity of these interrelations is probably greater than is the case in any other science. However, it is part

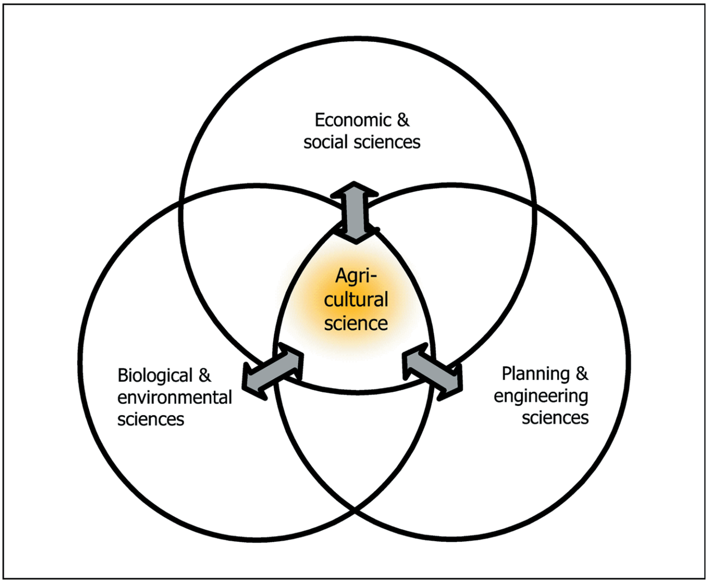

Figure 2: Interactions between agricultural science and related scientific disciplines.

of the nature of agricultural science as a systems science that it accesses both the methodological and theoretical tools and the empirical knowledge of the biological and environmental sciences, economics and the social sciences, of the planning and engineering disciplines and of other cross-sectional subjects (for example forestry, veterinary medicine and human medicine), in order to make these usable for resolving agricultural science issues.

The interrelations between agricultural science and related disciplines are particularly intensive at the level of sub-disciplines (for example plant breeding – genetics; agricultural engineering – mechanical engineering; agricultural economics – economics and business administration) and are also stimulated considerably at that level by the exchange of scientists. In these areas, the subdisciplines of agricultural science are frequently viewed as applied extensions of the respective basic subjects, which does not, however, do justice to the nature of agricultural science as a systems science. For what is applied science and what is basic science emerges from the system definition and the level of observation: In the same way that from the viewpoint of cell biology chemistry is a basic science, but from the viewpoint of nuclear physics it applies physical principles and methods, so yield physiology is on the one hand an “application” of plant physiology and on the other a “basis” of agricultural ecology and of agricultural economics. Each discipline is thus – depending on the level of observation – both a basic and an applied discipline. What distinguishes each discipline is its own scientific methodology, which makes use in part of methods taken from other levels but, according to its particular objective, adapts these, develops them further and combines them with other methods.

The interactions between agricultural science and its related disciplines take on a variety of forms and permeate all areas: empirical science, methodology and theory. In principle, all relevant methods found in related disciplines are also employed in agricultural research. These include

- general scientific methods, for example mathematical and statistical methods and modelling,
- natural science methods, for example physical, chemical and biological methods of measurement and
- specific social science and economics methods, for example quantitative and qualitative methods of empirical social research,

which cannot be given in detail here. In general, the use of a specific technology or method is determined by the objective or the hypothesis which shall be tested. It is thus primarily independent of the scientific field. For agricultural research problems, it has only to be checked whether these can be solved using existing methods or whether specific modifications and optimisations are required.

Agricultural research will in future continue to avail itself of existing methods from related disciplines and to adapt these where necessary to its own needs. However, the nature and intensity of the interactions with the various related disciplines is determined to a large extent by the current issues and problems. Thus, for example, the current paradigm change of agricultural research – especially in relation to agriculture in the industrialised countries – is leading to greater interaction with the environmental and social sciences, and ecology is gaining in importance as a source of relevant theory. This makes it clear that the significance of the individual related disciplines to agricultural research is tied less to the nature of the research than to its purpose.

The intensive interactions with related disciplines have recently also stimulated greater specialisation in agricultural science (for example livestock science, crop science, economics) and the dissolution of subject boundaries in special subject areas (for example biotechnology). Although specialisation within the subject – as in other scientific domains – appears timely and inevitable, it is not without problems if it is expanded at the expense of interdisciplinary or "generalist" skills. The latter are essential for the problem-solving capacity and are based on the ability to combine approaches from the natural sciences with approaches from the engineering sciences, economics and social sciences.

Agricultural research needs its own methodology and theory.

Although agricultural research draws extensively on the arsenal of methods and level of knowledge of related disciplines, it is also to a large degree dependent on developing its own original methodology and theory. This demand for an own methodology and theory exists primarily in the core area of agricultural research, where biological and ecological, economic and sociological and engineering science issues meet. Such interdisciplinary tools are rarely supplied by related disciplines. Multi- and interdisciplinary research, and the methodological and theoretical basis required for it, therefore fall within the actual core area of the systems sciences. These relate in particular to methods of integrating, evaluating, planning and forecasting which are used in managing creatively and sustainably conflicting goals of land use arising regularly in the area of tension between technological, socio-economic and ecological needs. Such methods are also used in other systems sciences.

The modelling and simulation of biological systems and their interactions with the environment are among the primary achievements of agricultural research.

Among the primary methodological achievements of agricultural science are the mathematical modelling and dynamic computer simulation of biological systems and their interactions with the environment, which originated in agricultural research and now belong to the most important tools of the biological and environmental sciences. In animal nutrition and nutritional physiology, innovative methods of fodder and food quality assessment and of nutrient efficiency as well as methods for determining the "carry-over" of certain substances in the food chain have been developed. Among the methods originating from agricultural science which have found their way into related disciplines are for example variance analysis, specific breeding methods (cloning), and quantitative genetic modelling (QTL, *Quantitative Trait Locus*), which has its origin in studies conducted by Sax (1923) on beans. The term "quantitative trait locus" emerged much later and appears in databases (PubMed) for the first time in Rick and Tanksley (1983). However, methods to assess quantitative attributes had already been presented in 1975 by Geldermann (Geldermann 1975). While before 1990 it were almost exclusively agricultural research departments which dealt with the analysis of QTLs in animals or plants, after 1990 a veritable explosion occurred in QTL studies which have recently also included studies in humans. As in the example described, agricultural science has made a large number of original and significant contributions to other disciplines such as biology, the nutritional sciences and food technology, as well as modern reproductive medicine. These examples illustrate that advancements in agricultural science and the development of related disciplines stand in a close dialectic relationship.

3.5 Criteria for Assessing Problem-oriented Research

Criteria for assessing the quality of agricultural research derive from its specific features as problem-oriented systems research. These consist principally of three elements:

- the close connection between basic and applied research,
- the multidisciplinary, interdisciplinary and in part transdisciplinary character of agricultural research and
- the orientation of the research towards the solving of issues of relevance to society.

Important quality criteria are research output, interdisciplinary collaboration and the transfer of innovations into practice.

These give rise to three types of quality criteria. Firstly, the research outputs, which provide information about the standard of the science, must be looked at. Secondly, the collaboration between the specialist disciplines of agricultural science must be examined and the resulting gain in terms of synthesised output and synergy effects evaluated. From these, the degree of successful interdisciplinary collaboration can be determined. Thirdly, the transfer of innovation into practice must be scrutinised in order to demonstrate successful application of research. In this process, account must be taken of both innovative products such as for example the rapid BSE test (BSE = *Bovine Spongiform Encephalopath*y), and innovative services such as advisory concepts.

When weighting the three criteria, the greatest importance should of course be attached to the research outputs. Internal knowledge transfer between the scientific disciplines and between basic and applied research, which must be guaranteed systematically and institutionally, stands in second place. This can succeed only if the scientific disciplines of agricultural science are adequately represented locally. The transfer of knowledge into practice forms part of the way agricultural research views itself and traditionally falls within its social remit. It must, however, always be built into research questions in order to generate both research-relevant and practical knowledge.

When evaluating the scientific quality of agricultural research, however, appropriate consideration must also be given to the particular characteristics and special functions of the various scientific disciplines. For example, modern research into breeding predominantly focuses on basic research and is consequently closely involved in exchanging knowledge with the basic natural science subjects, while agricultural engineering research tends to be more application-oriented and has close links to the engineering sciences. The three types of quality criteria must therefore be applied to agricultural research as a whole, but not with equal weighting to each discipline.

Evaluation criteria introduced must be specified for agricultural research.

In order to specify the three types of quality criteria for agricultural research, the evaluation criteria introduced, in particular those of the German Science Council, must be taken as a starting point (Wissenschaftsrat 2002 b; Röbbecke & Simon 2001). For evaluating research outputs, the following criteria are thus of prime significance:

- a coherent research concept with cogent focus of research interest, integrative research approaches and innovative strategic outlook, evident *inter alia* in raising the profile and emphasis of research directions such as environmental science, life sciences, molecular research, bioengineering or the generation of knowledge for political decision-making;

- peer reviewed publications in scientifically recognised journals and publishing houses, patents taking into consideration the specific characteristics of the disciplines;
- the international research landscape, which is documented in joint projects, the exchange of scientists and invitations to international conferences;
- attraction of competitively awarded third-party funds, national and international cooperative projects.

The internal transfer of knowledge, which is documented in research projects, publications, colloquia, conferences, etc. covering several specialist disciplines, is crucial to the evaluation of collaboration between agricultural science subjects. Innovative long-term cooperative projects (centres) and integrative research initiatives at the level of the overall phenomenon (for example food chain, systemic research) can be used as indicators of the synthesised output, in which the particular scientific profiling of agricultural research relative to other sciences is demonstrated. Particular attention should be paid to collaboration between natural, engineering, social and cultural sciences.

In order to assess the transfer of innovation into practice, the following criteria have proven useful:

- successful practical and field access (knowledge of structures and institutions in the agricultural sector, trials in farms);
- involvement in decision-making and advisory bodies (demand for research outputs in practice);
- publications which address the farming community (access to the media and organs of publication which are aimed at the agricultural sector);
- attraction of third-party funds for practically-oriented research;
- cooperative projects with the major players in the agricultural sector, satisfaction of users and practical implementation in innovative products and services.

The criteria also provide guidelines for the institutional and structural organisation of agricultural science.

The criteria described here should not, however, only be used for assessing the quality of agricultural research. Rather, they also contain guidelines as to how agricultural research should be organised institutionally and structurally in order for it to comply with scientific and social requirements. This applies in particular to the breadth of subject matter which must be assured in order to be able to support an interdisciplinary research concept and to form the link between basic and applied research, without which problem-oriented system research cannot be carried out.

4 Future Perspectives

4.1 Changed General Conditions in Society

Demands on agricultural research are subject to constant change.

As problem-oriented research, agricultural research is always carried out in the context of the general social conditions currently prevailing. Among these, the following are of particular importance:

- worldwide population growth against the background of increasingly scarce resources,
- global climate change,
- globalisation and liberalisation of world trade,
- changed preferences in society.

The world's population crossed the six billion mark at the end of 1999 and currently stands at about 6.3 billion. According to projections by the UN, this number will increase by between two and four billion by 2050. The mean forecast version predicts a world population of 8.9 billion for 2050. This growth will take place exclusively in developing countries, while in the industrialised countries stable population figures or even reductions in population are anticipated. One of the major uncertainties in the forecasts is migration, in particular migratory movements across international borders (Cohen 2003).

Food for the world's population is not secure.

Of the total of over six billion people living on the earth today, approximately one billion live in poverty and misery, three billion manage to make ends meet, one billion live well and one billion live in affluence (v. Braun 2002). Despite a significant improvement in the world's food situation over the last three decades – in which agri-

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cultural research has played a decisive role – the absolute number of people starving has not fallen significantly (v. Braun 2002). Food for the world's population is therefore by no means secure. In order to put an end to today's hunger and to ensure adequate nutrition for the next three billion people to arrive on earth, sustained progress will be required in eliminating poverty and thereby improving access to food (BMELF 1997). Over and above that, however, substantially higher growth in production than at present will be required in many regions.

The necessary increase in production will have to be achieved with diminished natural resources (Fig. 3). The cause of this is the population growth itself which, in conjunction with growing demands for land for housing, industry and transport, is leading to a steady loss of land for agricultural production as a result of soil sealing. Added to this are losses of land as a result of degradation and desertification, the latter being brought about by the growing shortage of water as a resource and by global climate change. The consequences of the geographical shift in cultivation zones as a result of climate change are still difficult to predict at present. The decline in biological diversity caused by the human population is also alarming. Plant and animal genetic resources for nutrition and agriculture, in particular, are, as part of this biodiversity, the focal point of agricultural research, because they form the biogenic foundation for world food security and the basis for existence of every human on the earth.

Against this background, combating hunger in the world will continue to present a tremendous challenge to science in future. As well as undernourishment, malnutrition (for example vitamin A and iron deficiency) is a grave and steadily growing problem. In all of this, the sustainability of resource use will ultimately have to be ensured so that short-term improvements in the food situation are not paid for in the long-term by an increase in global environmental problems. This task confronts not only the developing countries, where the bulk of undernourished and malnourished people live today and the further population increases will take place. For globalisation and the liberalisation of world trade will in principle make it possible to produce in the locations best suited for the purpose. This also includes the industrialised countries, where a surplus of food is available and/or (can be) produced.

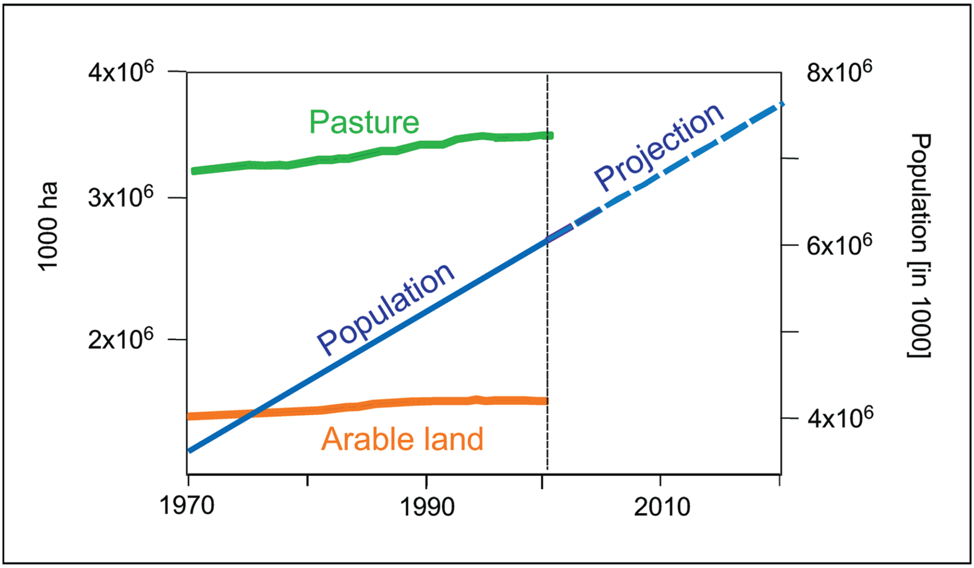

Figure 3: A growing global population is faced with a limited area for agricultural production (Source: FAOSTAT, 2001).

Growing world trade increases the risk of the spread of diseases and epidemics.

The rise in the degree of division of labour which the growth in world trade has brought about does not, however, only have positive effects on welfare. Rather, the global exchange of plants and animals also bears the risk of diseases and epidemics spreading worldwide, as the incidence of foot-and-mouth disease in Europe very recently demonstrated. Similar examples can also be cited in relation to crop production: the "tomato spotted wilt virus" (TSWV), which leads to substantially impaired quality in vegetables and ornamental plants, the bacterial pathogen of fire blight in fruit plants, *Erwinia amylovora*, and the soy bean rust *Phakopsora pachyrhizi*, which is already threatening the cultivation of this important protein plant in South America, or the "western corn rootworm" *Diabrotica virgifera virgifera*, which, accidentally introduced from North America, is now also threatening the production of maize in Europe (Fig. 4). The safety and quality of products are also gaining in importance as a consequence of globalisation. In the developed world, this is already visibly reflected by the increasing importance of consumer health protection.

The latter is simultaneously also an expression of changed social preferences, which are reflected above all in attaching greater importance to *quality* as opposed to

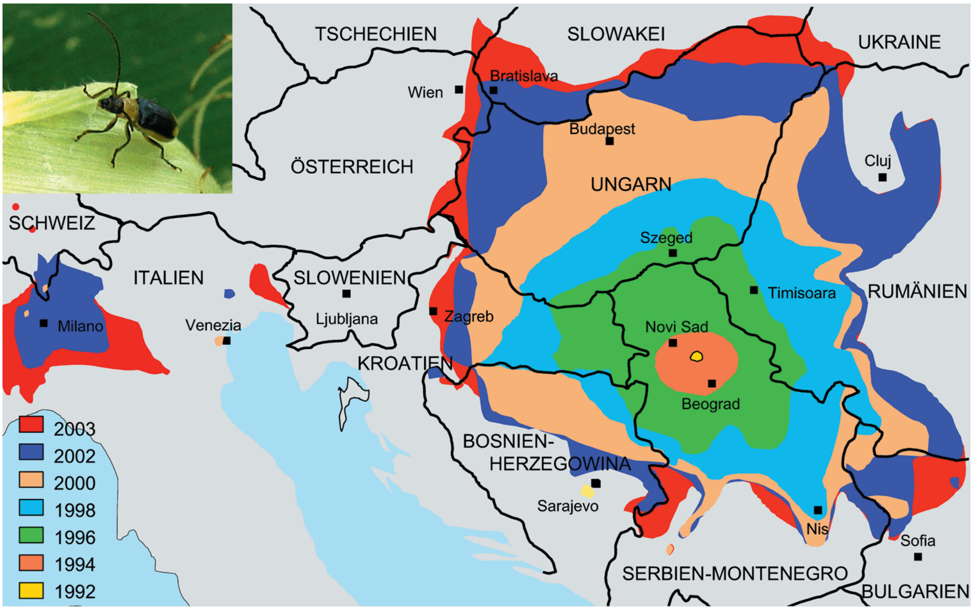

Figure 4: Spread of the western corn rootworm *Diabrotica virgifera virgifera* (introduced from North America to South-Eastern Europe) between 1992 and 2003 (amended according to FAO 2004).

quantity. Alongside product quality, process quality is also increasingly gaining in importance. This in turn is closely connected to the goals of sustainability and resource protection and requires attention to be paid to the entire process chain from land use and agricultural production to food manufacture and marketing in a systems science sense.

Worldwide problems place a special responsibility upon agricultural research.

To summarise, it can be stated that the problems which agricultural research faces have in no way diminished. They have, however, shifted in terms of content, creating new challenges that have to be confronted. The international dimension, which not only represents a challenge for agricultural research but also places a special responsibility upon it, no doubt merits particular attention.

4.2 Fields and Subjects of Research

Regional and global demands confront agricultural research with major challenges. In the way it sees itself covering the entire production chain from the management of natural resources to the supply of high-quality foods for the consumer and the sustainable disposal of waste and integrating itself as a discipline in ecosystem analysis, agricultural science will have to reorient itself and develop its research focal points and corresponding methods accordingly. Besides the core areas of agricultural science, this reorientation also covers issues of sustainability, landscape conservation and the establishment of recreational landscapes.

Problem areas of agricultural research are of global significance.

In intensive discussions conducted prior to the drawing up of this memorandum, key fields of research in the various disciplines of agricultural science were identified for priority treatment in the future. These include three subject areas of prime importance, although the listing is by no means exhaustive:

- environmental standards and quality assurance
- agricultural landscape research
- global food security

The discussions also made it clear that the three problem areas specified cannot be confined within national or regional boundaries but are of global significance, even if differing emphasis is attached to them regionally. Relevant fields and subjects of research are presented below by way of example.

4.2.1 Environmental Standards and Quality Assurance

If environmental standards and quality assurance targets are to be met, process chains must be investigated.

A key function of future agricultural research will be to ensure compliance with environmental standards and standards regarding assurance of quality in food production which are stipulated in a large number of environmental targets and plans of the federal states and of the federal government and including the reform of the *Common Agricultural Policy* (CAP) of the European Union published on 26 June 2003. This goal necessitates the study of process chains in the transformation process of agricultural products, both from the agricultural point of view and from the consumer-oriented viewpoint. This research also requires a systems-oriented approach which considers all the subcomponents of this process – from the soil to plants, animals and humans. Examples from the past, such as the BSE crisis, make it clear that in future environmental and quality assurance standards can only be fulfilled and appropriate risk management guaranteed if the details of process chains are known. The investigation of information flows is therefore a prerequisite of compliance with appropriate standards. This also includes new types of analytical procedures, for example stable isotope signatures of agricultural products which enable conclusions to be drawn as to their origin and the methods used to produce them.

Nutrient efficiency in agricultural ecosystems must be raised.

In order to be able to comply with environmental standards, the study of substances and matter fluxes in the soil/plant/animal/human system is necessary. Increasing nutrient efficiency is particularly important in this regard, firstly because low nutrient efficiency levels are regularly linked to increased environmental pollution (atmospheric pollution and water pollution), and secondly because scarce resources worldwide (e.g. in the case of phosphorus) make increasing nutrient efficiency an urgent necessity. Studies into increasing nutrient efficiency have to be conducted for different agricultural ecosystems with their own specific intensities. Finally, land use systems must be developed which, through the integration of new methods, such as for example methods from molecular biology and from GPS-assisted "precision farming", will enable more efficient deployment of these nutrients. This research focus is acquiring particular urgency against a background of intensified agricultural activity in connection with an increase of surpluses in nutrient balances and consequently with a reduction in nutrient efficiencies in many emerging and developing countries (for example China, Vietnam, Korea) (Syers et al. 2002). Developments are thus coming to light in these countries which have caused extensive environmental problems, such as for example the eutrophication of rivers and seas, in countries with highly intensive agriculture (Europe) in the past. As a result, in past decades substantial research funds have had to be spent in order to develop procedures for cleaning up these land use determined environmental problems.

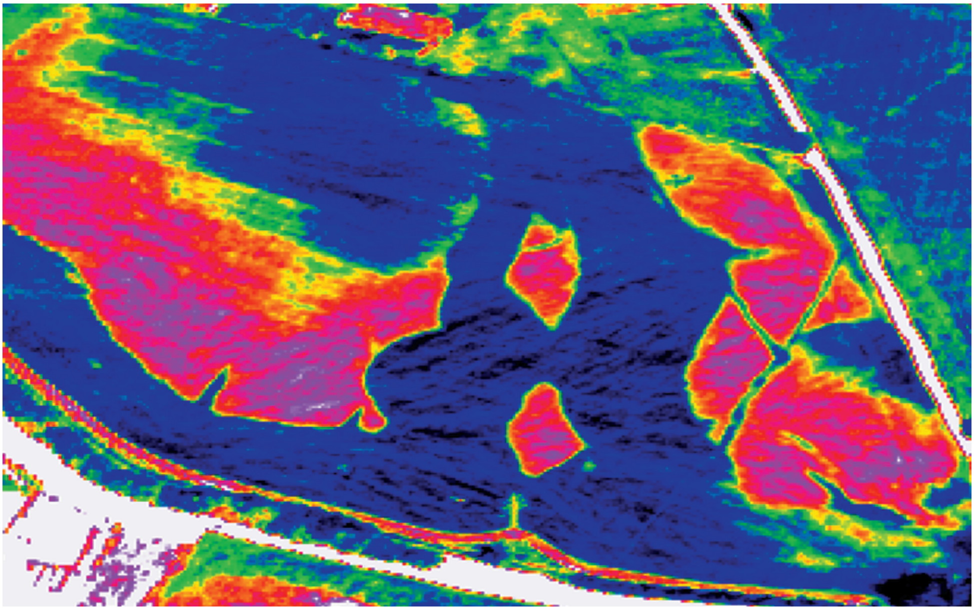

Image 5: Precision farming: evaluation of the heterogeneity of a wheat crop by means of digital thermography. The surface temperature of the plants correlates negatively with the transpiration rate giving a quantitative measure of the biomass or its vitality (Research Training Group 722 "Use of Information Technologies for Precision Crop Protection").

The analysis of substances and matter fluxes also covers the investigation of pathways of effects, the ecotoxicological assessment and the identification of detoxification mechanisms for so-called "new pollutants", such as cosmetics, pharmaceutical products, fire retardants and hormones. The selective control of biotic processes in the soil can help to reduce or avoid temporary ecotoxicological effects such as those caused, for example, by pesticides.

Waste must be included within the analysis of matter fluxes.

Finally, agricultural science must develop plans for the end products of matter fluxes, i.e. the waste. Agricultural science must show how the residues accumulating in the process chain can be channelled towards a use or managed within the cycle. In the face of global urbanisation, the use of waste materials in agriculture is becoming a critical problem. In 2030 two thirds of the world's people will live in mega cities with populations of over ten million. Mega cities have not only to be supplied but also need to have their waste disposed of. Agriculture absorbes a large share of the waste from these centres. New environmental risks are emerging as a result. For example, the entire sewage from the eighteen million inhabitants of Mexico City pours into an area used for agriculture to the north of the city. While the completely untreated waste water on the one hand restores large quantities of nutrients to the soils, it also delivers enormous quantities of pollutants, the number of which is increasing exponentially and the ecological effects of which are only gradually becoming clear. This applies in particular to the production of fresh produce such as fruit and vegetables, so periurban agriculture and horticulture are gaining increasingly in significance. The issue here is to develop solutions to problems both in terms of waste disposal and of protection against ecological and toxicological pollution and to introduce these into practical farming of different regions.

4.2.2 Agricultural Landscape Research

Agricultural landscape research requires holistic approaches.

Agricultural landscape research is no longer exclusively concerned with the production of animal- and plant-based agricultural products. These represent just one of many landscape services. Thus, man-made landscapes can also be managed without agricultural production, for example with the aim of creating recreational landscapes or of landscape conservation. Other landscape services which have to be examined are the biodiversity or sink and source functions for numerous substances. Within biodiversity research, the study of functional biodiversity is of pre-eminent importance. This branch of research is concerned with describing the functional role of populations of individual organisms and communities of organisms. It also includes the monitoring of biodiversity indicators, both of flora and fauna. As far as the study of sink and source functions of agricultural ecosystems is concerned, nitrogen, carbon and sulphur and their compound forms are of key importance.

Agricultural landscape research, in the definition given above, is opening up new opportunities for forging alliances with other disciplines such as the planning sciences, the social sciences and the earth sciences and for integrating these within its research concepts. Agricultural research will also continue to develop in this direction as a systems science that will increasingly pursue integrated land management approaches. These will simultaneously take into account ecological, technological, socio-economic and cultural concerns.

Agricultural landscape research will thus in future have to make greater efforts to obtain an understanding of complex ecosystems. In analysing ecosystems it will also have to examine "neighbouring" ecosystems, for example populated areas or forests, which are components of landscapes in the same way as agricultural areas.

The analysis of such complex ecosystems is inconceivable without process-based models. These models, which already exist in rudimentary versions, must be developed further in order to be able to analyse regional land use patterns and to forecast and evaluate their effects. Such analyses must also take into account geographical variants of soil/climate conditions as well as the general technological or political and economic situation.

The necessary ecosystem analysis is inconceivable without process-based models.

Image 6: Overgrasing in Inner Mongolia leads to increased erosion (Research Unit 536 "Matter Fluxes in Grasslands of Inner Mongolia as Influenced by Stocking Rate (MAGIM)").

The study of agricultural ecosystems of differing characteristics and intensities in the various climatic regions of the earth will continue to constitute a focal point of agricultural research in future. A key objective within this branch of research will be to analyse the functional capacity and stability of such systems. This analysis must reveal trade-offs between the various landscape functions, that is functional relations, for example, between economic and ecological variables. Such trade-offs play a key role in the planning and evaluation of the relative preferability of alternative actions. When conflicts of interest arise, as frequently occurs in agricultural production, trade-offs are an indispensable prerequisite for answering the question of where "utility-maximising" compromises may lie. Interdisciplinary research approaches combining socio-economic and scientific disciplines are indispensable for establishing trade-offs.

Under the influence of climate change, regional production conditions have altered.

Traditional agricultural landscape research is based on the assumption of "region-typical" or "landscape-typical" forms of land use, the abiotic site conditions of which are seen as being static. Under the influence of climate change, however, agricultural research will have to deal with the dynamics of changes in the natural production conditions at a site, i.e. above all with the changes in climatic elements (for example precipitation, temperature and ozone concentration) and their impacts on yields and crop rotations. Agricultural research will have to develop *inter alia* forecasts of how, under the influence of climate change, cropping systems will change or shift regionally. The weather extremes which climate change entails and their impact on yield development are a further important field of research. This also applies to studies of the influence of UV radiations on the regulation and activity of plant genes.

An important precondition for selectively changing the properties of crop plants is systematic research into their genomes. Researchers worldwide are working hard to decode the full genetic information of crops such as rice, maize or barley. Rice was the second plant after the model plant *Arabidopsis thaliana* to have its genome fully decoded.

Genome research is of crucial importance in plant breeding.

The involvement of plant breeding is of crucial importance where the concern is to use the findings of genome research for breeding new varieties with a higher yield potential and improved resistance and quality characteristics. An example is the breeding of sugar beets as winter crop that can be planted in the autumn and – like winter cereals compared with spring cereals – may exhibit a higher yield potential than spring beets. A prerequisite for this is the regulation of the genetic factors which prevent early shooting of beet caused by the influence of cold temperatures. The cultivation of winter beets would also reduce the threat of erosion which this crop carries on locations with heavy spring and summer precipitation since during periods of heavily erosive precipitation, a high degree of leaf mass and thus adequate soil cover would already be present.

An example of the successful breeding of resistance is the increase of the resistance of sugar-beet to "beet necrotic yellow vein virus (BNYVV)", a viral disease transmitted through soil-borne fungi. Initial breeding successes have also been achieved against the, likewise soil-borne, cyst nematode *Heterodera schachtii*, but combining these resistances with increased resistance to the soil fungus *Rhizoctonia solani* is still presenting a particular challenge. This causal agent of "rhizoctonia root rot" impairs not only the processing of the beet, but also the quality of the sugar. High priority is also being given to tracing and characterising resistances to Fusarium ear blight, which is caused by various phytopathogenic fungi of the *Fusarium* species. These fungi are of major significance to the quality of the cereal and its use as food and fodder, since they form a series of mycotoxins. These are substances which differ widely in chemical terms and are toxic to warm-blooded animals or are damaging to their health and well-being.

In addition to these, varieties with new types of characteristics can present new sources of added value and open up new markets to agriculture. Plants can be used to generate energy or as bioreactors (see also: European Commission 2004). Thus it is, for example, possible to obtain biologically degradable polymers with polyethylene-like properties from crops into which the appropriate bacterial genes have previously been incorporated.

Structural and functional genome analysis makes important contributions to livestock research.

Besides crops, livestock will also be given high priority in future agricultural research. Such research has in recent decades been aimed at obtaining findings which would lead to increases in important production characteristics such as milk yield and weight gain. Increasing problems in the area of animal health and rising demands by society with regard to food quality, animal welfare and the sustainability of production have led to some of the

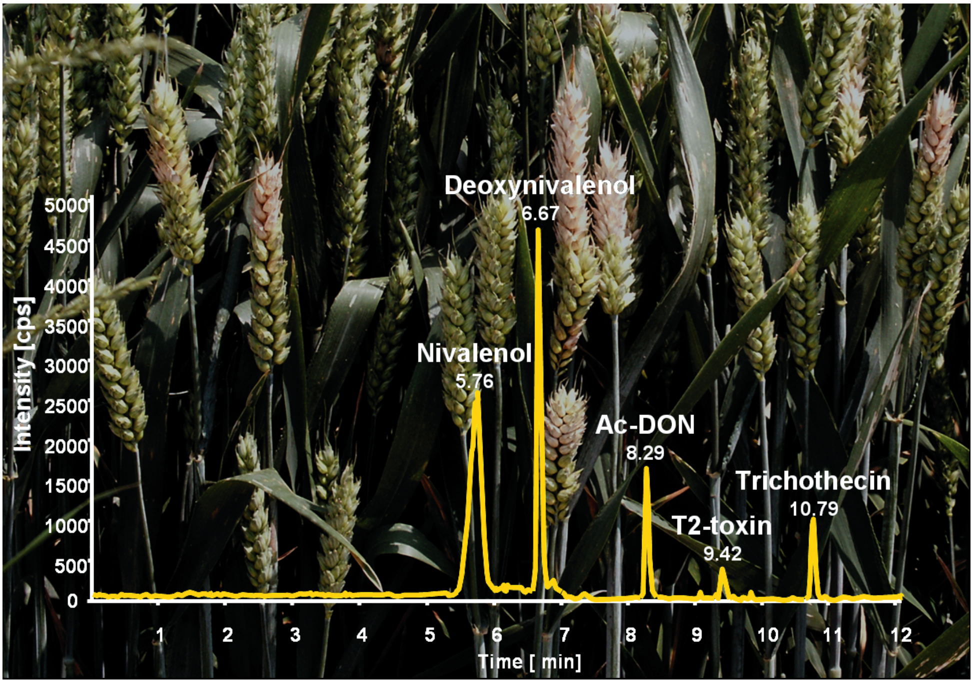

Image 7: Infestation of ears of wheat with Fusarium fungi leads to partial ear sterility and to contamination with various mycotoxins. These are tested using a combined method involving HPLC and mass spectroscopy (LC-MSMS).

focal points of research being changed and further changes are still to come.

Successful research in livestock science requires a better understanding of the interrelationships between genes, gene products and the phenotype and about the interaction of the animal with its environment. Structural and functional genome analysis will make an important contribution to this understanding. Methods of transcriptome analysis and proteome analysis in combination with bioinformatics, also applied in crop sciences, will enable a more detailed description of the diverse regulatory and functional interactions which lead to determination of the phenotype. Alongside further development of the range of methods in this area of research, the partially completed sequencing of livestock genomes will in the next few years lead to a major expansion of knowledge and significantly broaden our understanding of the interconnections described above.

Further examples of existing, as well as of future, research fields in the area of livestock science include structural and functional genome analysis in farm animals. While the genomes of the "classic" farm animals, namely cattle, pig, sheep and goat, and of poultry will be sequenced in the near future, other species used in agriculture such as horse, buffalo, ostrich and fish, are adding increasingly to the list. Some of the questions which need to be answered are (1) which genes influence important production characteristics and in what manner, (2) what influence gene variants have on important production characteristics and (3) which genes are involved in or cause the formation of hereditary diseases. Examples from the very recent past such as the molecular explanation of the Hampshire factor in pigs, the explanation of the genetic defect of complex vertebral malformation (CVM) in cattle, or mutation in the myostatin gene which leads to the "double-muscling" phenotype in certain breeds of cattle, are evidence of the extraordinarily major significance of this field of research (Kambadur et al. 1997; Milan et al. 2000).

Reproductive biotechnology research has been, is now and will remain a key field of research in the livestock sciences. The development and testing of new pro-

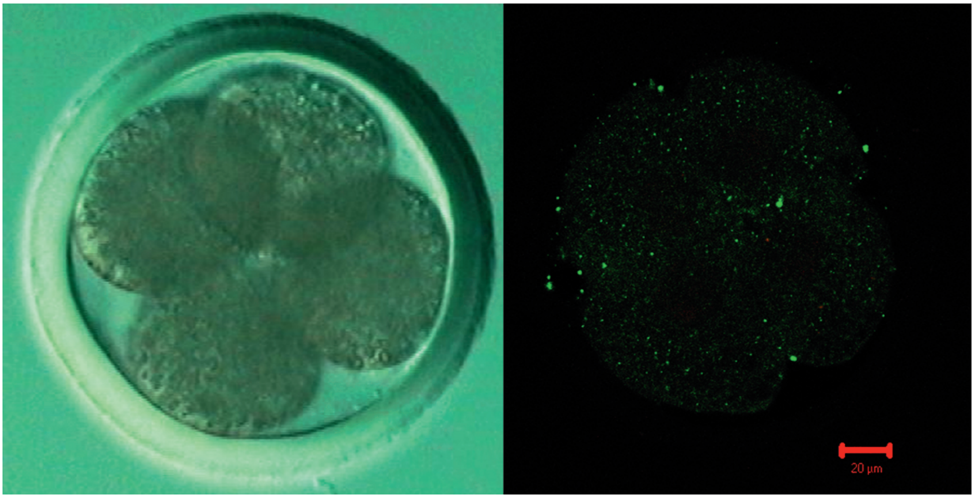

Image 8: Proteome analysis: Endothelial nitric oxide synthase (e-NOS) is of great importance to embryonic development. Immunohistological localisation of the enzyme in bovine embryos produced "in vitro" 48 hours after fertilisation (confocal laser scanning microscopy).

Reproductive biotechnology research is of great significance for medicine.

cedures in this area will, moreover, be of considerable significance for veterinary and human medicine. Many of the methods initially developed on farm animals will subsequently be used in the other areas. The combination of molecular biology research and reproductive biotechnology research in livestock is virtually in itself a genuine branch of agricultural livestock research. Significant examples from the recent past include the cloning of farm animals, which has simultaneously opened up a whole series of interesting new fields of research.

The continuing growth of the global population, the limited natural resources and global environmental pollution necessitate the effective conversion of feeds into high-quality food of animal origin. One of the issues facing animal nutrition is the efficient use of resources (for example water, fossil fuels, raw materials of limited availability such as phosphorus) in forage cropping and in the storage and processing of feed. This requires determination of the nutritional physiology requirements by animal species and category, performance level and other influencing variables together with new approaches and biotechnological measures to improve nutrient utilisation from conventional feed, by-products from agriculture and the food industry and feed from genetically modified plants (including a nutritional physiological evaluation and assessment of the safety of "second-generation" plants). Globally, more effective utilisation of grassland is of prime importance, since two thirds of utilisable agricultural area is grassland. This is giving rise to important research initiatives, particularly at the international level.

Infectious diseases with transmission pathways from animal to human need to be combated.

Finally, in matters of animal health, the fields of research extend from infectology to animal physiology and research into active ingredients and in terms of methodology call for both molecular and integrated approaches. Recently, research into the spread of infectious diseases and into the transmission of infectious agents from animal to human (zoonosis research) has acquired major importance. Examples of this are the appearance of new flu viruses and the transmission of diarrhoeal agents (for example salmonella) from livestock to humans. In addition, innovative vaccination concepts have been implemented in veterinary medicine which are also exerting an influence on the development of new vaccines in human medicine. In view of the problems of the use of antibiotics in animal feeding, probiotics represent an alternative which must be taken seriously and the scientific basis of which urgently needs further study. To do this, integrative approaches are required in order to explain their made of action, and these may also provide relevant data for other disciplines in the life sciences, especially in the area of veterinary and human medicine.

4.2.3 Global Food Security

A world population that is still growing must be supplied with high-quality agricultural products.

Despite lower growth rates, the world's population continues to rise – by more than 230,000 people per day. In 64 of 105 developing countries, the population is rising faster than food production. This population pressure has in the past led to increased degradation of arable land. Consequently the pressure on agricultural science to act to create the scientific conditions to sustainable increase and secure agricultural production and supply the world's population with high-quality foods is rising (Population Reports 2000). Agricultural science in Germany has a particular responsibility in securing food for the world. In a number of branches of science, for example in the research to the benefits and risks of technological advances, or in the integration of socio-cultural questions into approaches to solving agricultural problems, it has generated comparative advantages which are internationally recognised and used (DFG 2002).

Crop production is threatened by numerous biotic and abiotic damaging agents. Annual losses worldwide through viral diseases, bacterioses and fungal diseases and through competition from weeds alone amount to approximately 30% relative to an "undisturbed" production free of these biotic causes of damage. A factor of concern is the recognition that average loss rates have tended to rise worldwide in recent decades, since the global intensification of agricultural production (high-yielding varieties, irrigation, fertilisation, etc.), has not been accompanied by appropriate adjustment of crop protection measures (knowledge about the injurious effects of weeds and diseases or pests and the choice of appropriate measures, availability of active ingredients and their application for appropriate indications and at the appropriate time) in many regions (Oerke 1994; Oerke and Dehne 2004). In many developing countries, responsible intensification of crop-protection measures could significantly cut yield losses, and in some industrialised countries and/

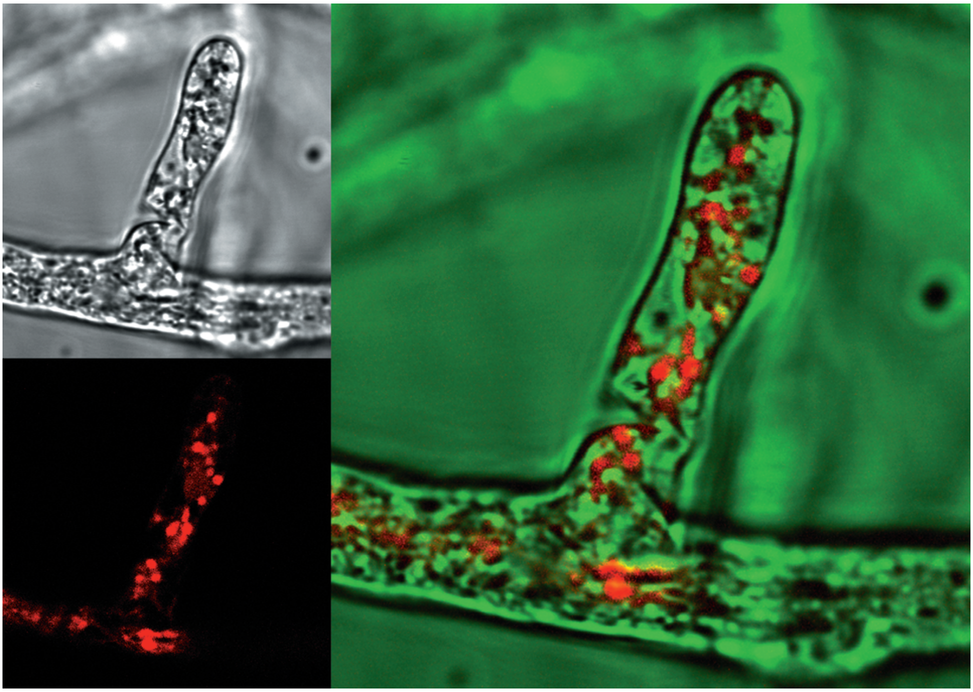

Image 9: The cytoskeleton is of key significance to the virulence of plant pathogens: microtubules in the mycelium of Phytophthora infestans (confocal laser scanning microscopy, tetramethylrhodamine-labelled tubulin).

or in the cultivation of a number of crops, expenditure on pesticides could be reduced without increasing the risk of losses.

Account must also be taken of the global changes in climate, biodiversity and soil fertility, the impact of which disproportionately enhances the negative effects of intensification (Parmesan and Yohe 2003; Chapin et al. 2000). This situation, which is acknowledged on all sides, presents agricultural science with a fresh challenge to develop production strategies which on the one hand guarantee a high degree of reliability (production security) and on the other hand are ecologically compatible, sustainable and resource-conserving. Two technologies will play an important role in the long-term, for example from the point of view of phytomedicine: firstly, crop protection that is adapted to the particular crop, appropriate to the location and environmentally compatible and that uses beneficial organisms, antagonists and symbionts and stimulates their activity and survival through suitable habitat structures and habitat management, and secondly the improvement through breeding of the resistance characteristics of crops. A combination of the two technologies, in particular, offers enormous potential to alleviate negative ecological side-effects.

The breeding of hybrids is of crucial importance where yield stability and yield potential are to be increased.

It is becoming more and more clear that yield increases in crop production will in future depend essentially on improving our crop plants through breeding. Here, raising yield stability and increasing yield potential stand at the fore. Hybrid breeding will therefore in future continue to grow in importance. Agricultural research will provide the essential foundations for this growth. Genetic-engineering methods by which plants with completely new characteristics can be bred will increasingly be applied in this context. Agricultural research is part of a network for researching into the genome structures of agricultural crops and animals. It has the crucial task of filtering the plethora of new findings for use in breeding and ensuring they are transferred into breeding practice and thereby into agricultural production. Modern breeds have a genetic yield and quality potential which they can best exploit where the growing conditions are optimal: a good supply of nutrients, sufficient water, no competition from weeds and no pathogens and pests hampering assimilation. In many regions of the world, however, marginal conditions prevail and inputs (fertilisers, pesticides) are not available. Selective use of modern technologies can also be found in organic farming, where the supply of nutrients to plants depends on the mineralisation conditions of the organic soils and where low level crop protection does not protect crops against stress to the same degree as in conventional farming. Adapting breeding objectives to low-input conditions like those that prevail in organic farming and in other farming systems would greatly increase the productivity of agriculture without any loss of sustainability. Such breeding programmes, which result in locally optimised varieties, make use of the powers of observation and regional knowledge of farmers and are therefore always participatory.

The previously mentioned options of “functional diversity”, i.e. alternative adaptation strategies, also offer considerable potential for long-term global food security: functional biodiversity, which the various populations of agricultural animals and crops have developed during the course of domestication, represents a key basis for developing innovative solutions for preserving biological diversity on the one hand and for securing sustainable animal and crop production on the other. Based on highly developed methods of comparative genome and proteome analysis, efficient strategies are being developed for identifying functional diversity, understanding its genetic and physiological foundations and converting the results into sustainable breeding strategies. In this way, this knowledge could, for example, be used for utilising appropriate genetic dispositions in a complementary way and/or for compensating for any adaptation processes (for example pathogen resistances) through alternative genetic function-based approaches to solving the problem. Agricultural landscapes are themselves distinguished by functional diversity. Ecosystem processes such as enemy pressure on pest populations or the decomposition of dead organic matter in the context of matter cycles are ecosystem services in the food security sense.

70% of the quantities of freshwater used worldwide are used in agriculture. Improved technologies must lead to more efficient water use.

The more efficient use of water is one of the major agricultural research issues of global food security. While total freshwater supplies worldwide are adequate, the unequal distribution of water is one of the main reasons for the shortage of food. Approximately 70% of the quantities of freshwater used worldwide are used in agriculture – partly at very low levels of efficiency. Even though highly efficient techniques of water use have been developed in the past, further developments are needed in all areas of agricultural research, including in socio-economic subjects in the face of existing problems further.

Through an improved understanding of the process, it will be possible to restrict the loss of land through erosion.

Research into physical, biological and chemical soil degradation processes and the monitoring of these processes will also be a global challenge facing agricultural research in the 21st century. Current land losses through erosion in the order of ten million hectars per annum (Pimentel et al. 1995) mean a huge loss of current and potential agricultural production area. Associated with that is inevitably a massive increase in socio-economic and ecological problems. Increasing land degradation as the population rises is a process that has frequently been observed in the past. This trend is not, however, inevitable if agricultural research can succeed in developing sustainable land use plans and in integrating the players involved in the planning process. However, for this to happen, it will be necessary to develop an improved understanding of the various forms of degradation processes and for the socio-economic disciplines to succeed in moti-

Image 10: Workshop of Thai and German scientists in Bangkok to discuss the results of the Research Unit 431 "Protected Cultivation – An Approach to Sustainable Vegetable Production in the Humid Tropics".

vating the population concerned to adopt sustainable methods of land use.

From the potential scenarios developed on the basis of the examples used, it can be seen that future research fields, in particular, can only be managed successfully if they are approached in an interdisciplinary way within the overall systems context and if the specialist and methodological skills available in agricultural science play at least a supporting role. In addition, the need to expand the geographical dimension of agricultural research is becoming clear. Traditionally, agricultural science has had a high level of involvement in international collaborative research projects and therefore, thanks to its international experience and networks and its generally high reputation and acceptance, it can make an even greater contribution to solving the problems indicated above.

4.3 Requirements for Efficient Forms of Organisation

The focus of this memorandum is primarily on questions regarding the content of agricultural research and less on structural and organisational aspects. Nonetheless, it seems appropriate to comment on a number of questions regarding the organisational arrangement of research and teaching within the predetermined structures.

4.3.1 Agricultural Science as an Independent Discipline

Agricultural science has traditionally been organised in independent institutions, i.e. faculties and non-university institutions. The reasons for this are primarily historical and go back to the time around the middle of the 19th century when model farms and agricultural institutes were founded at various locations with the task of contributing in a systematic way towards advancing productivity in agriculture. In the decades that followed, these institutions became academies and were later developed further into agricultural colleges. In the first half of the 20th century, the agricultural colleges were then integrated as independent faculties within the universities.

A development taking place at the same time was the founding of land-grant colleges in the USA: in order to enable broader sections of the population to receive university education, a bill sponsored by Senator J.S. Morrill was adopted in 1862 donating public land to all federal states, the returns from which were to be used primarily to provide long-term funding for colleges of agriculture and mechanical arts. Most of these colleges developed into full-scale universities over time. These land-grant universities, which all contain colleges of agriculture as independent units, today constitute the public university system in the USA.

Agricultural science in Germany forms – as in other countries – its own scientific community.

Just as was the case in Germany, agricultural science in the USA also formed its own scientific community from the outset, and this has continued until the present day. André and Jean Mayer (1974) describe the ambivalent nature of this development: it has on the one hand produced a really powerful branch of science, whose clear focus on its subject of investigation lends it a high degree of problem-solving competency; the reverse side of the coin is its isolation and its being cut off from other scientific disciplines – "Agriculture, the Island Empire", as the authors call it. They criticise above all the lack of communication and cooperation between disciplines, the consequence of which is that too little notice is paid in one discipline to relevant findings in another.

Obviously, the institutional independence has advantages and disadvantages. The latter have already been mentioned. The advantages stem from the peculiarities of the research approach which is characterised by interdisciplinarity and a systems orientation. The research issues which preoccupy agricultural science can usually be properly dealt with and resolved only by taking biological, technological, economic and social interconnections into consideration. This calls for close cooperation between the various sub-disciplines and can best be ensured within an independent institution with an appropriate strategic orientation to match.

The complexity of agricultural science requires, in addition to specialists, researchers with knowledge in multiple disciplines.

Solutions to problems in complex systems generally require a combination of scientific, technological, economic and sociological expertise. Besides specialists, researchers are needed for this purpose with knowledge in multiple disciplines. Imparting such knowledge is the function of the studies and training of young scientists. Institutional independence is also without doubt a major advantage in this respect. Without it, the interdisciplinary approach in teaching would be lost, which would in turn carry the risk of a decline in problem-solving skills.

The authors of this memorandum are convinced that the advantages significantly outweigh the disadvantages, since the disadvantages can be reduced by opening up and encouraging cross-disciplinary collaboration – a process which is already underway, both nationally and internationally. Bonnen (1996) describes the changes taking place in terms of the land-grant universities. Characteristic features of the developments in Germany are the inter-departmental and/or inter-faculty centres which are currently emerging in many universities.

A further point in favour of the preservation of agricultural science as an institutionalised specialist field is the present trend towards the establishment of interdisciplinary centres; to a certain extent, agricultural faculties and research institutions already constitute such centres.

Agricultural science as an institutionalised specialist field must be preserved.

They thus form an environment which favours interdisciplinary research oriented towards the systems approach. However, greater care will have to be taken in future to ensure that collaboration extends beyond institutional boundaries, even if the present shortage of funds and the resulting increasing competition do not exactly favour such collaboration.

If one looks at agricultural science's endowment with personnel and physical resources, then, measured against the breadth of the area with its teaching and research cover, it has to be classified as a comparatively minor scientific discipline. Nevertheless, its research activities are distributed among a large number of different research institutions (cf. chapter 2.2). Consequently, in overall terms, the research landscape is more diverse in agricultural science than in almost any other subject. This fragmentation, coupled with the overall reduction of funding, means that it is becoming more and more difficult to cover the full range of the discipline appropriately in line with the holistic approach. Many of the existing institutions in both the university and non-university sector have already fallen below critical mass. Due to prevailing financial restrictions, this situation is not going to change substantially in future.

All sub-disciplines of agricultural science must be represented in the particular integrated institutional set-up.

Nevertheless, for the systems approach to be implemented successfully in research it is essential that those disciplines which make up the core of agricultural science are represented in the particular integrated institutional set-up. Which disciplines these are can be seen from the area of study which was described in detail in chapter 3 and is illustrated in Fig. 1 (p. 94). Consequently, specialist skills are needed in the soil science, crop science and livestock science as well as in the environmental sciences, engineering, economics and the social sciences as cross-sectional disciplines which are essential to an understanding of system interrelationships. Depending on where the particular focus lies, the various areas can be developed to differing degrees. As a minimum requirement, however, each of the disciplines mentioned must be represented – at least through the collaboration with other institutions, since only this can ensure an integrated way of looking at things in the sense of the systems approach. In concrete terms, that means that in each of the areas mentioned (soil science, crop science and livestock science as well as the environmental sciences, engineering, economics and the social sciences as cross-sectional disciplines) the specialist disciplines they include must be represented by at least one professorship.

4.3.2 Necessity of Raising the Profile and Collaboration

Faced with the starting situation outlined above, agricultural research must re-orient itself strategically and organisationally, in order to be able to achieve its substantive goals. This will firstly include building a profile at the individual universities. Here, the faculties will be required to develop, based on an analysis of their respective comparative advantages, a substantive profile of their own. Synergetic effects can be produced only if they not all do exactly the same!

Cooperative projects across location and institutional boundaries are needed in order to preserve the problem-solving skills of agricultural research.

Capacity limitations and structural realities also determine the need for more intensive cooperation. This relates to both inter-location and inter-institutional cooperation between universities, universities of applied science, non-university institutions and related disciplines, in research as well as in teaching. In the case of the former, the prime concern in research is the expansion of cooperative research projects. Notable examples here are coordinated procedures of the DFG (Research Units at more than one location, Priority Programmes, Transregional Collaborative Research Centres as a variant of the Collaborative Research Centres based at more than one location) and projects within the Framework Programmes of the European Union.

Inter-institutional cooperation, i.e. principally cooperation between university and non-university institutions, should also be intensified. In addition to attracting more cooperative research projects, this relates chiefly to jointly appointing qualified leaders from research institutes to neighbouring faculties and to sharing the use of resources. Experience shows that this promotes lasting cooperation between institutions. Alongside dual membership in neighbouring faculties, the reciprocal membership of staff of university and non-university institutions in the other respective institutions also certainly has a positive impact on cooperation.

Bureaucratic obstacles hinder cooperative projects.

Sustainable collaboration can be established as subject matter oriented or regional cooperation, as suggested by Isermeyer et al. (2002). Such cooperation cannot, however, be decreed. Cooperative projects and integrated set-ups will only develop if the general conditions enable this to happen and if clearly recognisable mutual benefits will result from cooperating. This also means that the costs associated with establishing the cooperative project must not be prohibitively high. To this extent, it is very important to overcome bureaucratic obstacles. Such obstacles frequently stem from differing organisational responsibilities (federal government, federal states, different state or federal ministries), which lead at the very least to legal uncertainty, but in many cases where resources are to be used jointly also to more serious difficulties. Furthermore, care must be taken to ensure that inter-institutional cooperative projects make a positive contribution to the further scientific development of the subject and are not initiated merely on budgetary grounds.

The DFG's sponsorship enables cooperation between locations and between institutions.

As a further requirement, greater use must be made of funding instruments which enable cooperation between locations and between institutions. The DFG offers this through the programmes described. In addition, the pooling of individual applications offers smaller disciplines an effective facility for doing this. Greater use of all these instruments should also be made jointly with other disciplines. In addition, cooperative projects between locations within the framework of established agreements and thus relaxation of the location principle in some funding instruments undoubtedly suit the specific situation of agricultural research. The initiation and preparation of cooperative projects always entails considerable investment. This relates both to substantive and organisational aspects. This may be a reason why very few joint research projects are being sponsored in the area of agricultural research at present. The preparation of cooperative procedures requires considerable effort by all the parties involved. It is useful to involve strategically oriented DFG committees such as the Senate Commission on "Future Perspectives of Agricultural Science and Research". In order to initiate research projects, agricultural science can also develop strategic plans and commence initiatives with the "Senate Commission on Substances and Resources in Agriculture" and the DFG's Review Board on "Agricultural and Forestry Sciences, Horticulture and Veterinary Medicine". As far as cooperation between locations in the training of young scientists is concerned, it is first and foremost the agricultural faculties conference, which is required to launch and coordinate appropriate activities.

4.3.3 Promotion of Junior Researchers

An attractive environment should improve the employment options for young scientists.

The growing diversification of research topics dealt with in agricultural science has led to a change in the profile of agricultural scientists in recent years. On the one hand, the handling of thematic areas requires scientists with specific knowledge of methods originating from related disciplines, which make it possible to manage specific issues successfully. On the other hand, there must be an understanding of system interrelationships. In recent years, the number of graduates of agricultural science courses interested in entering postgraduate research has decreased, and as a result it is becoming increasingly difficult to recruit qualified and motivated doctoral students for research projects. In order to alter this situation, an attractive environment for carrying out research work and possibly for continuing a scientific career should be created.

The promotion of young scientists must, however, commence even before they begin their research. It must be borne in mind here that in teaching it is sometimes difficult to reconcile the goal of professional qualification with the goal of qualification for scientific research. The transition from Diploma courses of study to the Bachelor/Master system provides the opportunity to offer certain modules and/or make them compulsory in the Masters courses as preparation for certain doctoral topics.

Graduate schools are an important instrument for agricultural science.

A further logical consequence of switching to the system used in the Anglo-Saxon countries is the introduction of formal doctoral studies as a separate stage of training. Syllabi of this type generally serve to broaden, as well as to deepen, basic knowledge, and can be institutionalised in the form of graduate schools. Due to the complexity of the subject area, it is more important for agricultural science than for many other disciplines to establish such graduate schools. In view of the limited resources available, appropriate courses should also be arranged supra-locally, for example as block courses in summer schools. Similarly, skills should also be drawn upon from related disciplines for the syllabus. From the viewpoint of the teaching staff, it is important that the work in doctoral training will be counted towards the teaching allowances and be taken into account in capacity calculations.

The Research Training Groups sponsored by the DFG are already making an important contribution to improving doctoral training. Agricultural scientists should make more intensive use of this instrument. The International Research Training Groups, in particular, provide a sound basis for current fields of research in agricultural science. The thematically focussed Research Training Groups can, furthermore, be integrated exceedingly well into the above-mentioned graduate schools.

For young scientists, there are a variety of funding opportunities available through the DFG and other sponsors which provide good support for scientific careers. The supply of grants must, however, take appropriate account of the different portions of a scientific career. Funding programmes from the DFG which facilitate independence at an early stage – for example through establishing their own working group – are adequately available in the existing junior research group programmes. However, the reluctance among young agricultural scientists to go abroad with a fellowship is considerable. The variety of alternative careers and the lack of opportunities for scientists to return to Germany both play a role here. Attractive funding specially intended to encourage scientists to return to Germany could create incentives for the programmes to be taken up.

As regards the funding of projects, the same funding instruments are available to young scientist as to established scientists. However, since young scientists have been underrepresented specifically in the DFG's Individual Grants Programme in the past, opportunities should be sought for improving this situation.

Young scientists should use the available funding options deliberately.

In order for graduates from agricultural science courses or courses in related disciplines to continue to decide upon a scientific career in future, it is essential that they are offered career prospects in each of the various phases of training. Greater use should be made for example of the DFG's tailored programmes, which facilitate stays abroad in very good groups and the establishment of junior research groups. Longer-term prospects after the introduction of junior professorships are currently limited. The basic idea behind the junior professorship of early, independent scientific work is entirely welcomed. There are, however, as yet no recognisable solutions or alternatives if, after termination of the contract of employment, no professorship is yet available. The aim here is to offer young scientists flexible, performance-based transitional solutions.

Current plans to restructure and further diminish faculties of agriculture will result in specialist areas being covered less comprehensively and in part by highly specialised basic scientists – including some from related disciplines. Thus significant shortfalls are already apparent in the coverage across the full range of agricultural science. In the area of livestock science, for example, there are scarcely any professorships in the fields of poultry and small ruminants, and consequently appropriate research and teaching no longer takes place here. In appointment proceedings, therefore, the orientation of candidates should be taken into account, so that the growing discrepancy between the specialisation of scientists and the concern to cover the full breadth of the subject area can be counteracted.

5 Recommendations

Ever since it came into existence, agricultural research has performed considerable services for society and the economy. New challenges facing agricultural science in the light of social and technological change are: food security, food safety and changes in society's demands in terms of food quality and agricultural landscape management methods. These challenges can be solved only through an interdisciplinary and international approach and through cooperation with related disciplines.

As a science whose subject of research is of global significance, agricultural science is concerned with the basic essentials for mankind. These include the efficient use of water resources and of scarce nutrients as well as worldwide food security. In order to meet this responsibility, agricultural science needs firstly to be preserved as a scientific discipline and also to be consistently and systematically developed in terms of its content and organisation. This applies in particular to the international dimension.

From these requirements the DFG has drawn up the following recommendations:

1. Agricultural science must focus more on new research fields because both its content and methodological advances, such as the increasing "molecularisation" across the entire range of life sciences, have changed in the last few decades. These include the areas of environmental impacts, sustainability, quality assurance, agricultural landscape research and global food security.
2. Agricultural science is by its very nature a systems science, under whose umbrella scientists from different disciplines jointly develop approaches to solving problems. The soil science, crop science and livestock science, as well as economics, social sciences and engineering

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must therefore interact in a coherent organisational network. The new research fields require a systems-oriented approach on all accounts, and this must therefore consistently be developed in agricultural research and teaching. The strengthening of interdisciplinary and transdisciplinary approaches is closely linked to this.

3. Under changing conditions, sciences draw their innovative strength and their validity above all from theory and methodology. The theoretical and methodological base must therefore continue to be developed in all the subdisciplines of agricultural science. This requires an intensification of basic research of the type supported in particular by the DFG. In this context, it is recommended that, taking agricultural ecosystems as the subject of research findings, an independent theory be developed, for example in the sense of an "agricultural systems theory".

4. A special feature of agricultural research is that it develops its basic findings in the systems context further to obtain solutions to specific problems. Examples of the combination of basic and applied research can be found in new breeding methods, in precision agriculture or in providing policy advice. This requires on the part of agricultural scientists specialist capabilities and the willingness to carry out both basic and applied research.

5. The independence of "agricultural science" as a subject area was a key factor in contributing towards the establishment of the specialist capabilities required for problem-oriented research in the past. In the future, too, institutional independence will be a key requirement for the specialist capabilities and coordination of interdisciplinary research. This applies not least in the light of the unity of research and teaching. Agricultural science cannot be represented adequately by its related disciplines (biology, economics, etc.).

6. The research achievements of German agricultural science are highly regarded internationally. Its international prominence can, nonetheless, be further improved. Involvement in joint international research projects, membership in international research networks, the exchange of visiting scientists and the sending of junior scientists to centres of excellence in agricultural research abroad make important contributions to this end.

7. Future organisational structures must lead to the promotion of interdisciplinarity and systems thinking. To this end, all research areas within the soil science, crop science and livestock science and, as cross-sectional dis-

ciplines, the environmental sciences, engineering and economics and social sciences, must each carry at least one professorship.

8. In order to ensure the necessary breadth of coverage of agricultural science, cooperation across regional and institutional boundaries must be strengthened in future. Cooperative projects between universities and non-university institutions must be promoted more intensively.

9. The promotion of young scientists is of particular importance to the further development of the subject area and the preservation of its core competency. Measures must be taken here to enhance the attractiveness of a career in science. These include for example the introduction of formal doctoral studies within the framework of graduate schools in order to improve doctoral training.

10. In order to do justice to the international dimension of agricultural research, the performance capability of locations must be reinforced. The present uncoordinated cuts in resources must therefore be seen as being particularly critical for the preservation of agricultural science as a systems science.

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Annex

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Picture Credits

Image 1: Typical land use system in mountainous regions of Vietnam, Collaborative Research Centre 564 "Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia"; Photographer: R. Friederichsen.

Image 2: Virtual plants; Source: Research Unit 472 "Virtual Crops – Architecture and Process-oriented Modelling and Visualisation of Crop Stands".

Image 3: Distribution of land use; Source: Collaborative Research Centre 299 "Land Use Options for Peripheral Regions".

Image 4: Participatory field research with farmers in Thailand, Collaborative Research Centre 564 "Sustainable Land Use and Rural Development in Mountainous Regions of Southeast Asia"; Photographer: A. Neef.

Image 5: Precision Farming, Research Training Group 722 "Use of Information Technologies for Precision Crop Protection"; Photographer: J. Lenthe & E.-C. Oerke, Institute for Plant Diseases, University of Bonn.

Image 6: Overgrasing in Inner Mongolia, Research Unit 536 "Matter Fluxes in Grasslands of Inner Mongolia as Influenced by Stocking Rate (MAGIM)"; Photographer: H.-G. Frede, Institute for Landscape Ecology and Resource Management, University of Gießen.

Image 7: Infestation of ears of wheat with *Fusarium*; Photographer: E.-C. Oerke, G. Meyer & H. W. Dehne, Institute for Plant Diseases, University of Bonn.

Image 8: Proteome analysis; Photographer: K. Schellander, Institute of Animal Breeding Science, University of Bonn.

Image 9: The cytoskeleton is of key significance to the virulence of plant pathogens, Priority Programme 716 "Mechanisms and Interactions in the System Plant, Damaging Agents and Beneficial Organisms"; Photographer:

G. Jende, U. Steiner & H.W. Dehne, Institute for Plant Diseases, University of Bonn.

Image 10: Workshop for Thai and German scientists in Bangkok, Research Unit 431 "Protected Cultivation – An Approach to Sustainable Vegetable Production in the Humid Tropics"; Photographer: H.-M. Poehling, Institute of Plant Protection and Plant Diseases, University of Hannover.

Figure 1: System studied by agricultural science; Source: own figure.

Figure 2: Interactions between agricultural science and related scientific disciplines; Source: own figure.

Figure 3: A growing global population is faced with a limited area for agricultural production; Source: FAO-STAT, 2001.

Figure 4: Spread of the western corn rootworm *Diabrotica virgifera virgifera* (introduced from North America to South-Eastern Europe) between 1992 and 2003; Source: amended according to FAO 2004; Photo "Western Corn Rootworm": P. Baufeld, Biologische Bundesanstalt (BBA) [Federal Biological Research Centre], Braunschweig.