Strategic Research Agenda

ICT-AGRI

Coordination of European Research within ICT and Robotics in Agriculture and related Environmental Issues

ERA-Net ICT-AGRI Strategic Research Agenda

Prepared by Work Package 4 (Deliverable 4.3) in interaction with the Network Management Group and the Expert Advisory Group of ICT-AGRI

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1. Executive Summary

The key concerns of the ERA-Net ICT-AGRI [European Research Area Network for Coordination of Information and Communication Technology (ICT) and Robotics in Agriculture and Related Environmental Issues] are to strengthen the international competitiveness of the European Union and to reduce the negative impact of agricultural production on the environment. In this context, the Strategic Research Agenda (SRA) has the following aims:

- to identify future challenges for European agriculture;
- to distil objectives and solution domains based on ICT and robotic technologies as they apply in primary agriculture;
- to determine further research and innovation (R&I) requirements;
- to create a vision for ICT and robotics in agriculture; and
- to develop recommendations for SRA implementation.

The SRA is intended to serve as a reference for future planning of R&I at both European and national level.

Significant growth in world population combined with changing food habits has led to an increasing global demand for safe, high-quality food. Moreover, without substantial changes in lifestyle habits and innovations in food production, population growth will exacerbate climate change, degradation of our natural resources and energy shortages, with adverse effects on soil productivity and food production. The situation is further aggravated by the decrease in arable land due to urbanization and other uses such as bio-energy.

The challenge to European agriculture is therefore to become greener in terms of sustainable management of natural resources, reduced environmental footprint, and climate change. At the same time, agricultural production must remain effective, competitive and profitable. In this context, the EU's 'Europe 2020' growth strategy places emphasis on a resource-efficient Europe. In addition, reform of the Common Agricultural Policy (CAP) aims to strengthen the competitiveness and sustainability of agriculture.

Research and Innovation requirements

Innovative ICT and robotic applications can help pave the way towards more-sustainable, more-efficient agricultural production systems. The ICT-AGRI concept combines several ICT and robotic solution domains for plant and animal production and farm management which contribute to the identified goals in order to meet the aforementioned challenges:

- The Farm Management and Information System (FMIS) is defined as the backbone system for all other ICT and robotic solution domains. FMIS provides a common user interface across solution domains and a repository for farm information. It includes tools for communication and information exchange with external bodies, e.g. providers, food chains and government authorities. Decision support systems (DSSs) provide information for economically and environmentally appropriate farm management. Time-consuming and error-prone manual data collection may be replaced by automated information collection and storage. The FMIS of tomorrow will be a modular system from which farmers choose the modules or services they wish to use.
- Variable-rate application (VRA) is the site-specific application of fertilizers, pesticides or water. VRA requires empirical information on the current state of crop and soil, at a suitable spatial resolution, measured by sensors or human observation. Automated information exchange between different applications and components is essential to generate decisions for optimum applications. The incorporation of FMISs and DSSs in web-based approaches is a particularly important aim. As technology costs decrease and the cost of agricul-

tural input factors increases, the economic case for implementation of VRA will improve.

- Controlled-traffic farming (CTF) enables the geopositional control of field traffic in order to optimize yields and input and reduce negative environmental impacts. Further experiments under different soil and climatic conditions are required to enable us to gather knowledge on the effects on soil compaction and regeneration, greenhouse-gas emissions, and plant and yield development. Feasibility and cost-benefit assessments in association with alternative soil-protection measures are required in order to thoroughly convince farmers and encourage widespread uptake.
- The main goals of precision livestock farming are improved profitability, work ergonomics, and animal health and welfare based on sensor measurements as well as on advanced ICTs. Several innovative automation technologies for precision livestock farming are now on the market. Some, such as automatic milking and feeding systems, are well established, and boast a high degree of functionality and reliability. Others, especially sensors and analysis algorithms, have not yet reached this level of maturity. The sensitivity and specificity of biosensors must be improved and the information obtained must be combined and evaluated continuously in order to provide helpful decision support systems for the farmer.
- Advanced systems for automated indoor climate control should help to reduce energy consumption and greenhouse-gas emissions, as well as improve the environment in greenhouses and buildings for livestock. The latter helps to achieve healthy animals and livestock-friendly housing systems. Integrated or coupled heating-ventilation systems should be adopted in agriculture. Energy recovery is also a crucial aspect that could be enhanced by automated probes and control systems.
- Quality, safety and traceability of food and feed are the main objectives of automated quality control. This is essential for ensuring safe, high-quality food produced under animal- and environmentally friendly conditions for a continuously growing market. Research is needed on harvest and post-harvest food- and feed-quality issues. Sample-based quality control is currently common practice, but future technologies should enable close monitoring of individual product quality. A crucial requirement is the permanent information exchange with FMISs for alerts, documentation, and automatic quality supervision and regulation purposes.
- Agricultural robots can replace humans in the performance of manual labour – notably in the case of hazardous or tedious work – in order to improve safety at work, labour ergonomics and efficiency, product quality, and environmental sustainability. Replacing heavy vehicles with small field robots may reduce soil compaction. The development of agricultural robots will be influenced by a number of different factors, e.g. legislation, economic aspects, and society's perception and acceptance of robots. Advances in robotic engineering must be applied in the agricultural sphere in order to step up innovation. Despite being of the utmost importance, safety issues vis-à-vis humans, crops, animals and the environment have not yet been adequately addressed in this field.

The ICT-AGRI choice of solution domains was confirmed and enhanced by an online expert consultation. Voting on R&I requirements underscored the importance of combining agronomic research and engineering skills without neglecting economic and environmental expertise. It also showed that solutions should bear in mind user demand for system compatibility and user-friendliness.

Vision for ICT and Robotics in Agriculture

In the ICT-AGRI vision for the future of European agriculture, precision crop and livestock farming have become real-world solutions for agricultural production. This is due to new ICT technologies which make management of individual plants or animals more operational and easier for farmers. Many manual tasks can be performed by automated systems, offering improved control of production processes for better efficiency of production factors and improved product quality. Agricultural robots operating to high safety standards are available to perform physically strenuous and dangerous tasks. Modular and scalable ICT and robotic solutions take Europe's diverse agricultural structures into account and can be adapted to specific farm situations and individual farmers' needs. This transformation will not happen in the short term, but rather will develop gradually as a result of the complexity of agricultural biosystems and the interactions among plants, animals and people.

Recommendations for SRA implementation

ICT and robotics are among the fastest growing technologies. They will shape our future on the economic, ecological and societal scale, pervade all spheres of life, and become ever-more-indispensable components of our daily life. A great deal of attention must be focused on the interaction between science, engineering and practice in order to speed up development and transfer knowledge to agricultural practices. This requires strong coordination and cooperation in various fields and at various levels of research and innovation: in science and engineering spheres, among stakeholders in the Agricultural Knowledge and Innovation System (AKIS), and within Public-Private Partnerships. Recommendations for SRA implementation cover three aspects:

Developing ideas from different areas of academic expertise to arrive at innovative solutions

- Future ICT-AGRI research and technological development (RTD) must focus on coordinated, cross-thematic research approaches. Much effort will need to be put into networks where researchers from different disciplines can establish contacts and develop innovative ideas. Funding and research initiatives should stimulate interdisciplinary RTD comprising agronomics, engineering, computer science, economics and social sciences as well as Public-Private Partnerships.
- Horizon 2020, Joint Programming Initiatives (JPIs), European Innovation Partnerships (EIPs) and ERA-Nets are well-suited instruments for introducing interdisciplinary research into national research programmes. Moreover, Entrepreneurship and Innovation Programmes and the Knowledge and Innovation Communities (KICs) funded by the European Institute of Innovation and Technology (EIT) have the potential to bring together industry, education and research, in order to enhance the entrepreneurial culture and bring innovations to market.

Achieving the greatest profit by combining stakeholders' expertise

- The public and private actors who maintain the basic farm data and who are familiar with advice and support to farmers must be involved in the integration of knowledge-based systems and robotic machines into farm-management systems. Public services play an important role by providing ICT for environmental regulation and subsidy administration.
- It is essential to introduce appropriate technologies and business models for incorporating third-party software and hardware in farm-management systems and for sharing of essential data. This should be done in a European context

so as to ensure better utilization of research results and a larger market for commercial products.

- The rapid development of technologies places high demands on the education and training of farmers. National and transnational agriculture knowledge and innovation systems should place a greater focus on the continuous training and qualification of farmers and farm consultants.

Investing in compatible systems to harness the full potential of the technology

- A European effort is needed to propose, endorse and disseminate *de facto* and *de jure* standards for data exchange in the agricultural domain. Standards can grow out of recent and ongoing European research projects, but it is essential to establish follow-up strategies to promote the application of the project results in the automation manufacturing industry and the ICT development industry. Such efforts can be established by ERA-Nets, EIT and Entrepreneurship and Innovation Programme initiatives in collaboration with ETPs (European Technology Platforms), and other initiatives such as Enterprise Europe Network.
- Common standards for communicating with national authorities throughout Europe will be an important incentive for improved interoperability of ICT and automation applications. ERA-Nets in combination with relevant EU activities can be an effective means for establishing such a collaboration between national administrations.

ICT-AGRI initiatives

In addition to the development of this SRA, the ICT-AGRI ERA-Net has undertaken a number of initiatives designed to promote coordination, collaboration and innovation in the use of ICT and robotics in agriculture:

- The Meta Knowledge Base (MKB), developed by ICT-AGRI, is a central internet-based resource for researchers, developers and users. This information platform with technical and social content constitutes a structured framework for mapping and analyzing all relevant knowledge within ICT and robotics in agriculture. The tool stimulates cooperation and coordination of R&D through user-driven initiatives and activities, leading to the pooling of fragmented human and financial resources.
- ICT-AGRI launched two transnational research calls based on funds of EUR 10 million from participating countries. The calls enabled collaborative projects based on complementarities and sharing of expertise within ICT and robotics in agriculture. The aim was to pool fragmented human and financial resources in order to improve both the efficiency and the effectiveness of European research efforts.
- The ICT-AGRI PPP action aims to encourage Public-Private Partnerships (PPPs) by creating consortia of concerned actors in order to facilitate product innovation for a specific challenge.

Although the ICT-AGRI ERA-Net will conclude by April 2014, its work is expected to continue in a second ERA-Net on ICT and robotics in agriculture, with a higher number of partner countries as well as recommendations and topics derived from this Strategic Research Agenda.

2. INTRODUCTION

According to the statistical and economic information on rural development in the EU (EC 2011a), the primary sector (agriculture, forestry and fishery) in the EU-27 generated EUR 169 billion in 2009. In 2010, the EU-27 accounted for approximately 12 million farms and 170 million ha of utilized agricultural area (UAA). Between 2003 and 2010, the average annual rate of decline in the number of farms was about 3%, while ha of UAA remained fairly stable. Consequently, the average size of farms increased in many European countries.

The composition of production factors has evolved towards more machinery and fewer workers. There has been a noticeable increase in mechanization: for example, in the EU-15 the share of farms owning a tractor increased from 44% to 56%, and the average number of tractors per farm with machinery increased from 1.7 to 1.9 between 1995 and 2005.

The labour productivity of agriculture in the EU-27 grew at an average annual rate of 3.4% between 2002–2004 and 2007–2009. Gross fixed-capital formation (GFCF) is a key element for future competitiveness, measuring how much of the value-added is invested rather than consumed. From 2005 to 2008, the GFCF of agriculture in the EU-27 grew at an average annual rate of 4.3%. Despite this, the average figures given above do not reflect the significant disparities between member states and regions.

A strong agricultural sector is vital for both the EU food industry and global food security. Owing to their leading role in the agricultural-engineering sector, Europe and the Associated Countries harbour a huge potential for producing safe, high-quality food for a continuously growing market. However, pressure on European agriculture and on agricultural income in particular is expected to continue as farmers face more risks, a slowdown in productivity, and a margin squeeze due to rising input prices (COM2011 627).

Many other countries in the world are able to produce food more cheaply. A cutback of subsidies on both the European and national levels is imminent. The legal and administrative requirements for environmentally friendly land use and animal friendly livestock-production systems continue to increase. Meanwhile, we face new challenges such as climate change, the protection of biodiversity (Le Foll, 2010), producing food for a growing world population, and future natural-resource scarcities.

Producing more food from the same amount of land while reducing the environmental impact requires an intensification of production systems. The concept of sustainable or ecological intensification aims to increase yield with fewer inputs and adverse consequences. This calls for a set of multifaceted measures and developments that complement and interact with one other. The 3rd SCAR Foresight Report suggests three innovation pathways: consumer-driven, technology-driven, and organizational-driven (SCAR 2011). Information and communication technology (ICT), robotics and automation can contribute in different ways to all of these pathways.

Automation solutions as well as ICTs including sensors, global positioning and decision-support systems can play a considerable role in the development of sustainable and efficient farming systems. Firstly, there is precision farming, which offers different technologies for assisting the farmer in improving efficiency, reducing labour costs and enhancing flexibility on the farm. Automatically collected information, for example, enables farmers to precisely dose fertilizers and pesticides or sow seeds and apply other inputs by controlling agricultural machines. Information and communication technologies permit the optimized application of inputs, thereby reducing the adverse impacts of agriculture on the environment. This can help to enhance efficiency in food production and obtain higher outputs for lower inputs. An increase in outputs has a positive effect on farmers' profits and competitiveness. When used in conjunction with other measures, precision farming can increase productivity and farm profitability while reducing environmental degradation and conserving natural resources. This win-win potential – production benefits and environmental benefits – is in line with the recently developed 'green growth' strategies (OECD 2011) and the Europe 2020 sustainable-growth strategy (EC 2010a).

The second role played by automation solutions and ICTs is the use of ICT platforms and processes to promote communication, information exchange and networking among very large numbers of individuals, organizations and businesses. ICT therefore plays an important role in consumer information, influencing eating habits and consumption patterns. It can also potentially be used to promote the adoption of new techniques and best practice throughout the farming community.

The third role is the use of ICT to monitor land-use patterns. Applications include environmental databases for tracking the status of various indicators and impacts for sustainable environmental management, soil-erosion assessments, and inventories of cultivated land by slope, steepness and wetland (Hall and Dorai 2010).

The key concerns of the ICT-AGRI ERA-Net are to strengthen the international competitiveness of European farmers and to reduce the negative impact of agricultural production on the environment. Furthermore, ICT-AGRI aims to facilitate the use of information and communication technologies by farmers, as a way of meeting future challenges.

The ICT-AGRI ERA-Net has formulated a Strategic Research Agenda (SRA) for ICT and robotics in agriculture to facilitate the full utilisation of R&D capacity in Europe and the Associated Countries by coordinating and prioritizing research activities. The SRA strives for new perspectives in ICT, automation and robotics as they apply to primary agriculture. The aims of the SRA are to identify future challenges for a sustainable European agriculture, to arrive at goals and solution domains based on ICT and robotic technologies, to determine research and innovation (R&I) requirements, to create a vision for ICT and robotics in agriculture, and to develop recommendations for SRA implementation.

The SRA is intended to serve as a reference for future planning of R&I in the EU (including ICT-AGRI), in national research-funding organizations, and in the national research organizations themselves. As a strategic agenda, the recommendations of the SRA are general in nature, leaving the formulation of specific R&I topics to the concrete cases to which the SRA is applied.

3. FUTURE CHALLENGES FOR A SUSTAINABLE EUROPEAN AGRICULTURE

This chapter is based on a review of recent foresight studies. The review was undertaken to identify future European and global challenges for agriculture and society. The challenges fall within the scope of the EU's Europe 2020 growth strategy (EC 2010a).

3.1 Global food security

World population is predicted to reach 9.3 billion by 2050, while in Europe the population is projected to decrease. European agriculture will be faced with a higher global demand for food and feed owing to changes in global demographics, the growing per capita GDP, and a shift towards meat consumption in the food preferences of developing countries (FAO 2009, ESF/COST 2009; Boden *et al.* 2010).

Food security will be negatively affected by the degradation of natural resources. Degraded ecosystems are more susceptible to the adverse impacts of climate change, pests and diseases. The growing global demand for food will be a major challenge for European agriculture. At the same time, the amount of arable land in Europe is decreasing (by e.g. 27 000 ha in France every 10 years). The growing global human population will fuel climate change, biodiversity loss, and energy scarcity. Furthermore, the increasing demand for bio-fuels and fibre crops competes with land use for food production.

Need for action: To increase food production, greater efficiency in the sustainable use of resources will be required. Intelligent and sustainable use of natural resources and the protection of ecosystems are prerequisites for meeting all of these challenges in the long term (PBL 2009).

3.2 Sustainable management of natural resources

Natural resources including soil, water, air and biodiversity have deteriorated over the last few decades. Owing to high water demand, detrimental effects on the environment and high energy dependence, agriculture and related industries potentially overstress the capacity of ecosystems to maintain food production and to provide fresh water. Climate change and a growing world population are likely to further aggravate water scarcity, soil erosion, nutrient depletion, contamination and salinity (Evans 2009; The World Bank 2009; Boden *et al.* 2010). Moreover, human overexploitation of natural resources causes disturbances in ecosystems and exerts adverse effects on climate change and biodiversity (Boden *et al.* 2010).

Soil

Land degradation in its various forms is a fundamental and persistent global problem (COM2012 46). The European Environment Agency’s 2010 Status of the Environment Report demonstrates that soil degradation is also increasing in the EU (EEA 2010): (i) soil sealing leads to the loss of important soil functions (such as water filtration and storage or food production); (ii) soil erosion by water affects soil functions and has an impact on the quality of fresh water, since it transfers nutrients and pesticides to bodies of water; (iii) the continuing expansion of irrigation (with its accompanying problems of water scarcity and the increasing use of groundwater of marginal quality) accelerates salinization, thereby affecting soil productivity; (iv) soil biodiversity is under threat, particularly in areas of high population density and/or intense agricultural activity.

Water and nutrients

The global decrease in per-capita availability of fresh water is mainly attributable to copious withdrawals from water reservoirs, resulting in sinking stocks of groundwater and the contamination of ground- and surface water. Inefficiencies in water use for irrigation in agriculture are high, and inadequate draining of soils causes salinization, leading to reduced fertility (Evans 2009; Boden *et al.* 2010). Europe's water stocks are also under pressure. Since 1980, the number and severity of droughts in Europe have increased.

Recent figures show that 20% of surface water is at serious risk from pollution, 60% of European cities overexploit their groundwater resources, 50% of wetlands are endangered, and demand for water is continuously growing (WFD 2010). Contamination of water is closely related to nitrate application. Across Europe, the amount of fertilizer applied is on average approximately twice that needed for current crop production. Climate-change scenarios show that farmers in already-intensive production areas will be forced to increase their use of fertilizers to maintain optimum crop yields. In addition, regions with a relatively low nutrient input such as the Nordic countries may increase their fertilizer applications, since such regions will become more suited for crop production as the planet warms (Mulligan *et al*. 2006). However, production of phosphorus may have peaked, leading to the possibility of global shortages.

Air

Agriculture is the main source of ammonia (NH_3), methane (CH_4) and nitrous oxide (N_2O) released into the atmosphere. About 90% of agricultural NH_3 production is caused by animal husbandry and half of the greenhouse gas CH_4 comes from ruminant husbandry (Möller 2009).

Biodiversity

There is growing evidence that the current rates of extinction of biological species are dozens to hundreds of times the normal background rates. Biological communities and ecological systems are profoundly affected by human activities through habitat loss and disturbance, changes in land use, introduction of invasive species and climate change. Several reviews published in recent years stress that biodiversity loss will reduce nature's ability to maintain ecosystem services such as water filtration, nutrient cycling or pollination (e.g. The World Bank 2009; Boden *et. al*. 2010). The loss of biodiversity and the degradation of ecosystems therefore constitute a major scientific and societal challenge, a "grand challenge of our time", as outlined in the Lund Declaration of July 2009. This declaration emphasized the wisdom of taking a global lead in the development of enabling technologies such as biotechnology, information technology, and materials and nanotechnologies (ERA Expert Group 2009).

Need for action: The sustainable management of nutrients and water resources requires the modification of farming practices. Modern technologies have the potential to improve resource-use efficiency. Higher energy costs will increase fertilizer costs, thereby creating an imperative for further optimization of inputs (ESF/COST 2009). The sustainable management of natural resources as well as intact agricultural ecosystems are crucial for safeguarding global food production for future generations. Increased production of food for a growing world population implies more-intensive food-production systems combined with higher impacts on the environment. Eco-functional intensification, which is geared to more efficient use of natural resources and the recycling of scarce resources, would help to ensure sustainability (EC 2009a).

3.3 Energy consumption

Whilst fossil-fuel resources are declining, worldwide energy demand is projected to grow by 44% between 2006 and 2030 (EIA 2009). This development will be accompanied by a continuing increase in energy prices. In 2030, energy imports of the European Union (EU) will account for nearly 70% of energy needs (EC 2009b), and the EU will be highly dependent on fossil energy from non-European countries. Reinventing the EU energy system according to a low-carbon model is therefore one of the critical challenges of the 21st century.

To achieve this aim, the EU is working to mobilize public opinion, decision-makers and market operators, and to set minimum energy-efficiency standards and rules on labelling for products, services and infrastructure (EC 2011b). Energy technology is vital if Europe is to meet its objectives for 2020 and 2050 as regards combating climate change, safeguarding energy supplies, and increasing the competitiveness of European companies. With the Strategic Energy Technology Plan, the European Commission proposes various approaches to development and innovation in order to drive down the costs of existing energy technologies and bring about a step change in their market take-up, as well as to develop the next generation of technologies for the sustainable energy system of the future (EC 2011c).

Present-day agricultural technologies (e.g. farm machinery, heating of animal housing and greenhouses, irrigation of crops) depend on limited fossil resources. Although energy consumption in agriculture is low compared to other sectors of the economy, modern agricultural operations are highly vulnerable to energy shortages because they are generally performed by powered agricultural machinery which often operates within short time-windows (sowing, plant protection, harvest).

Need for action: Energy consumption must be reduced and energy efficiency must either be increased, or alternative sources of energy must be developed. The increasing scarcity of fossil-fuel resources combined with a rise in energy prices demands higher resource efficiency in order to make European agriculture globally competitive and to reduce greenhouse-gas emissions (ESF/COST 2009; Brinkhorst 2010). Another approach to counteracting dwindling fossil resources aims to ease the transition to sustainable energy production. The use of bio-based energy sources is widely rejected as an alternative to fossil fuels, because the production of bioenergy is expected to compete with food and feed production (Brinkhorst 2010; Koning *et al.* 2010). Unlike the first generation of bioenergy, however, the second generation, which is based on inedible biomass and residues, does not directly compete with food production for scarce land, water and nutrient resources (ESF/COST 2009; Koning *et al.* 2010). The sustainable use of bio-based energy can be appropriate for bridging the transition period from the current fossil-energy system to a renewable-energy system relying on wind and solar energy (ESF/COST 2009; WBGU 2008). Energy sources derived from waste and crop residues will increasingly be used as control energy in power grids to balance fluctuations in the generation of electricity from renewable sources (WBGU 2008).

3.4 Food quality and safety

Innovative technologies will be required in the coming decades in order to meet increasing consumer demand for food quality and safety. Environmental pollution and the degradation of natural resources adversely impact food quality and safety. In future, product traceability will play an important role in both of these areas.

Food quality is important, because consumers are sensitive to any indication that food is of low quality. Food quality refers to characteristics such as appearance, flavour, texture, odour and nutrient composition. In addition, hygiene requirements are relevant in food processing and marketing. The EU approach includes strict monitoring and control systems, such as beef-cattle identification systems and labelling rules designed to enable the full traceability of meat from retail outlet back to the farm of origin.

Food safety aims to protect consumers. The proper handling and regulatory control of food is essential for preventing hazards to human and animal health, which can be pathogen, chemical (residues), or physical in nature. Food-safety crises of international consequence have occurred, such as the recall of export products from supermarket shelves, or the large-scale, ethically problematic slaughter of thousands of animals. Until now, the extremely high costs thereby incurred have not been borne in mind in cost calculations or in technology assessments, nor have those responsible been held financially accountable for the effects. The EU integrated approach to food safety aims to ensure a high level of food safety, animal health, animal welfare and plant health within the European Union through systematic farm-to-fork measures and adequate monitoring.

3.5 Climate change

Climate change is widely recognized as a major global challenge. Combating climate change is a top priority for the EU. The greenhouse gas most commonly produced by human activity is carbon dioxide (CO_2), which accounts for 63% of man-made global warming. Methane, the next-most-common greenhouse gas after CO_2, is responsible for 19% of global warming from human activity (EC 2010b). Though present in the atmosphere in very low concentrations, methane is a comparatively powerful greenhouse gas: one tonne of methane has about 33 times the warming effect of the same amount of carbon dioxide (Henderson 2009). In global terms, agriculture is a significant source of methane. Much of the methane produced on farms is from cattle and sheep.

An increase in global mean temperatures causes glaciers and arctic sea-ice to melt, which in turn causes the sea level to rise. Climate-change impacts also include changes in precipitation, extreme weather events such as floods, landslides, storms and droughts, and shifting seasons (e.g. SCAR 2011; IFPRI 2009; EC 2010c; FAO 2011). Changing weather conditions are expected to bring new crop diseases and pests in formerly unaffected regions. Furthermore, climate change is expected to cause pronounced regional shifts in agricultural production. Natural ecosystems are highly vulnerable to even moderate rises in temperature, and climate change can seriously affect agricultural productivity (Richardson *et al.* 2009; The World Bank 2009). Water scarcity, an elevated risk of crop failure, pest infestation and increased weed pressure are major threats of climate change. It is projected that the demand for agricultural water increases by 6 to 10% for each increase in temperature of 1° C (The World Bank 2009; FAO 2011).

Need for action: Efforts to address climate change aim to reduce carbon dioxide emissions in the atmosphere and to substitute fossil fuels with renewable-energy sources (The World Bank 2009). Low-carbon technologies and higher energy efficiency in transport, buildings, industry and agriculture are crucial for a resource-efficient economy (Edenhofer and Stern 2009; Richardson *et al.* 2009; TEEB 2009). Enhancing carbon dioxide 'sinks' (forests, wetlands, oceans) is also an effective measure for reducing carbon dioxide in the atmosphere (The World Bank 2009; WTO-UNEP 2009). Climate-change adaptation consists of adjustments in agricultural systems to mitigate the negative impacts of climate change or exploit its potential benefits. Technological innovations (dykes, infrastructure for water supply, energy) (WTO-UNEP 2009), improved farm-management practices, modifications in land-use and harvesting patterns, and efficient irrigation systems are all important measures.

3.6 Social aspects and demands

For centuries, European farming adhered to firmly established structures encompassing a rural way of life and working methods in which knowledge geared to food self-sufficiency was passed down from generation to generation. The advent of industrialization in the late 19^{th} century initiated changes which continue to this day. Farming systems have grown in size, and have thus focused on a smaller number of larger farms, with downward trends in agricultural workforce numbers. Whereas 80% of the population was still employed in agriculture at the start of the 20th century, today this figure is less than 5% (Golter 2002).

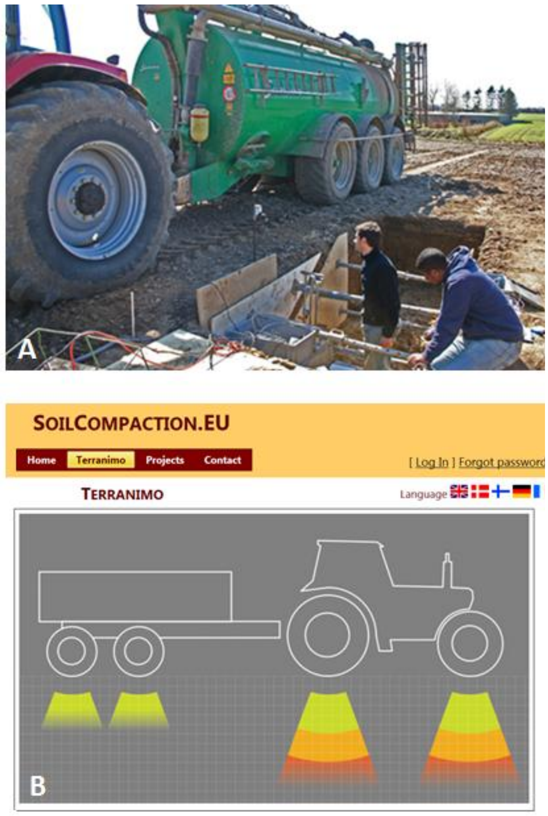
The decrease in agricultural workforce numbers is linked to technological progress as well as to economic competition (SCAR 2011). Since former price guarantees for most agricultural products have been abolished, farms today are under pressure from world markets, with rising prices for agricultural inputs and uncertain producer prices. Increasing energy costs have further exacerbated the worldwide crisis in farming.

Critics see industrial farming as susceptible to the risk of agricultural products being viewed as the equivalent of industrial parts. Such a concept would inevitably lead to as much as possible being squeezed from raw materials, resources and livestock, and would entail the environmental impacts and problems associated with factory farming (Baldenhofer 1999).

Need for action: The challenge is to support the emergence of biosystem-management technologies capable of meeting environmental and ethical standards whilst promoting efficiency and a healthy work environment. It is essential for a variety of sizes and types of farming systems to be maintained, with a sufficient and qualified workforce to safeguard the potential for the development of food systems that are more sustainable and efficient (SCAR 2011).

3.7 Conclusions

The significant growth in world population coupled with changing food habits has resulted in growing global demand for safe, high-quality food. Moreover, without substantial changes in lifestyle habits and innovations in food production, population growth will continue to fuel climate change, degradation of our natural resources, and energy scarcity, with associated negative effects on soil productivity and food production. The situation is further exacerbated by the decrease in arable land due to urbanization and other uses such as carbon sequestration and bio-energy. To bridge the growing gap between food requirements and the scarcity of resources such as water, energy and land, which is further aggravated by climate change, European agriculture must focus on farming systems that are more sustainable and more efficient.



Preparing for the EU Soil Framework Directive through optimal use of information and communication technology across Europe (Predictor): Assessment of soil strength and stress (A) for the development of decision-support tools (B). ICT-AGRI project.

4. Current Situation

4.1 Policy context

The European Commission appreciates the significance of innovative ICT and robotic solutions for tackling global and European challenges in agriculture in the decades to come. Research into ICT and robotics in agriculture as well as related environmental issues is therefore a major priority for the Commission (EC 2010a, SCAR 2011).

The EU's **'Europe 2020'** growth strategy (EC 2010a) aims to develop a smart, sustainable and inclusive economy in the EU. To achieve this goal, the Union has set five ambitious objectives to be reached by 2020, covering employment, innovation, education, social inclusion, and climate/energy. The Europe Union has identified new engines to boost growth and jobs. These areas are addressed by **seven flagship initiatives**.

One of these initiatives supports a resource-efficient Europe, outlining a framework for ensuring that long-term strategies in areas such as energy, climate change, research and innovation, industry, transport, agriculture, fisheries and environmental policy lead to increased resource efficiency. This requires technological improvements, a significant shift in energy, industrial, agricultural and transport systems, and changes in producer and consumer behaviour. In the roadmap for moving to a low-carbon economy in 2050, the European Commission is looking at cost-efficient ways to make the European economy more climate-friendly and less energy-consuming.

The Innovation Union plan, another flagship initiative with over thirty action points, aims to make Europe a world-class scientific performer, to remove obstacles to innovation, and to revolutionize the way public and private sectors cooperate, particularly through **European Innovation Partnerships** (EIPs) between European institutions, national and regional authorities, and business.

The 'Agricultural Productivity and Sustainability' EIP aims to foster a competitive and sustainable agriculture and forestry sector that "achieves more from less" and works in harmony with the environment (COM 2012 79). Operational objectives of the EIP include successful bridge-building between cutting-edge research and technology on the one hand and stakeholders comprising farmers, businesses, industry, advisory services and NGOs on the other. An indicative priority area is the increase in agricultural productivity, output, and resource efficiency. Within this area, the potential of green technologies such as ICT, precision farming and pest warning systems needs to be explored.

The European Commission recently proposed a **reform of the Common Agricultural Policy** (CAP) after 2013. The intention of this reform is to strengthen agricultural competitiveness and sustainability. In line with the Europe 2020 strategy, EU-wide priorities for rural-development support in the years 2014–2020 have been proposed. These include: fostering knowledge transfer and innovation; enhancing the competitiveness of all types of agriculture as well as farm viability; promoting food-chain organisation and risk management in agriculture; restoring, preserving and enhancing ecosystems dependent on agriculture and forestry; promoting resource efficiency and supporting the shift towards a low-carbon and climate-resilient economy in the agriculture, food and forestry sectors (COM 2011 627).

4.2 Funding and cooperation initiatives

Novel ICT and robotic solutions for European agriculture are an important part of **Horizon 2020**, the new framework programme for the period 2014–2020 (EC 2011d). This programme states that "Emphasis will be placed on integrated and diverse production systems and agronomic practices, including the use of precision technologies and ecological intensification approaches to benefit both conventional and organic agriculture. […] Innovations in information and communication technologies can constitute a key tool to […] provide options for integrating agronomic and environmental goals into sustainable production, [...] notably through automated processes, real-time monitoring and decision-support systems." A defined goal of the programme is to reinforce "…European scientific and industrial leadership in industrial and service robotics, cognitive systems, advanced interfaces and smart spaces, and sentient machines, building on increases in computing and networking performance and progress in the ability to build systems that can learn, adapt and react."

European Technology Platforms (ETPs) represent a policy instrument promoted by the European Commission for strengthening the European research and innovation area. ETPs provide a framework for stakeholders, led by industry, for defining research priorities and action plans for a number of technological areas where achieving EU growth, competitiveness and sustainability requires major research and technological advances in the medium- to long term. The main objectives of the ETPs are to strengthen the European innovation process, improve knowledge transfer, and stimulate European competitiveness across the food chain. Technology platforms pertinent to the ICT-AGRI ERA-Net are Manufuture-AET, EUROP and NESSI.

The aim of the **Manufuture** technology platform (http://www.manufuture.org/) is to propose, develop and implement a research-and-innovation-based strategy capable of speeding up the rate of industrial transformation to high-added-value products, processes and services, safeguarding highly skilled employment, and obtaining a major share of world manufacturing output in the future knowledge-driven economy. **Manufuture AET**, a special working group on agricultural engineering technology, is defining medium-to-long-term research priorities for this particular sector.

EUROP http://www.robotics-platform.eu), the European robotics technology platform, aims to mobilize all stakeholders in the field, including the robotics industry, researchers, and private and public investors, in order to maintain Europe's leading position in industrial robotics and to extend it to new applications (professional service, domestic service, security and space robotics).

NESSI (http://www.nessi-europe.eu), an acronym that stands for Networked European Software and Services Initiative, is the European technology platform dedicated to software and services. The aim of the initiative is to achieve impact in the Internet of Services through specific activities in research, standards and policies, building contributions through a united industrial and academic community.

The **Joint Programming Initiative** (JPI) is another cooperation concept introduced by the European Commission. The overall aim of joint programming is to pool national research efforts through the joint and concerted planning, implementation and evaluation of national research programmes in order to make better use of Europe's precious public R&D resources and to tackle common European challenges more effectively in several key areas. **FACCE JPI** (http://www.faccejpi.com/), a special Joint Programming Initiative on Agriculture, Food Security and Climate Change, will integrate research on climatic trends with extreme events, natural sciences with social sciences, research with actual policy and management, ecosystems with products and services, and production with health, food-security and food-quality issues.

The **European Institute of Innovation and Technology** (EIT) was established by the European Commission in 2008, with a mission to "increase European sustainable growth and competitiveness by reinforcing the innovation capacity of the EU". In order to accomplish this mission, the EIT has created integrated structures known as 'Knowledge and Innovation Communities' (KICs). These aim to link the higher education, research and business sectors with one another, thereby boosting innovation and entrepreneurship. KICs focus on priority topics with high societal impact. There are currently three KICs: Climate-Change Mitigation (Climate-KIC), Information and Communication Technologies (EIT ICT Labs), and Sustainable Energies (KIC InnoEnergy). A new call for KIC applications is expected in 2014, and 'food4future (sustainable food-supply chain, from farm to fork)' has been identified as a possible topic for such a call. In order for a KIC, once established, to have a significant EU-wide impact, it is expected that it should have a total spend of at least EUR 50–100 million per annum.

4.3 European research projects

Several transnational EU research projects of the 6th and 7th Framework Programme address issues within the scope of ICT-AGRI. Within the 6th Framework Programme, a set of projects covered topics related to 'Automated Quality Control'. Current projects deal with 'Farm Management and Information System' (FMIS), 'Agricultural Robots', and 'Precision Crop and Livestock Farming'(Table 1).

Table 1. European research projects of the 6th and 7th Framework Programme covering topics relevant to ICT-AGRI

European Projects related to 'Farm Management and Information System'		
agINFRA	A data infrastructure for agricultural scientific communities (2011–2014)	http://aginfra.eu/
SmartAgriFood	Smart food and agribusiness (2011–2013)	http://www.smartagrifood.eu/
AgriXchange	Network for data exchange in agriculture (2010–2012)	http://www.agrixchange.eu/
FutureFarm	Meeting the challenges of the farm of tomorrow (2008–2011)	http://www.futurefarm.eu/
ICT-ENSURE	ICT for environmental sustainability (2008–2010)	http://ict-ensure.tugraz.at/en/index.php
European Projects related to 'Agricultural Robots'		
RHEA	Robotic systems for effective weed management (2010–2014)	http://www.rhea-project.eu/
CROPS	Clever robots for crops (2010–2014)	http://crops-robots.eu/
European Projects related to 'Precision Crop and Livestock Farming'		
ENORASIS	Environmental optimization of Irrigation management with the combined use and Integration of high-precision satellite data, advanced modelling, process control and business Innovation (2012–2014)	http://www.enorasis.eu/
EFFIDRIP	Enabling next-generation commercial-service-oriented automatic irrigation-management	http://effidrip.eu/

	systems for highly efficient use of water, fertilizers and energy in drip-irrigated tree crops (2012–2014)	
BrightAnimal	Precision livestock farming (2008–2010)	http://www.brightanimal.eu/
European Projects related to 'Automated Quality Control'		
BIOTRACER	Improved biotraceability of unintended micro-organisms and their substances in food and feed chains (2007–2010)	http://www.biotracer.org/
TRACEBACK	Traceability of food-supply chains (2007–2010)	www.traceback-ip.eu/
CHILL-ON	Novel technologies for a safe and transparent supply of chilled/frozen food (2006–2010)	http://www.chill-on.com/
OTAG	Operational management and geodecisional prototype to track and trace agricultural production (2006–2009)	http://cordis.europa.eu/search/index.cfm?fuseaction=proj.document&PJ_RCN=9637575
BIODET	Networking in the application of biosensors to pesticide detection in fruits and vegetables (2006–2008)	http://www.biodet.eu/index.htm

Authenticity, origin of food, geographical location ('terroir'), traceability, and security and safety of food production are areas requiring new diagnostic tools and the implementation of new information systems. Projects in the field of **automated quality control** were intended to develop cost-effective technologies, devices and approaches for continuous monitoring and recording of the relevant data and for processing information-management data throughout the entire supply chain. An overall objective was to increase consumer confidence in the food supply by improving the necessary technology to ensure complete traceability along the entire food and animal-feed chain. Furthermore, research was intended to promote the introduction of biosensors as devices for the analysis of pesticides in the agri-food industry and to track and trace the mobility, provenance and state of beef cattle, in order to manage the spread of diseases.

A number of ongoing projects aim to improve and develop new **farm management information systems** (FMISs). These systems are expected to improve farm management, farm operation logistics, and product documentation. Data-intensive

A number of observations can be drawn from the agriXchange country reports:

- Farmers are offered ICT and automation products by many different providers.
- Products from different providers are usually not compatible or coordinated. In some countries, coordination of information exchange has begun, but only on a national level.
- ICT products are often bundled with other products (e.g., advice, accounting, supply- and food-chain management, regulation, use of machines and robots).
- Relationships between direct and indirect providers are bilateral or within-company:
  - Agricultural research organisations do not offer knowledge-based ICT products to be integrated in packages from several direct providers;
  - Manufacturers do not offer access to the computer systems embedded in their products (access for open-standards-based information or programs);
  - ICT companies do not offer agricultural-software modules to be incorporated in products from direct providers.
- The ICT companies specializing in agriculture are mostly nationally based, and have only accessed a small part of the potential market.

technologies such as precision farming and robotics provide a wealth of information and are specifically considered. Standards from cross compliance, regional regulations or buyers should be implemented automatically in the FMISs in order to support the daily on-farm planning and management of information. The systems are expected to take advantage of future developments in internet technology, including among others: (1) integration and standardization of applications and devices; (2) reduction of costs; (3) provision of user-friendly applications and interfaces; (4) the guarantee of high interoperability; and (5) the guarantee of a greater degree of privacy, which in turn ensures the protection of personal data.

New technologies, including global positioning systems, geographic information systems, sensors, the automation of agricultural machinery, and high-resolution image sensing are the prerequisites for developing a new generation of automatic and robotic systems. Two ongoing FP7 projects, RHEA and CROPS, are carrying out research for a new generation of **automatic and robotic systems**, including highly configurable, modular and smart carrier platforms. Overall objectives are to reduce the use of agricultural chemical inputs and to improve product quality by the selective harvesting of fruit.

BrightAnimal was not intended to initiate new research in **precision livestock farming (PLF)**. Instead, it conducted a worldwide review of existing research and PLF practices and standards, with a view to making recommendations on how PLF can be made more accessible to small and medium-sized producers. The main finding was that although PLF has been around for some time now, it has not lived up to expectations. Much more work is needed before PLF becomes the standard method of livestock farming worldwide.

The following are important recommendations for improved uptake of precision livestock farming (PLF) techniques on-farm, and for precision farming (PF) in general:

- Research must be interdisciplinary. It must focus on the real needs of the farm, develop economically viable techniques, and stimulate farmers' interest. Engineering must be balanced with natural science and economics. Farmers and consumers need to be involved in research programmes.
- Sensors and sensing systems such as image and sound analysis systems are essential to PF, because they deliver the raw data stream. However, more emphasis should be placed on interpretation and control. PF is about assisting farmers in making suitable decisions. Future research must therefore be balanced between control, interpretation and sensing. Research should be led by the parameters that need to be controlled, rather than being driven by the sensors that are available.
- There is a need for holistic farm-evaluation systems and related standards for assessing welfare, environmental impact and financial stability of a farm.
- Research into animal-welfare-related PLF techniques must be aware of, and find solutions for, potential conflicts between animal welfare, environmental considerations, and farmers' profits.
- Education, training, communication and success stories are needed to improve uptake of the PF techniques.

5. MEETING CHALLENGES THROUGH ICT AND AUTOMATION

5.1 From challenges to solutions

There are many areas where innovative ICT and robotic applications from the different solution domains can help pave the way towards agricultural production systems that are more sustainable and efficient. ICT-AGRI has identified six main challenges for agriculture in the coming decades, and outlined key goals for meeting these challenges (Fig. 1). The goals are placed in the context of solution domains for both plant and animal production and farm management. The basis for the concept design was a review of current technologies used in plant and animal production as well as farm management.

The solution domains of Precision crop farming, Precision livestock farming, Automated indoor climate control, Automated quality control, Agricultural robots, and FMIS were designed to cover nearly all of the contributions of ICT and robotics to primary agricultural production and to the agriculture-related environment. The rationale for choosing the solution domains and the goals for successfully meeting the challenges are shown below. Detailed descriptions of the solution domains are given in section 5.2.

'Global food security' challenge: All solution domains of the concept have the potential to increase production efficiency in terms of input (production factor) and output (surface productivity). Together with reducing waste in the food chain, this is essential for safeguarding the global food supply for future generations.

'Sustainable resource management' challenge: Increased intensity of agricultural production need not be associated with further deterioration of the environment. Sustainable management of natural resources aims to optimize the efficiency of production factors (e.g. fertilizers and pesticides, water, soil) so as to reduce negative environmental effects. Other related goals are to maintain soil quality, to mini-

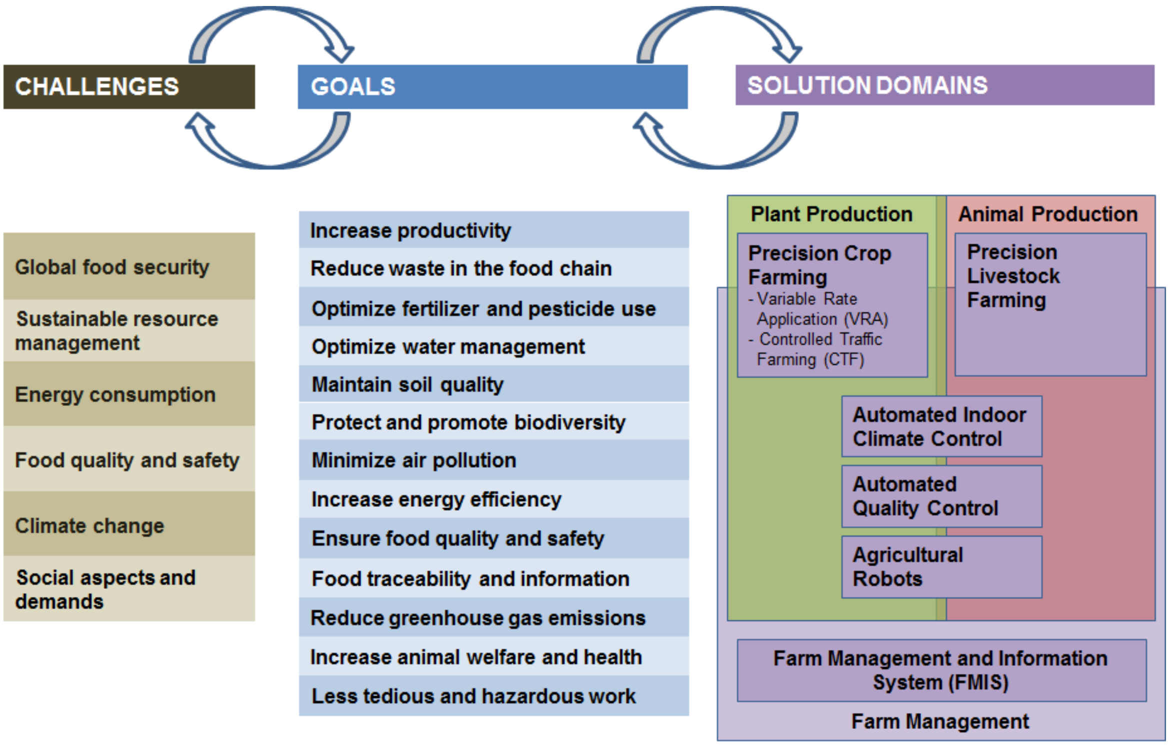


Fig. 1 Challenges, goals and solution domains for a sustainable European agriculture as identified by the ERA-Net ICT-AGRI.

mize air pollution by reducing emissions, and to protect and promote biodiversity. ICT and robotic solution domains contributing to these goals are the site-specific variable-rate application (VRA) of fertilizers, pesticides and water, as well as the geopositional control of field-operation traffic, known as controlled-traffic farming (CTF). VRA and CTF are combined in the term precision crop farming.

'Energy consumption' and 'Climate change' challenges: Controlled traffic farming can also help to overcome problems related to energy consumption and climate change. Controlling field traffic increases energy efficiency and reduces energy demand (particularly for fossil fuels) and greenhouse-gas emissions from agriculture. The use of energy-saving systems for automated indoor climate control is another important approach for increasing energy efficiency.

'Food quality and safety' challenge: Automated quality control is essential for ensuring food quality and safety. ICT and robotic solution domains influencing product quality and safety are Variable-rate application, Precision livestock farming (the use of advanced technologies to optimize the performance of each animal) and Automated indoor climate control. The use of agricultural robots to replace human manual labour can also improve product quality and safety. Advanced farm management and information systems (FMISs) are needed to optimize the information flow between farm software applications in order to ensure the effective management of farming (including traceability) based on automation and robotics.

'Social aspects and demands' challenge: Social aspects and demands will continue to play an important role in the European agricultural sector, and must be given due consideration in the process of developing innovative solutions. Precision livestock farming and automated indoor climate control contribute to animal welfare and health. Animal-specific feeding, milking, monitoring and housing result in prolonged productivity. The use of agricultural robots for tedious and hazardous animal- and plant-production processes improves workplace safety and labour efficiency.

5.2 Research and innovation requirements for the different solution domains

5.2.1 Precision crop farming: Variable-rate application

Description: Precision crop farming aims to optimize inputs to sub-areas of fields in order to increase overall efficiency and eliminate or reduce adverse effects on the environment. As one focus of precision crop farming, variable-rate application (VRA) is the site-specific application of fertilizers, pesticides or water. Based on application maps or real-time sensor measurements, this solution domain includes sensors, sensor information and decision algorithms for variable rates, decision support systems, and tools for creating application maps, as well as auto-guidance systems and spreaders for variable-rate application. VRA requires empirical information on the current state of crop and soil, at a suitable spatial resolution, and measured by sensors or human observation. This information must be interpreted to generate decisions for optimum variable-application rates. Automated information exchange between different applications and components is therefore essential.

Specifications: Although commercial systems are already quite good at managing variable-rate application of nitrogen, further development and validation of sensing technology as an indicator of crop nitrogen requirement for yield and quality is needed in crop production. A further potential area is the use of sensors to detect the nitrogen status of plants, with particular reference to the forecasting of grain quality (i.e. protein content of the grain). Nitrogen requirement in oilseed rape has been linked to canopy size, which sensors could detect relatively easily, enabling the application of nitrogen on a variable-rate basis.

Site-specific application of pesticides is still an underdeveloped field. Computerized sprayers and further developments in the detection of weeds, fungal diseases and stresses are necessary. Sustainable plant protection relies on the precise timing of monitoring and control measures for pests and diseases based on their phenology. Weather-based decision-support systems (DSSs) that simulate local pest phenology can provide information on pests and management options, thereby increasing the efficacy of pest management and reducing the number of sprays and pesticide applications per treatment. The potential of VRA (or spot spraying) in weed-control strategies in the various regions of the EU must be determined by field trials comparing spot and overall control measures with target weed species, in order to assess the impact on weed control and pesticide use.

The potential of VRA for fungal-disease control in major crops must be established by determining the response to various crop treatments based on potentially detectable, spatially variable crop differences in the field. This must be done in different EU regions, with different economically important diseases and disease pressures. This step is essential before focusing resources on sensing the spatial variation in disease (or disease-influencing factors). If variable-rate application in this context encompasses spatial variation at a relatively low resolution (i.e. multiples of hectares rather than square metres), then the use of decision-support systems and integrated pest-management strategies is vital. Research is needed prior to developing these systems for, or adopting them in, different regions with different disease pressures. There is a particular need to develop these approaches for northwestern Europe, where the climate favours the rapid development of fungal diseases and alternatives to prophylactic application are needed in order to reduce pesticide use and lessen the pressure on pathogen-resistance development.

Increased effort is still needed to reduce the cost of high-precision sensors and improve the durability of sensors for in-field operation. The development of in-situ and on-the-go measurement systems through the use of VIS-NIR spectroscopy analysis must be encouraged. Proximal sensing using crop-reflectance sensors on machines seems to be the most suitable option. Alternatives such as remote sensing (satellite or small plane) require more research.

Further input is needed with respect to soil conditions. Soil surveying is the process of classifying soil types and other soil properties in a given area, and mapping such information. Maps can show the chemical and fertility properties of the soil, as well as its physical and biological characteristics. Such maps are very useful for precision farming, where recommendations on the application of various inputs (e.g. N, P, K and lime fertilizer) can be spatially optimized for maximum yield and minimum input.

The operation of VRA equipment is currently difficult for farmers, which is often claimed as a serious impediment to the use of this approach in practice. The main problems are the lack of automated information exchange between various components, as well as the scarcity of user-friendly and efficient ICT tools for farm managers. The inclusion of farm management information systems (FMISs) and decision-support systems (DSSs) in web-based approaches is a particularly important aim.

The cost-benefit assessment of VRA is dependent upon a number of interrelating factors. As technology costs decrease and the cost of agricultural input factors increases, the economic case for implementation of VRA will improve. The solution domain harbours labour-saving potential, in particular as regards the documentation of actual applications. A case study may permit the comparison of different kinds of systems.

5.2.2 Precision crop farming: Controlled-traffic farming

Description: Controlled-traffic farming is the geopositional control of field-operation traffic in order to optimize yields and inputs (including fuel and labour) and reduce negative environmental impacts. Controlled-traffic farming is a sub-area of precision crop farming which focuses on reducing the total amount of fertilizers, pesticides and water applied to fields through the use of GPS-guided machinery (see also chapter 5.2.1: Variable-rate application). The 'Controlled-traffic farming' solution domain comprises the areas of decision support to minimize traffic and soil compaction, auto-guidance, fixed-tracks guidance, and fleet management, and requires agronomic knowledge linking crop development to field operations. The operation and traffic-planning tools as well as the real-time monitoring and steering tools require comprehensive information exchange and interoperability.

Specifications: More experiments under various soil and climate conditions are required in order to gather knowledge on the effects of CTF on soil compaction and regeneration, greenhouse-gas emissions, and plant and yield development. An understanding of the correlations between trafficability and workability, soil status and traffic effects is essential for the site-specific control of machine operation (e.g. inflation pressure, dynamic axle load).

Optimization is needed for operation and traffic planning, including scheduling and route planning. Traffic management requires mechanisms for information distribution among vehicles, traffic controllers, FMISs (farm management and information systems) and traffic planners (systems or humans). Mechanisms for information consolidation and interpretation as well as for presentation are also necessary. Common information exchange and representation protocols are therefore an essential focus for R&D.

The use of CTF has the potential to allow farmers to reduce input costs (time, fuel and machinery) whilst increasing crop yields. CTF costs and profitability are not quantitatively known, however. Feasibility and cost-benefit assessments are therefore required in association with alternative soil-protection measures to thoroughly convince farmers and encourage widespread uptake. Compatibility between products from different vendors will also be necessary for farmers.

5.2.3 Precision livestock farming

Description: The main goals of precision livestock farming are to improve profitability, work ergonomics, and animal health and welfare based on sensor measurements and advanced ICTs. Livestock production nowadays is not limited to these goals, however. Modern society is also concerned about food safety and quality, efficient and sustainable animal farming, and the acceptable environmental impact of livestock production (Berckmans 2004). The solution domain includes feeding, cleaning and milking systems, sensor-based detection of animal status in terms of breeding, health and welfare, and handling of farm animals. Monitoring and decision-support systems allow efficient herd management.

Specifications: Several innovative automation technologies for precision livestock farming are on the market. Some, like automatic milking and feeding systems, are well established and work with a high degree of functionality and reliability. Others, especially sensors and analysis algorithms, have not yet reached that level of development. Most biosensors require an improved degree of sensitivity and specificity, and the information obtained must be combined and evaluated continuously in order to provide helpful decision-support systems (DSSs) for the farmer. Such systems should always consider the variation between individual animals. Closer monitoring of individual animals should lead to higher production efficiency, and hence to a lower environmental footprint per kilogram of product produced.

The rational management of greenhouse gas (GHG) emissions from animal operations still poses a major challenge. There are considerable gaps in knowledge, especially as regards ammonia, nitrous oxide and methane emissions from solid-manure regimes. The development of low-emission stables with optimized surfaces and adapted cleaning systems is one of the main goals in this field.

Disease-risk management and modelling must be improved. Early detection of problems will reduce the risk of pharmaceutical residues in meat and manure. Optimal route-assessment tools in case of animal-disease outbreaks as well as dispersion modelling for diseases should be further developed and applied.

Precision livestock management should contribute to increased profitability in livestock farming. It is therefore crucial to focus on the technological developments with the highest value-added, in particular with regard to labour savings, e.g. feeding systems on dairy farms (including the integration of grazing with automatic milking).

Full integration of precision livestock farming should also include animal-handling infrastructure. Integrating facility information with animal information would be a very powerful way of improving profitability and sustainability. The focus should be on the development of user-friendly precision livestock farming systems, including the monitoring of animals, facilities, forage and waste. A basic requirement for such complex systems is compatibility between the hardware and software products of different vendors.

Environmental and animal-welfare effects should be investigated together with the economic effects. Improvements in the animal system may impact animal welfare and the environment. Possible trade-offs must be detected early on to ensure progress in terms of the sustainability of the system.

5.2.4 Automated indoor climate control

Description: Advanced systems for automated indoor climate control should help reduce energy consumption and GHG emissions as well as improve the environment in both greenhouses and buildings for livestock. The latter helps to ensure healthy animals and livestock-friendly housing systems. The optimum indoor climate for greenhouses and livestock buildings is based on sensor measurements and automated regulation. The solution domain requires an understanding of the reactions of plants and animals to temperature, light and air (including humidity and CO_2 levels), and encompasses the automated control of these components as well as the adaptation to outdoor climate.

Specifications: Complete climate systems are available both for greenhouses and the main farm-animal species, but often lack suitable mechanisms for reducing energy consumption and CO_2 footprint, especially in terms of compliance with animal health and welfare standards.

Innovative climate systems must be easy to use without reducing the potential of the system, and should include checking functionalities for air-flow rate, temperature, pressure difference, etc., as well as controlling functionalities (flow rate as a function of indoor gas concentrations such as CO_2, NH_3, etc.). Smart ventilation control will facilitate optimal control of emissions.

Already-existing, state-of-the-art integrated or coupled heating-ventilation systems should be adopted in agriculture. It is no longer feasible to heat a room with one installation and ventilate it with another (unrelated) installation.

Energy recovery is also a crucial factor that might be improved by automated probes and control systems. Automated natural ventilation is considered an energy-efficient technology for controlling indoor climate. If this can be adapted to ambient weather conditions, a reduction in GHG emissions is possible.

5.2.5 Automated quality control

Description: Quality, safety and traceability of food and feed are the main goals of automated quality control. These aims are essential for ensuring safe, high-quality food produced under animal- and environmentally friendly conditions for a continuously growing market. Automated quality control is accomplished by taking sensor measurements during harvest, transport, storage and delivery to the food chain. It requires information on, and an understanding of, the reactions of food and feed to harvest, transport and storage conditions. Automated quality control comprises quality-measuring sensors in food and feed, information exchange with farm management and information systems for alerts and documentation, and control loops for automatic quality-maintenance control.

Specifications: Consumer confidence depends on trust in a high level of product quality and safety. Inspection principles for ensuring traceability of quality and origin, bio-organic compliance, etc. should therefore be a priority so as to guarantee satisfied consumers and higher retail prices. Research is needed on the reactions of food and feed to harvest and storage conditions (correlations with climate control). These are determining factors for subsequent food and feed quality, influencing the taste, concentration of constituents (e.g. vitamins) and safety aspects (e.g. possible presence and growth of fungi with potential production of mycotoxins, etc.) of the end products.

The development of sensors for effective quality and contamination control in plant and livestock production and processing is critical, and requires intensive research. Innovative sensors in plant production, for example, should monitor both the stage of maturity and the nutritional or organoleptic qualities of fruits and vegetables. This will help to optimize agronomic practices and to pinpoint the ideal harvest time as a function of the required quality level. In livestock production, further developments such as new sensors for determining additional milk parameters (lactose, urea, progesterone, ketones, enzymes etc.) would improve quality control.

Automated quality control can also contribute to the optimization of water recycling in food-chain processes. Water availability and quality are becoming limiting factors for agriculture, which is why improved management is required.

Although sample-based quality control is common practice nowadays, future technologies should enable individual product quality to be closely monitored. A crucial requirement is the permanent information exchange with the farmer’s FMIS (Farm Management and Information System) for alerts, documentation, and automatic quality supervision and regulation. ICT products from different vendors should be compatible, ensuring within-farm efficiency as well as promoting information exchange and traceability along the food chain.

5.2.6 Agricultural Robots

Description: Agricultural robots can take the place of manual labour, in particular to perform hazardous or tedious tasks and to improve work safety, labour efficiency, product quality, and environmental sustainability. Replacing heavy vehicles with small field robots may, for example, reduce soil compaction. The solution domain comprises a robotic approach to performing specific agricultural tasks. Issues to be addressed include autonomous navigation (often on rough terrain), sensor-based operation, and safety issues concerning humans, animals and the environment. The solution domain includes robots for cleaning animal housing, weeding, greenhouse harvesting, sorting, and pot-plant production.

In 2010, worldwide sales of service robots for professional use were in excess of 13,700. Whilst 45% of these were for military applications, field robots (chiefly milking robots) accounted for 30% of the total unit supply. Agriculture is thus the second-most important sector for professional service robots, and sales are forecast to increase steadily in the period 2011-2014 (IFR 2011).

Specification: The development of agricultural robots will be influenced by a number of different factors, e.g. legislation, economic aspects, and the perception and acceptance of robots by society. While technological development will obviously be key, a multidisciplinary approach combining agronomy, economics, farm logistics, etc. will be essential. In some cases, a robot's task can be made easier by simplifying the working environment through the adoption of new and less-complex systems of cultivation. Advances in robotic engineering must be applied to the agricultural domain in order to accelerate innovation.

Robotic technology will not be able to completely replace humans in the short and medium term. Humans and machines will thus have to co-exist, coordinate and cooperate in order to achieve overall improved efficiency. Relevant research can develop along two major axes. The first should examine the synergy of a single worker with a single robot (e.g. supporting the manual labour performed by an employee, enhancing productivity, safety). The other should examine synergy at a system level (robots and multi-robotic systems serve and support human labour so that overall efficiency is safely maximized).

Today, the major limiting factor to the use of agricultural robots boils down to safety concerns for humans or animals sharing the same work environment as the robot. Although of the utmost importance, safety issues concerning humans, crops, animals and the environment are still poorly addressed in this field. If autonomous machines are to be commercially available, they must have reactive features so as to achieve a high degree of functionality, safety and reliability.

Another key issue in robotic solutions is fast and effective eye-hand coordination. This includes sensing, perception and transformation of the obtained information into effective manipulation.

Robotics offers a chance to buck the trend towards bigger and heavier tractors and agricultural machinery in any field of application by using a swarm of small robots instead of a few large ones. In this context, cooperation and fleet management become important issues, requiring intensive information exchange with FMISs (farm management and information systems) for settings, logs and alerts.

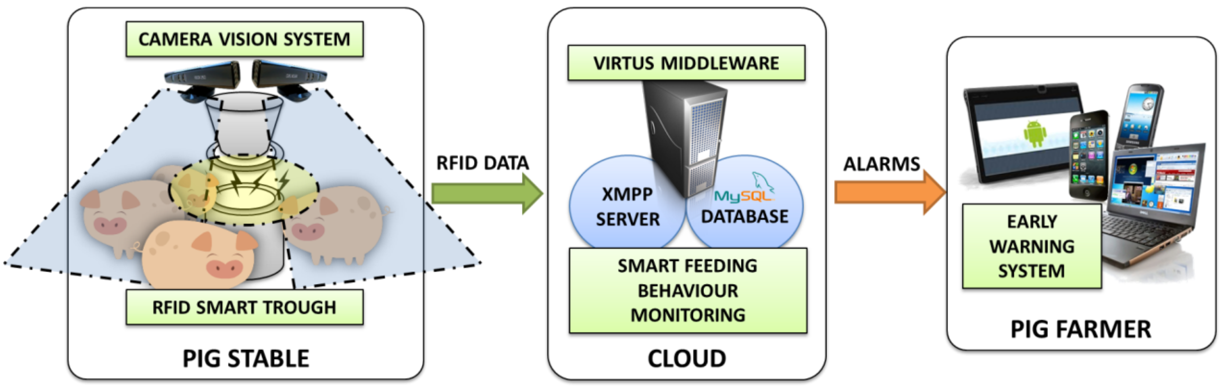
5.2.7 Farm management and information system

Description: The farm management and information system (FMIS) is defined as the backbone system for all other ICT and robotic solution domains. FMIS provides a common user interface across solution domains as well as a repository for farm information (fields, crops, buildings, facilities, inventories, animals, past operations, goals, quality measures, etc.). FMIS also includes tools for communication and information exchange with external bodies, e.g. providers, food chains and government agencies. An efficient FMIS is based on defined agronomic information that effectively reflects agricultural production and its inherent decision-making processes. Decision-support systems (DSSs) provide information for economically and environmentally appropriate farm management, and thus help the farmer in his daily work. The necessary information exchange requires interoperability between products from different vendors.

Specifications: Data concerning farm inventories, events and operations are for the most part entered manually. This time-consuming and error-prone approach must be replaced by automated information collection and storage. Bar-code or RFID readers could be used to maintain on-farm storage inventories. On-farm cabled or wireless networks could be used for internal information exchange, and web-based farm-management approaches would allow the integration of decision-support systems (e.g. crop suitability models, early-warning systems for pests and diseases, sustainability check, full life-cycle assessment) to increase the efficacy of the system.

The FMIS of tomorrow will be a modular system. Farmers must be able to choose which modules or services they want to use. Some of the services will be available for free, whilst others will require subscriptions. These services need to work together, integrate and interoperate as one transparent FMIS. A desktop client could synchronize the online and desktop databases in order to integrate all necessary services. The interoperability of common software components, however, can only be achieved when research institutions, end-users and manufacturers are prepared to work together (to co-create or co-innovate). The involved parties must agree on certain (open) standards (process models, information models and semantics, messages, code lists, etc.) and overcome problems of information privacy and the reluctance to share information, as well as social and cultural barriers.

The ultimate success of an FMIS is measured by its adoption and use at farm level. The level of uptake varies dramatically depending on the individual farm, age of the farmer, region, and level of technological development. Research should focus on the background reasons for these differences and should create specific guidelines around FMIS development adapted to the individual farm, region and system. Demonstration of value is an important prerequisite for implementation in practice. Investments in and the operating costs of complete and efficient FMISs are considerable, and farmers will expect genuine business improvements in terms of income development and working-time requirements. In addition, the interfaces must be as easy to use as possible, so that the farmer is able to manage the system without problems. This is a prerequisite for the adoption of all new technology.



Optimizing the performance and welfare of pigs using high-frequency RFID and synergistic control at the individual level (PIGWISE): Architecture scheme. ICT-AGRI project.

6. Vision for ICT and Robotics in Agriculture

European agricultural production systems must face upcoming challenges. A growing world population and climate change require the development of farming systems that are both more sustainable and more efficient in order to deliver better natural-resource management, lower energy consumption, and high food quality, safety and security. ICT and robotic technologies will be one of the key bases for this evolution. Transformation will not happen in the short term, but will develop gradually owing to the complexity of agricultural biosystems and the interactions between plants, animals and people.

The vision illustrated in Fig. 2 shows the future interactions between farmers, the agro-industry and government agencies when employing (the full potential of) ICT and robotic technologies.

The introduction and widespread adoption of sophisticated ICT and robotic solutions profoundly improves agricultural process management, and paves the way for the development of sustainable, high-intensity crop and animal production systems. These advanced agricultural production systems deliver safe, high-quality food to a growing market whilst respecting the requirements of natural-resource management, climate action, and public health.

Thanks to new information and communication technologies, precision crop and livestock farming have become real-world solutions for agricultural production, making the management of individual plants or animals more operational, and hence easier, for farmers. Many manual tasks can be performed by automated systems, offering better control of production processes for improved production-factor efficiency and product quality. Agricultural robots manufactured to high safety standards are available to perform dangerous and physically strenuous tasks.

In plant production, ICT-driven solutions for the variable-rate application of fertilizers, pesticides and water are commonly used in combination with positioning systems for controlled traffic and geographic information systems. The latter are used as a general decision-making basis for mapping and statistical analyses. The ability to apply the right amount of inputs in the right place and at the right time is a great help in optimizing fertilizer and pesticide use as well as water management. This has positive effects on soil conditions, water-use efficiency, air and groundwater pollution, and biodiversity. Energy consumption and greenhouse-gas emissions from plant

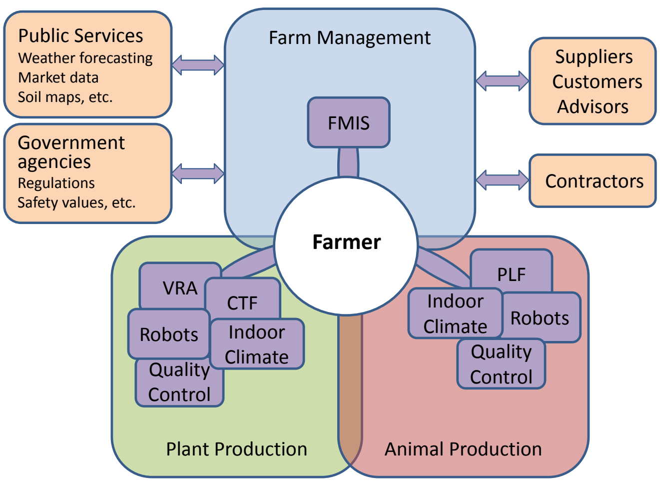


Fig. 2 Conceptual model of the ICT-AGRI vision

Future agricultural production systems must be:

- able to produce sufficient safe, high-quality food for a growing world population;
- sustainable in economic, environmental and social terms.

Advanced ICT and robotic solutions can contribute to these goals by:

- increasing agricultural productivity and product quality;
- reducing the environmental footprint of agricultural production;
- making agricultural jobs & workplaces more attractive.

production can also be reduced by the systematic use of variable-rate application and controlled-traffic farming techniques, as well as by installing intelligent automated systems for the ventilation and heating of greenhouses.

In livestock production, advanced technologies help to optimize the performance of individual animals. Highly automated feeding, milking and cleaning processes along with closer monitoring and decision-support systems (including disease-risk management and modelling) enable greater profitability and improvements in workplace ergonomics and animal health and welfare. Using modern ICT for the automatic acquisition and interpretation of a vast number of individual animal attributes provides opportunities for producing safe, high-quality products with a lower environmental footprint. Smart systems for automated indoor climate control can help reduce energy consumption and greenhouse-gas emissions from animal husbandry, and provide an optimal indoor climate to promote animal health and welfare.

Available modular and scalable ICT and robotic solutions take into account Europe's diverse agricultural structures, and can be adapted to specific farm situations and individual farmers' needs. They are user-friendly and inter-brand-compatible in terms of hardware and software components, and are therefore readily adopted by farmers. An efficient farm management and information system with integrated decision-support systems is an essential tool for everyday farming tasks. It enables optimal management of the information obtained, and the logical deduction of the right actions for improving economic viability and reducing the environmental impact of agricultural production.

Beyond farm level, transnationally compatible information-exchange systems enable better communication with stakeholders such as extension services, suppliers, purchasers or public administration. Intensive knowledge exchange and dissemination is accomplished efficiently, and transnationally relevant issues such as automated control, tracking and tracing along the food chain are feasible. The use of ICT and robotic technologies has brought partners closer together and targets increased profitability for all involved parties.

Ambient Awareness for Autonomous Agricultural Vehicles (QUAD-AV): Tractor with RADAR and odometer, rotating LIDARs, stereo cameras and thermographic camera (A); and view from a thermographic camera, in which a person hiding in a maize field is clearly visible (B). ICT-AGRI Project.

7. Conclusions and Recommendations

Agriculture in Europe faces the challenge of becoming 'greener' in terms of sustainable management of natural resources, reduced environmental footprint, and climate change. At the same time, agricultural production must remain effective, competitive and profitable. Agricultural research and innovation is increasingly addressing these issues, and knowledge of how to deal with the challenges is continuously growing. Since the impact on the challenges depends on the transfer and application of this knowledge to agricultural practices, there is also an increased focus on agricultural knowledge and innovation systems.

ICT and robotics are among the fastest growing technologies. They will shape the future of our economy, environment and society, pervade all spheres of life, and become even-more-indispensable components of our daily life. The strategic research agendas of the European Technology Platforms in ICT (NESSI 2011) and robotics (EUROP 2009) outline the state of the art and the research efforts necessary to promote technological development. A strong focus must be placed on the interactions between science, engineering and practice in order to speed up development and knowledge transfer. New knowledge generated by science will lead to technological achievements (technology push), whilst a clear understanding of market requirements will stimulate target-

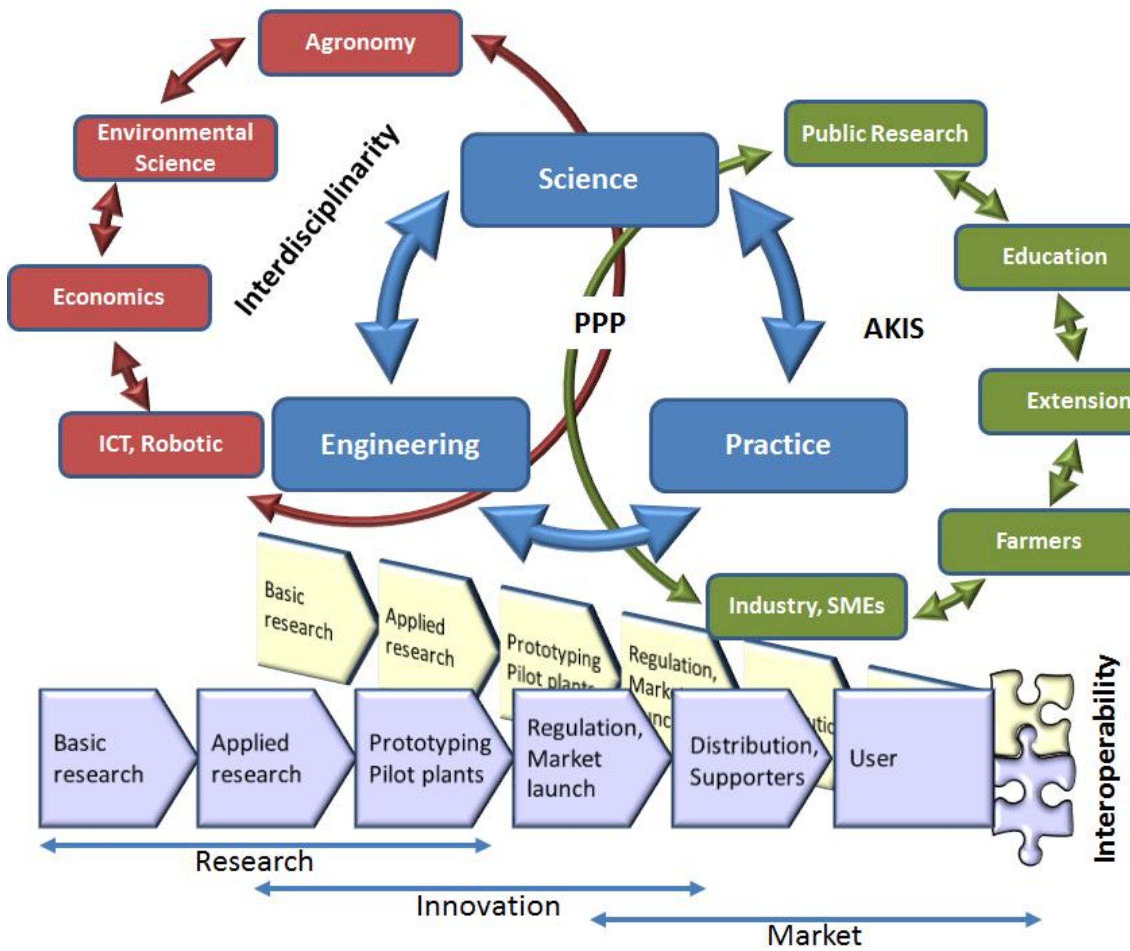


Fig. 3 Axes of coordination and cooperation along the research and innovation chain to ensure interdisciplinarity in research and interoperability/compatibility of applications, and to manufacture products tailored to customer requirements. PPP = Public-Private Partnership, AKIS = Agricultural Knowledge and Innovation System.

oriented engineering (market pull). This requires strong coordination and cooperation in various fields and at various levels of research and innovation: in science and engineering, among stakeholders in the agricultural knowledge and innovation system (AKIS), and in Public-Private Partnerships (PPPs) (Fig. 3). Recommendations for the SRA implementation cover three aspects:

Developing ideas from different areas of academic expertise to arrive at innovative solutions

The application of ICT and robotics to agricultural and environmental issues poses a major challenge for the ICT-AGRI sector. Further progress in the adoption of ICT and automation in primary agriculture requires complete solutions addressing all relevant aspects including functionality, usefulness, user-friendliness and cost-effectiveness, as seen from the farmers' point of view. Substantial progress can only be expected with close inter- and transdisciplinary cooperation**.** Future ICT-AGRI research and technological development (RTD) must therefore focus on coordinated, cross-thematic research approaches. A great deal of effort must be put into networks that allow researchers from different disciplines to establish contacts and develop innovative ideas.

- Funding and research initiatives should stimulate interdisciplinary RTD, consisting of agronomics, engineering, computer science, economics and the social sciences, as well as PPPs. Interdisciplinary RTD can be implemented in the form of wide-ranging holistic projects, as well as by narrow projects having efficient interfaces with reference frameworks.
- Horizon 2020, JPIs, EIPs and ERA-Nets are well-suited instruments for introducing interdisciplinary research to national research programmes, while Entrepreneurship and Innovation Programmes and the EIT-funded KICs have the potential to bring together industry, education and research in order to strengthen the entrepreneurial culture and bring innovations to market.

Achieving maximum profit by combining stakeholder expertise

ICT and automation products are usually supplied to farmers in combination with other product or services: (1) Agricultural advisory and extension services are major suppliers of ICT to farmers, in addition to providing production advice, accountancy services, and help with subsidy applications. Provision of ICT is followed by training and support in the use of the systems. (2) Public services responsible for environmental regulations and subsidy administration often provide ICT solutions to ease the administrative burden of farmers. This may include online reporting systems and GIS applications for field locations. (3) Manufacturers of automation machines and equipment often deliver software packages designed for the optimal utilization of their products. (4) Private software companies offer ICT solutions for specific purposes, such as a single area within animal production, arable farming, or decision support for plant protection.

The characteristics of end users must be borne in mind when seeking a strategy for improving the effectiveness of ICT and automation. Firstly, access to basic farm information (fields, maps, crops, animals, inventories) is essential, as automation requires management decisions to be expressed explicitly, e.g. in terms of a field map with spraying instructions. Secondly, farmers need substantial support in the purchase, installation and use of ICT and automation. Both of these characteristics indicate that direct providers who manage basic information for farmers and who are in dialogue with the latter, are key actors in improving the effectiveness of ICT and automation.

ICT systems for agriculture are primarily produced and distributed by manufacturers on a national or regional basis, in conjunction with specific automation products. Data sharing between systems is almost completely absent, and there is little tradition of incorporating specialized ICT and automation components into the systems offered to farmers. This situation increases the costs of producing ICT and automation systems for farmers, slows down the introduction of new products to the market, and may cause frustration among end users.

ICT has enormous potential for the sharing of experience among farmers and for data and information exchange among stakeholders. Digital agriculture involves the collection of vast amounts of data which represent a valuable source of information on farm practices, crop and animal health, and the productivity and performance of production systems. These data can become an important basis for monitoring and further development towards a new and greener agriculture.

- The public and private actors who maintain the basic farm data on e.g. fields, crops, animals, inventories and machines, and who are familiar with advice and support to farmers, must be involved in the integration of knowledge-based systems and robotic machines into farm-management systems. Public services play an important role by providing ICT for environmental regulation and subsidy administration.
- Appropriate technologies and business models for incorporating third-party software and hardware into farm-management systems and for sharing essential data must be introduced. The provision of third-party components should be included in the development of direct-provider systems. This should be done in a European context to ensure better utilization of research results and a larger market for commercial products.
- The rapid development of technologies places high demands on the education and training of farmers. National and transnational agricultural knowledge and innovation systems must place greater stress on the continuous training and qualification of farmers.

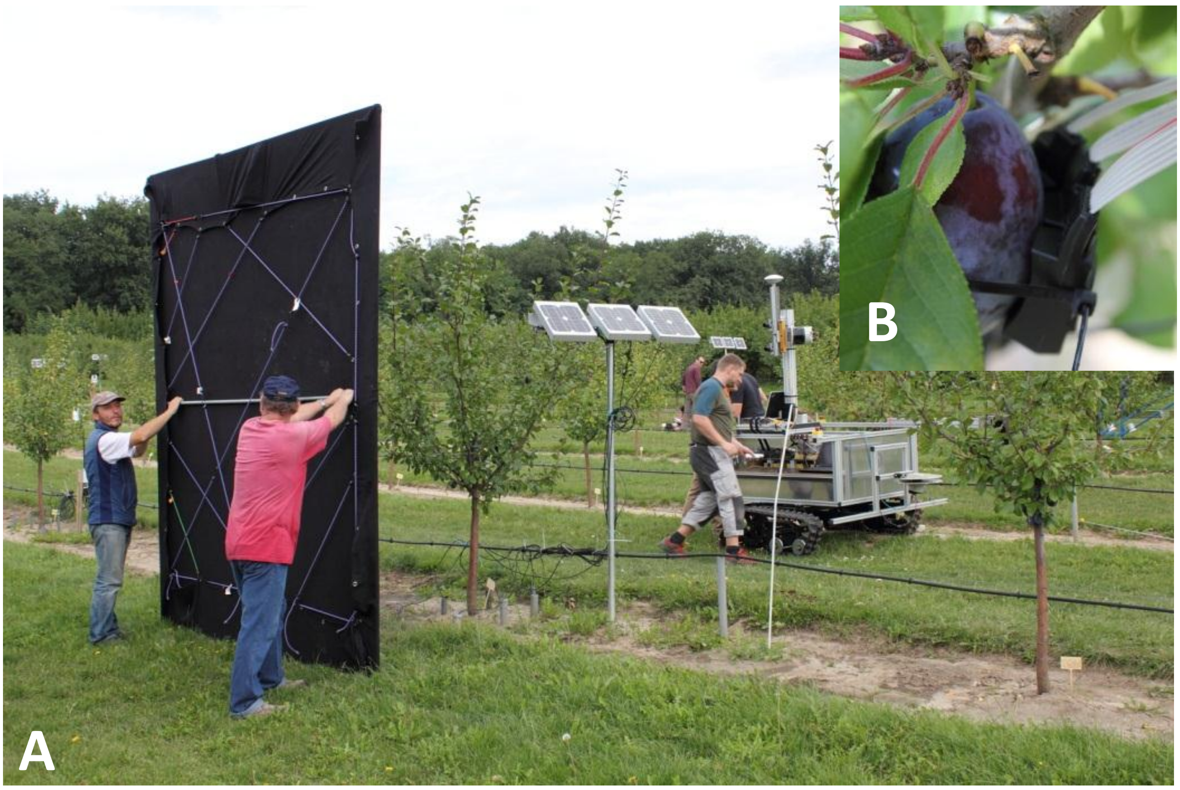
Investing in compatible systems in order to utilize the full potential of the technology

A user-driven approach should be applied in the transformation of ICT and automation products for agriculture. The purpose of this transformation should be to improve the usability and user-friendliness of the products, thereby improving the uptake of ICT and automation. The user-driven approach implies cooperation along three nodes in the value chain: development, supply and support, and end use. A better understanding of the business requirements of the supply and support companies as well as of the operational logistics on farms must be acquired.

Although there are several examples of successful application, the development and dissemination of ICT and automation within agriculture can only be described as highly ineffective. Direct providers develop software in multiple versions for some purposes, but do not develop essential new software for other purposes owing to a lack of resources. End users (farmers) struggle with many incompatible and inadequate products. Knowledge-based ICT products such as decision-support systems developed by agricultural research are not being used in practice. Computerized machines and robots are not integrated with farm-management systems. New and innovative information and communication technologies, e.g. the Internet of Things, are only slowly being adopted in agriculture.

- In order to overcome standardization problems from the past, it is essential to act on a trans-European level. A joint public-private effort is needed to propose, endorse and disseminate *de facto* and *de jure* standards for data exchange in the agricultural domain. Standards can grow out of recent and ongoing European research projects, but it is essential to establish follow-up strategies to promote the application of the project results in the automation manufacturing industry and the ICT development industry. Such efforts can be implemented by ERA-Nets, EIT and Entrepreneurship and Innovation Programme initiatives in collaboration with ETPs, and other initiatives such as Enterprise Europe Network.

- Public procurement at EU level in terms of national administration of the CAP and other European actions such as the Water Directive may be important for enhancing standardization within ICT for agriculture. Common standards for communicating with national authorities throughout Europe will be an important incentive for improved interoperability of ICT and automation applications. In partnership with the relevant EU activities, ERA-Nets can be an effective means for establishing cooperation of this sort between national administrations.



Advanced Monitoring of Tree Crops for Optimized Management (3D-Mosaic): Field trial (A) and a plum equipped with a sensor prototype (B). ICT-AGRI project.

8. ICT-AGRI Initiatives

The EU's 'Europe 2020' Strategy (EC 2010a, follow-up programme of the Lisbon Strategy) underscores the fact that ICT has now become one of the most vital of the enabling technologies. ICT-related development and innovation is responsible for approximately half of the productivity growth in modern economies. The potential gains from coordinated ICT-related research and development within the fields of knowledge-based bio-production will represent a major step forward in one of the most important sectors of the European economy. The enabling technology – ICT – drives improved efficiency and better products across the private and public sectors. It has a strong potential to contribute to growth and jobs through innovation and investments in the knowledge-based bio-economy built by Europe to protect European standards of living and sustainable development. In order to achieve the 'Europe 2020' objectives, coordination of the ICT-related research strategies of the private and public sectors in Europe must be further developed. The ICT-AGRI ERA-Net supports the EU's 'Europe 2020' strategy by contributing to better coordination, competitiveness and industrial development within the agri-food sector.

8.1 Finding partners for cooperation

Given the many institutes, organizations and enterprises possessing substantial knowledge in the ICT-AGRI sphere, there is significant potential in mobilizing research and innovation efforts in ICT and robotic technology within the EU. A helpful tool for cooperation in European research initiatives is the Meta Knowledge Base (MKB), developed by ICT-AGRI. An information platform with technical and social content, the MKB is a structured framework for mapping and analyzing all relevant knowledge within ICT and robotics in agriculture, as well as a central internet-based resource for researchers, developers and users. This tool stimulates cooperation and coordination of R&D through user-driven initiatives and activities, leading to the pooling of fragmented human and financial resources. In this way, both the efficiency and the effectiveness of Europe's research

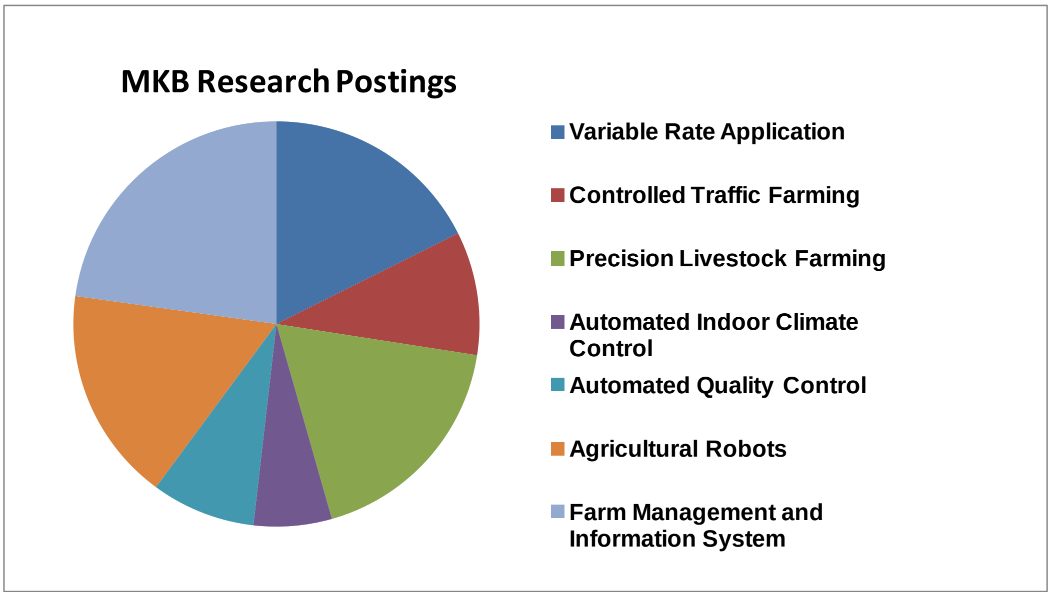


Fig. 4 Research postings of the ICT-AGRI Meta Knowledge Base (MKB), classified by ICT-AGRI solution domains (status as at March 2012). Both the research postings and the information on users and organizations make the MKB a helpful tool for cooperation in European research initiatives.

efforts can be improved. The database currently comprises 1000 registered users, over 200 organizations, and almost 200 research postings related to ICT and automation in agriculture. All postings are classified by keywords and associated with the solution domains identified by the ICT-AGRI ERA-Net. Figure 4 gives an overview of the MKB research postings.

8.2 Calls for transnational research projects

ICT-AGRI has launched transnational research calls based on funds from participating countries. The calls have enabled collaborative projects based on complementarities and the sharing of expertise within ICT and robotics in agriculture. The aim has been to pool fragmented human and financial resources in order to improve both the efficiency and the effectiveness of Europe's research efforts.

First call 2010

Projects were expected to apply a systems approach addressing farm-level integration of information technology, communication technology, automation and robotics, and were expected to fall into one of two categories: (1) a broad-based approach combining existing or new software and hardware products to demonstrate a system meeting important challenges within a specific application area; (2) a narrow-based approach focusing on specific elements of vital importance for the functioning of integrated systems.

Second call 2012

The overall objective of the second call was to foster progress – by means of ICT and automation – in agriculture in the sustainable use of natural resources, the reduction of agriculture's environmental footprints, and climate-change mitigation, while safeguarding the agricultural economy, good working conditions, and food supply, quality, and security, as well as animal welfare. The call topics referred to five issues essential for the improved use of ICT and automation in agriculture: (1) Open farm-management systems; (2) Enabling framing based on ICT and robotic machines; 3) Knowledge- and solution transfer; (4) ICT- and automation-based interactions between farmers and public services; and (5) Retrieval of agricultural knowledge based on empirical data in farm-management systems.

Project title	**Budget** in 1,000 €	**Partners**
First call		
3D-Mosaic: Advanced monitoring of tree crops for optimized management	€1,150	DE, DE, DE, TR, IL, IT, IT, CH, CH, ES
GeoWebAgri: Geospatial ICT infrastructure for agricultural machines and FMIS in planning and operation of precision farming	€420	FI, FI, DK, DK, DE, DE
PIGWISE: Optimizing performance and welfare of pigs using high-frequency RFID and synergistic control on an individual level	€520	DE, BE, BE, DK, IT
Predictor: Preparing for the EU Soil Framework Directive by optimal use of information and communication technology across Europe	€630	DK, DK, CH, CH, FI, DE, NL
QUAD-AV: Ambient awareness for autonomous agricultural vehicles	€450	DK, FR, DE, DE, IT
ROBOFARM: Integrated robotic and software platform as a support system for farm-level business decisions	€480	IT, UK, GR, TR
STRATOS: Open system for tractors' autonomous operations	€560	IT, LV, CH, IL, BE

Second call		
DairyICT: ICT in large and small dairy systems	€614	DK, DK, UK, UK, UK, FR, IT, CH, IR
FarmFUSE: Fusion of multi-source and multi-sensor information on soil and crop for optimized crop production	€692	UK, GR, DE, DE, TR
GrassBots: User-centric adoption of sustainable farming operations involving ICT and robotics – Case: Grassland harvesting operations for biogas and biorefinery plants	€324	DK, DK, DK, DK, DK, DK, UK, FI, FI
ICTGRAZINGTOOLS Use of ICT tools to capture grass data and optimize grazing management	€539	IR, IR, UK, FR
i-LEED: Advanced cattle feeding on pasture through innovative pasture management	€749	DE, DE, FR, FR, TR
ITApic: Application of information technologies in precision apiculture	€689	LV, TR, DE, DK
SILF: Smart Integrated Livestock Farming: integrating user-centric & ICT-based decision-support platforms	€703	DK, DK, GR, IR, BE, BE, FI,
USER-PA: Usability of environmentally sound and reliable techniques in precision agriculture	€1316	IL, DE, DE, TR, CH, GR, UK, IT, DK,

8.3 Public-Private Partnerships (PPPs)

As mentioned previously, new developments in ICT and robotics in agriculture are recognized as having great potential to ease the transition to a more sustainable agriculture. Progress in the implementation and use of these promising technologies at farm level requires the development of solutions in which hardware (e.g. machines, sensors, computers) and software together support manageable and profitable use by farmers. Only those technological solutions providing a clearly observable economic advantage are marketable, and industry sees to the development of these commercial products. This calls for interdisciplinary R&D, as well as cooperation between research, industry, providers and farmers in the form of Public-Private Partnerships (PPPs).

The ICT-AGRI/PPP action aims to encourage PPP by creating consortia of concerned actors, in order to facilitate product innovation on a specific challenge. One definition of innovation is the process of going “from an idea to a concrete product”. All the bricks and links playing a part in this process constitute the ‘value chain’. The ‘value chain’ analysis will provide the following: (1) A comprehensive overview of all components and actions needed to build the product and bring it to market; (2) A comprehensive list of all actors concerned at each link (e.g. developers, disseminators, research actors); (3) The opportunity for all said actors to work together to deal with questions, subjects or difficulties that must be resolved in order to reach the final aim; and (4) Benefit from possible complementarities between countries. Concrete products directly related to the market must be defined and validated in order to attract private actors to the PPP process.

9. ANNEXE

From April to June 2011, an online consultation was conducted with the dual aim of identifying solutions for ICT and automation applications with the highest potential for meeting the challenges facing European agriculture, and determining research and innovation (R&I) requirements.

The online consultation was designed as a real-time Delphi survey, so participants could see the R&I voting results and the comments of the other responders. Around 180 participants from 21 countries voted and commented. They were given the opportunity to modify the descriptions of the solution domains and components. They also had the option of creating and commenting on additional solution domains, all of which turned out to be sub-cases of the more-narrowly-defined ICT-AGRI solution domains. The participants' ideas were therefore incorporated into the solution domains defined by ICT-AGRI.

The solution domains were designed to cover nearly all of the contributions of ICT and robotics to primary agricultural production and to the agriculture-related environment. The basis for the concept of solution domains was a review of current technologies used in plant and animal production and farm management.

Evaluation of the solution domains included the assessment of R&I needs for six different solution components. These components describe the requirements for making a solution domain work at farm level:

Solution component	Description
Agronomy	Required agronomic knowledge (agricultural research)
Economics	Knowledge about profitability and non-economic values (economics and social science)
Environment	Knowledge about the effects on the environment (environmental research)
Inter-Operation	Compatibility of hardware components, information exchange (computer science)
Operation	Feasibility and user-friendliness (agricultural research and engineering)
Technology	Mechanics, electronics, buildings, hardware (engineering)

Research and innovation needs – an overview

The R&I voting for the various solution domains revealed that all of the solution domains require further research and innovation, although good technical solutions already exist for 'Automated Quality', 'Indoor Climate Control', and 'Farm Management and Information Systems'. 'Agri-

For the graphic presentation of the R&I voting results, the absolute voting numbers were triple-, double- or single-weighted. Figure 5 shows the weighted averages of the R&I voting.

- **Voting on research and innovation (R&I) needs**
  - High: - Important component coupled with a lack of knowledge
  - Medium: - In between
  - Low: - Less-important component and/or lesser lack of knowledge
- **Weighting of absolute voting numbers**
  - High: - Triple value
  - Medium: - Double value
  - Low: - Single value

$$\frac{\sum \text{weighted voting numbers}}{\sum \text{absolute voting numbers}}$$

cultural Robots' is seen as the solution domain with the highest R&I needs (Fig 5). This is perhaps because to date, there has been little progress in the use of robots in agriculture, and little experience in technology application. A comprehensive examination of the different solution components reveals that Technology and Agronomy were voted the components with the highest R&I needs. This underscores the ICT-AGRI ERA-Net's objective of bringing together interdisciplinary know-how from ICT and agricultural experts, thereby enabling the creation of new, innovative solutions.

Table 2: Specific improvements needed within the solution domains, as indicated by participants in the Delphi survey.

Solution domain	Improvements needed
Variable-Rate Application	• Proximal sensing technologies for plant-nutrient status • Detection of biotic and abiotic stresses: weeds, fungal diseases, water stress • Mapping of soil characteristics (new and improved sensors) • Remote sensing • information management, farm management and (weather-based) decision support • cost-benefit analyses
Controlled-Traffic Farming	• Long-term experiments (soil compaction, GHG, crop development etc.) • Operation and traffic planning (information exchange, representation protocols) • Feasibility and cost-benefit assessments • Compatibility between products from different vendors
Precision Livestock Farming	• Biosensors: better sensitivity and specificity • Improved decision support • Management of GHG emissions • Disease-risk assessment and modelling • Feeding systems • Compatibility between products from different vendors
Automated Indoor Climate Control	• Reducing energy consumption and GHG emissions - Improved regulation and management - Integrated/coupled heating-ventilation systems - Automated natural ventilation systems
Automated Quality Control	• Traceability: inspection principles • Sensors for quality- and contamination control in plant and livestock production • Control of each individual product instead of sample-based QC • Interoperability of products throughout the entire food chain
Agricultural Robots	• Safety issues • Fast and effective 'eye-hand' coordination • Multidisciplinary approach (e.g. technology, agronomy, economy, farm logistics) • Application of engineering methods to the context of agriculture and robots • Intensive information exchange with FMIS
FMIS	• Automated information collection and storage • Communication between research institutions, end-users and manufac-turers • (Open) standards for achieving interoperability • Web-based approaches for farm management and decision support • Easy-to-use interfaces • Added value for farmer

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11. ICT-AGRI Partners and Observers

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3. Ministry of Agriculture of the Flemish Community, Institute for Agricultural and Fisheries Research (EVILVO), Belgium
4. Ministry of Agriculture and Forestry (MMM), Finland
5. CEMAGREF Technical Centres Development (CEMAGREF), France
6. Federal Agency for Agriculture and Food (BLE), Germany
7. Federal Ministry of Food, Agriculture and Consumer Protection (BMELV), Germany
8. Greek Research and Technology Network (GRNET), Greece
9. Ministry of Agriculture and Rural Development (MARD), Israel
10. Ministry of Agriculture, Food and Forestry Policies (MiPAAF), Italy
11. Latvian Academy of Sciences (LAS), Latvia
12. Malta Council for Science and Technology (MCST), Malta
13. Swiss Federal Office for Agriculture (FOAG), Switzerland
14. Ministry of Agriculture and Rural Affairs, General Directorate of Agricultural Research and Policies (GDAR), Turkey
15. Scientific and Technological Research Council of Turkey (TÜBITAK), Turkey
16. Netherlands Organisation for Applied Scientific Research (TNO), Netherlands
17. Agriculture and Food Development Authority (TEAGASC), Ireland
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