Boosting Research for a Sustainable Bioeconomy

A Research Action Plan to 2020

Plants for the Future
European Technology Platform

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‚The Research Action Plan is part of four documents: Part I - Summary of Action Plans, Part II – Innovation Action Plan, Part III – Research Action Plan and Part IV – Education Action Plan. All documents can be downloaded from the website www.plantetp.org

Boosting Research for a Sustainable Bioeconomy
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Key actions to boost plant research to address global food and nutritional security and sustainable production of plant-based products

Summary of Key Actions

Securing a sustainable global supply of high quality food and feed, and supplying renewable biomass for the production of bio-based products and energy are key priorities for both European and global society. In the coming decades, the European plant sector will play a central and essential role in meeting this challenge and achieving this will depend strongly on the generation and transfer of new knowledge, and greater innovation in the plant sector.

The European Technology Platform 'Plants for The Future' (Plant ETP) has developed three Action Plans based on the pillars of innovation, research and education of which each action plan is part of an integrated strategy sector for the plant sector to build industrial leadership, boost research and educate the next generation.

Within the Research Action Plan, Plant ETP identified seven key actions for research for plant and agricultural sciences and industries and their practical application to farming, to be addressed and overcome by innovation. These key actions for the plant sector outlined in the Research Action Plan are:

Actions for sustainable plant production and yield

Action 1 – Improve resource use efficiency and resource stewardship
Action 2 – Enhance yield and yield stability for increased resilience in dynamic environments
Action 3 – Improve plant health for resilient production

Actions for quality of food, feed and non-food products

Action 4 – Develop plants with improved composition for human and animal nutrition and health
Action 5 – Improve composition and performance of plants for non-food products

Actions for a vibrant research environment

Action 6 – Develop and implement horizontal actions
Action 7 – Strengthen basic and applied research and research infrastructure to secure innovation

Introduction

Plant sciences and the plant production sector are now more than ever central to meeting the major inter-connected challenges facing European and global societies: producing more with less impact. All food, feed and renewable bioenergy production on our planet relies on solar energy, which is converted by plants and photosynthetic microorganisms to the chemical energy that maintains all life on Earth. Feeding a global population set to reach 9 billion by 2050, in the face of climate change and pressure on finite natural resources, will require a 70% increase in global agricultural output while reducing input use and GHG emissions[1]. At the same time, there are growing opportunities and demands for the use of plant-derived biomass to provide livestock feed and for other uses, including renewable materials to support the bioeconomy, thereby decreasing dependency on imports and reducing regional and global environmental impact.

Projections from HIS Global Insights show large increases in the global demand for crops, while the amount of arable land per capita continues to decline due to population growth and urban development[2]. Unfortunately, current innovations and growth rates in agriculture are insufficient to meet the dramatically increasing demand for food anticipated in the decades ahead. FAO-OECD projections indicate that agricultural productivity within the EU-28 is falling behind other major global competitors, with a growth rate of just 4% projected over the next decade, compared with 40% in Brazil and 16% in North America[3]. As a major agricultural producer, the EU has a key role to play if it wants to succeed in sustainably increasing plant production for food, feed, fibre and other products. Major innovations and a more effective, efficient use of recent advances in crop omics approaches and crop management practices are required to unlock the potential of a rapidly-advancing science base and increase agricultural productivity while improving the efficiency and resiliency of the entire food system. This will enable the EU both to produce a higher proportion of its domestic demands for food, feed, fibres and other products for the bioeconomy while, at the same time, contributing solutions to achieve full environmental sustainability at the production levels needed to meet the food security challenge both within and beyond EU borders.

Scarcity of resources is becoming increasingly evident. Water availability is already a major limitation on agricultural production in some regions of the EU and globally. It will become even more severe with the expected increase in intensified agriculture, together with growing issues of water quality, and as a result of modified rainfall patterns due to **climate change**. These changes include climate-induced forest decline, which disrupts ecosystem services such as water-cycle regulation globally. Some key components of fertilizers, especially phosphate, will at some point reach their peak of production from concentrated reserves. This will require alternative approaches to be developed to increase nutrient use efficiency and to reduce the environmental footprint of agricultural production, whilst achieving enhanced yield per unit of input. Shortages of arable land and pressure on marginal regions will rise with the constant need to increase agricultural production. Biological resources are at risk, increasing pressure on biodiversity, while at the same time we need to make better use of those available to us.

Food security is a challenge seen in the form of increasingly volatile food prices, which affect the poor and create social unrest, and this needs immediate action. At the same time long-term solutions are needed to produce the 60% extra biomass that may be needed by 2050 to feed the rising population (FAO). It is not, however, only a matter of producing more biomass, but also one of improving the nutritional quality of diets, to help curb the increasing burden of diet-related chronic disease.

1 *FAO, 2009. How to Feed the World in 2050. Discussion Paper*

2 *http://www.ihs.com/industry/agriculture/index.aspx*

3 *http://www.oecd.org/site/oecd-faoagriculturaloutlook/highlights-2013-EN.pdf*

Global demand for meat will also increase, mainly in developing countries. Rising incomes will shift food demand from cereal-based diets to meat and dairy products. Therefore, the demand for protein crops for both human food and animal feed will increase further, exacerbating the conflict between environmental concerns and the need for productive farming.

Increasing yield in a sustainable way is one important approach to overcome the bottleneck of biomass availability. This overarching challenge is compounded by the need to make crops more resilient to the increasingly variable and fluctuating conditions driven by climate change, and the expansion of agricultural production into less fertile land. This will require improvements in stress tolerance, particularly to combined abiotic and biotic stresses, together with the development of novel agricultural techniques that address both future production needs and the narrowing of existing yield gaps. At the same time, there is a requirement to **reduce loss of biomass** during production and along the entire value chain, while adapting plant production to novel challenges and pests that may arise from changing conditions and production scenarios.

Protecting yield is a key concern if we wish to produce more food using fewer resources. Losses to pests, weeds and diseases not only destabilize yields but also mean that land, water, fertilizer and energy used to grow crops are wasted. The EU is currently implementing the Sustainable Use Directive (2009/128/EC) which sets out to reduce the risks and impacts of pesticide use on human health and the environment while promoting Integrated Pest Management (IPM) and the use of less hazardous alternatives. However, in many cases effective alternatives simply do not exist and efficacy of control with existing plant protection products (PPPs) is being eroded by the development of pesticide resistance. EU farmers have become dependent on pesticides. Crops have been bred in a pesticide-treated background for many decades and have become genetically impoverished in natural resistance traits. Research to develop alternatives to pesticides and to reduce the vulnerability of agricultural ecosystems is urgently needed to maintain efficient and stable production and to avoid increasing the environmental footprint of agriculture.

The use of biomass for non-food purposes is increasingly debated, both as presenting promising new opportunities and revenue streams, and also as presenting potential risks, when it is not properly integrated into value networks that take food security into account. There the challenge is to take the best advantage of new opportunities, whilst avoiding risks for food production.

Addressing these global challenges requires significant changes in the way we work and how we transfer knowledge into practical breeding and crop production practices in agriculture, horticulture and forestry. This also reflects cross-cutting issues of general importance. It is a prerequisite for transforming our present production system into a knowledge-based bioeconomy which essentially depends on plants. Given the urgency of these challenges and the limited resources available to address them effectively, we need to build on existing synergies and develop networks that go beyond ´more of the same´. We also have to realize that, while we have to deliver results in Europe and for European society and industry, many problems can be solved only at a global level. This requires less in the way of isolated discussions on specific technologies which can tackle these challenges and more participation in a wider risk/benefit discussion about how to achieve targets through global initiatives.

Given the global agricultural challenges we now face, agricultural research must again become a high priority if we want to combat new strains of pests that destroy crops, generate new crop varieties high in nutritional value and with improved yield, develop resistance to disease and drought, and provide environmentally-friendly tailor-made cultivation practices. Finding innovative ways to produce crops with higher yields and novel traits is a feat that will require extensive capacity building – both to generate the expertise needed as well as training the scientists to feed into industry to make the potential a reality. Moreover, a recent study[4] found that, around the world, the rate of return on investment in agricultural research is ten to one. This brings into question the concerns linked to the scaling back of funding for agriculture research and development in many rich countries. Going forward, we must direct more resources into plant biology research in a coordinated fashion, to boost output and to train tomorrow's scientists. This is particularly true for the plant sciences, where the next generation of researchers must overcome significant challenges to feed a growing world population in a changing environment.

Based on these facts and challenges, the European Technology Platform 'Plants for The Future' has identified seven key actions for research for plant and agricultural sciences and industries and their practical application to farming, to be addressed and overcome by innovation. These key actions are outlined in the following Research Action Plan, clustered in three thematic areas:

Actions for sustainable plant production and yield

Action 1 – Improve resource use efficiency and resource stewardship
Action 2 – Enhance yield and yield stability for increased resilience in dynamic environments
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Action 7 – Strengthen basic and applied research and research infrastructure to secure innovation

4 *Jones, 2014: Opinion – the Planet needs more Plant Scientists*

Details of specific proposed research solutions to the actions are given in the annexes of this document which are only available on the website www.plantetp.org. The annexes also provide the actions linked to the Plants for the Future Strategic Research Agenda, the EC's Proposal for the Horizon 2020 Specific Programme (Headings) and the EC's proposed Horizon 2020 Strategic Programme for the Work Programmes 2014 -16. A summary of the connections and relevance to Horizon 2020 are shown in the table 1.

	Actions proposed by Plant ETP to address the societal challenges						
European Commission proposals	1-resources	2-yield	3-plant health	4-healthy compounds	5-non-food products	6-horizontal actions	7- basic & applied research
Specific Programme							
Industrial Leadership							
· Biotechnology	xxx	xxx	xxx	xxx	xxx	xx	x
· Risk Finance							
· Innovation in SMEs	xx	xx	xx	xx	xx	x	
Societal Challenges							
· Health				xxx	xxx		x
· Food	xxx	xxx	xxx	xxx	xxx	xxx	x
· Sust. Agri/forestry	xxx	xxx	xxx	xxx	x	x	x
· Sust. Agri-food	x	x		xxx			
· Aquatic living resources					x		x
· Sust biobased industries	x	xx	xx	xx	xxx		x
· Implementation actions						xxx	
· Climate action	xx	xx	xx		xx	x	x
· Inclusive societies		xx					
Focus area							
Health and care			x	xxx	xxx	x	x
Sust. Food security	xxx	xxx	xxx	xxx		x	x
Blue growth	x	x	x	x	x	x	x
Smart cities & communities	x	x	xx	xx	xxx	x	x
Low-carbon energy (GHG)	x	x		x	xxx	x	x
Energy efficiency	xxx	xx	xx		x	x	x
Waste (prevent and use)	xx	xxx	xxx	x	x	x	x
Water innovation	xxx	x	x			x	x
Overcoming crisis				x		xxx	
Disaster resilience		xx	xx	xx	xx	xx	

Table 1: Summary of links and relevance of the actions to the Plant ETP SRA and Horizon 2020 programmes ('xxx": most relevant to 'x' least relevant)

Actions for sustainable plant production and yield

Action 1 - Improve resource use efficiency and resource stewardship

Description

Production of biomass for food, feed, materials, chemicals and bioenergy depends on the utilization of increasingly scarce and unevenly available resources including water, nutrients, arable land and energy. Resource use efficiency is thus a central focus for developing and managing more productive crops in agriculture, horticulture and forestry. The growing scarcity of natural resources is being further accelerated by climate change. With the decrease in availability of concentrated nutrient sources for fertilizer production, there will be even more economic pressure to reduce fertilizer use. In order to achieve the high expectations for an essentially plant-based bioeconomy, we have to use these limited resources as efficiently as possible. Moreover, there is a need to provide answers to the growing concerns about threats to ecosystems that might affect ecosystem services, for example water-cycle regulation.

Improvement of resource use efficiency is likely to become even more important, if we take into account that it will not be possible to increase the availability of arable land significantly. The yield per hectare therefore has to increase significantly even on less favourable land. This places an increased emphasis on the implementation of a sustainable intensification strategy with a significant reduction in biomass losses combined with measures to restrict nutrient losses to the harvestable "products" ("nutrient loops"). At the same time, climate mitigation and adaptation policies require the environmental footprint of agriculture and forestry to be reduced, particularly by reducing greenhouse gas emissions and loss of carbon from agricultural soils. Integrated agricultural production with appropriate management practices, including the closure of nutrient loops, has the potential to improve nutrient availability and soil quality by long-term carbon sequestration to soils and will thus contribute to sustainable production. The need to reduce the environmental footprint of agriculture and the opportunity to farm less fertile soils through the use of more efficient plants offer important opportunities for innovative research on crops and crop production systems that address major challenges, whilst also contributing to income and job creation.

The essential resources required for crop production also include biological resources, in particular crop biodiversity. Today´s biological resources which are used in breeding programmes are limited – relative to the large numbers of species and intra-species variation – to quite a small and rather narrow range of genetic diversity. This increases the risk of crop failure and restricts the potential of future plant breeding programmes. Not only do we need to increase the use of a wider range of genetic resource, but we also need to conserve the diversity that currently exists, if we are to produce the crops and the varied crop products that are required for the future, particularly in developing countries.

Objectives

Optimise resource use efficiency in agricultural systems

Resource use efficiency has many different definitions. Agronomic resource use efficiency is often defined as the ratio of output (often yield) to input (often in terms of added resources like fertilizer or water). Researchers define a wide range of different resource use efficiencies from the perspective of plants (e.g. photosynthesis rate per unit of water transpired at the leaf level, or biomass produced per unit of water used at the stand level). This range of definitions highlights the composite nature of agronomic resource use efficiency, namely that it is assembled from numerous individual components of resource use that operate at different scales. One can thus define and optimise different resource use components, analogous to the concept of yield components. Different crops and cropping systems, including no-till options, will require tailored improvement strategies and have different resource optimisation for their specific environmental and agronomic conditions. Thus crop improvements must be integrated into well-adapted crop management systems. At the crop level, factors relevant to improved resource uptake or improved use/ partitioning have to be addressed.

Enhance the use and productivity of marginal and degraded lands

Since high quality arable land is limited, crops that can produce economically viable yields on marginal lands with few additional inputs will become more important in the future. One key factor here is the enhancement of crop productivity under conditions of multiple environmental constraints, with the ability to achieve yields that are close to those achievable under near optimal conditions. While these farming systems will not necessarily be used for food production, because marginal lands could also have various soil contaminants, they could well be used for non-food production. Another aspect of this is phytoremediation; cultivating crops which improve soils that contain toxic elements like heavy metals. The development of crops specifically suited for this task will require the application of all available technologies. Integrated plant production systems including legumes, which fix atmospheric nitrogen, and using residues from biomass processing can also significantly improve the footprint of agriculture. Closing the nutrient loop is actually a prerequisite for a sustainable bioeconomy. Here, significant scientific and breeding advances are needed to reintroduce improved legumes into agricultural practice and also to use the potential of perennial plants. Studying adaptive processes in plant populations that grow on marginal land is crucial for understanding the future impact of environmental constraints.

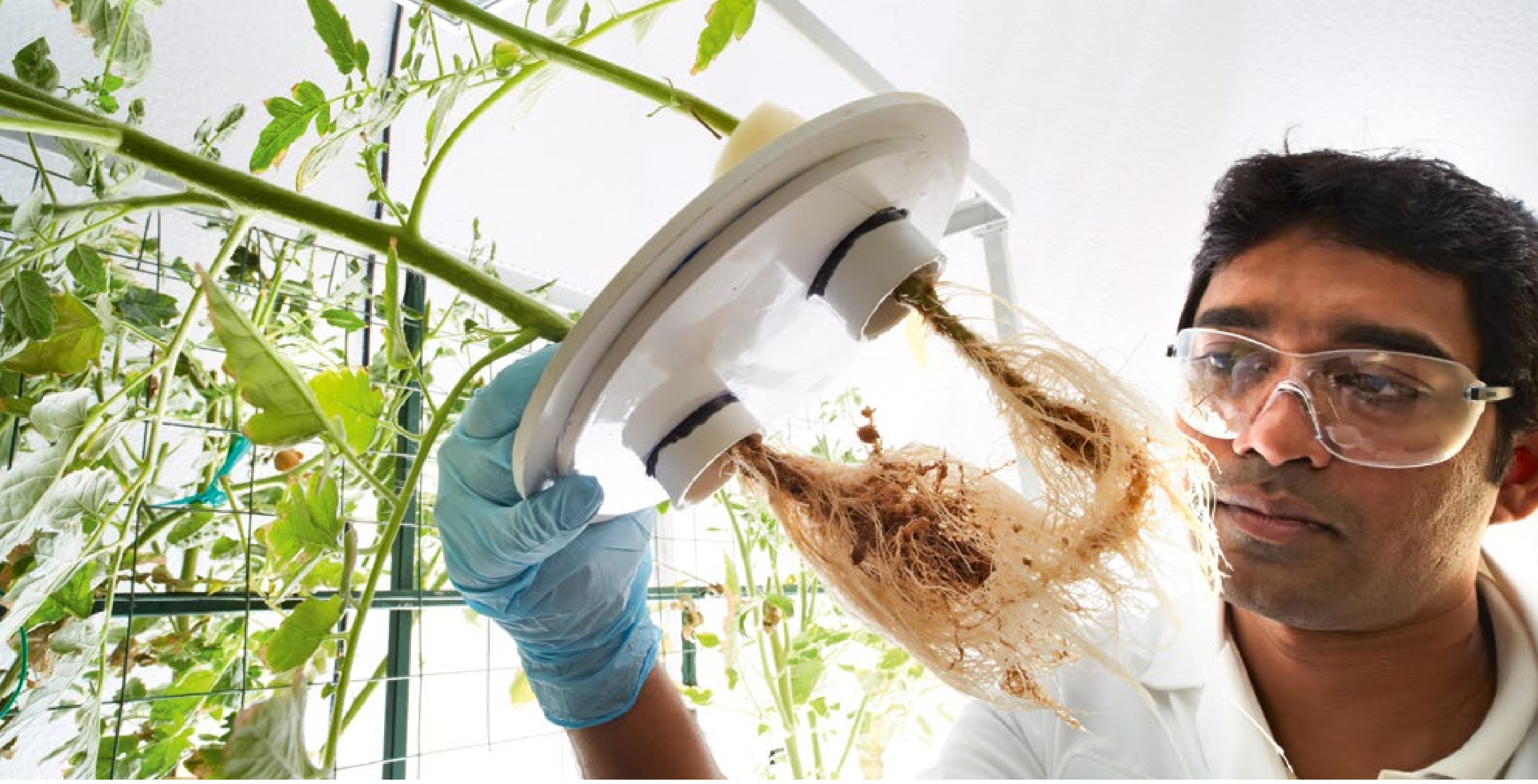
Reduce the environmental footprint of agriculture

Agriculture is a significant contributor to greenhouse gas emissions. Besides CO2, the main greenhouse gases (GHG) coming from farming are nitrous oxides – linked to rainfall events, soil structure and application of N-fertilizer – and methane under wet conditions. Whilst modified agricultural management practices may be the most obvious ways to reduce GHG emissions, improved crops with higher resource use efficiency could also contribute. Given that GHG emissions are increasingly linked to crop-dependent supplies of labile carbon that support microbial oxidation processes, it may be possible to breed for differences in plant-associated GHG emissions. Energy is also a significant input parameter for agricultural production. In fact all major steps associated with yield increases in the past, including mechanisation or use of synthetic nitrogen fertilizer, clearly increased the energy intensity of agricultural production. In the present situation, reducing energy intensity while increasing overall agricultural productivity is an obvious economic and ecological objective.

Agricultural crops continuously remove nutrients from fields. During the last century, soil organic carbon decreased in many agricultural soils in Europe, contributing to the increase in CO2 concentration in the atmosphere as well as reducing soil health and fertility. In order to compensate for this, soil carbon stores need to be replenished, ideally with forms of carbon that have long retention times and effectively restore soil functional characteristics, giving improved gaseous exchange and nutrient- and water-use efficiency.

Improve biodiversity and its use in agricultural eco-systems

Use of a wider range of biological diversity and its integration into agricultural production systems offers interesting opportunities. The development of monocultures and use of fewer varieties in cropping systems has improved productivity but also increased risks in the long term. Biodiversity can have a positive impact on agricultural production, at both macroscopic and microscopic levels. The impact of more biodiverse agricultural



systems, which can provide suitable environments for beneficial organisms, needs to be addressed. Improving soil health by cultivation of more diverse crops can lead to more fertile soils with beneficial microbial populations and thereby increase productivity of both existing and novel crops. Food security and the development of new markets in developing countries are additional reasons for stimulating greater use of biodiversity: the huge number of regional crops and landraces, including vegetables and fruits, are an important source of genetic potential as well as providing a staple food source in many local communities.

Conserve and enable use of wider plant genetic diversity

Plant genetic diversity has to be conserved and made available for genetic improvement. Ex situ collections of crop species and in situ conservation of many crop wild relatives are the foundation for the future development of improved cultivars of major crops that form the backbone of EU agriculture. Genetic resources collections provide the material to start the genetic improvement of neglected crops and to develop novel crop species. To develop high performing, efficient and diverse crops and cropping systems, access to genetic resources must be secured, and informed approaches to the optimal utilization of genetic resources need to be devised.

Basic research and infrastructure to be developed

Omics platforms for poorly-studied crops and crop wild relatives to unlock the potential of seed banks (Action 1, 2, 3, 4 and 5). A large number of seed samples are preserved and stored in global seed banks. This global heritage and treasure needs to be analysed and developed into a valuable resource for plant breeding. In the mid- and long-term this will allow this hitherto underutilised resource to be tapped into and made available for projects improving plants for sustainable production. To tackle this huge task adequately, all omics and phenotyping technologies need to be developed beyond today's focus on the major commodity crops.

Understanding the synergistic relationships between plants and other biological systems (Action 1, 2, 3, 4 and 5). The interaction between plants, microbes and other organisms in the soil is an essential field of research that can provide many novel insights in the food and interaction web as well as the signalling between organisms. This will provide the basis for future development of beneficial interactions useful for sustainable production.

Integration of environmental and developmental signals in growth and yield improvement (Action 1, 2 and 3). The actual yield performance of plants in the agricultural environment is strongly dependent on the species, cultivar, developmental stage and specific environmental stresses. These interactions are highly dynamic and depend on the potential of the plant genome. Fundamental research to elucidate the mechanisms and systematic strategies of a wide range of plants in these complex interactions will be essential to move towards knowledge-based development of crop adaptation strategies.

Infrastructure for plant phenotyping in pre-breeding (Action 1, 2, 3 and 4). Plant phenotyping has been identified as a crucial bottleneck in knowledge growth, as well as in application-oriented research. Recently developed and emerging national platforms for plant phenotyping and the European Plant Phenotyping Network (EPPN), a European infrastructure network, require further expansion of capabilities for European scientists and breeders to maintain their global competitive advantage.

Infrastructure for testing crops in future climate scenarios (Action 1, 2 and 3). Crops will have to perform well in the field with higher CO2 concentrations, increased and more variable temperatures and uncertain water availability. The capacity to test plants under these future environmental scenarios is not available today. For example, free-air carbon dioxide enrichments sites (FACE) have been the main facilities used for assessing the impact of global change, but such sites are not readily available. The development of a European-wide infrastructure network allowing standardised testing of germplasm would allow basic research as well as provide a significant competitive advantage for European breeders.

Example for a research solution to Action 1

Improving resource use components for water and nutrient utilisation by breeding for root traits

Improved uptake of water and nutrients requires root systems that either have more suitable geometry to tap into the soil-based resources or better (active) uptake mechanisms. Despite their importance in acquiring nutrients, root traits have rarely, if ever, been used by plant breeders due to the limited information on the suitability and relative effectiveness of different root traits and their heritability. The relationship between root traits and performance in the field strongly depends on the specific environmental conditions. For example, while a deep root system might be beneficial in seasonal rain-fed agriculture or where there is a low but fairly constant water table, a shallow root system is likely to perform better with all-year round rain or in irrigation-based agriculture.

Given the relative paucity of knowledge about root efficiencies and on the mechanisms that control root architecture, the increasing availability of platforms able to quantitatively characterize root geometry and function will provide important information for tailoring more resource-use efficient root systems in all major crops. Making use of symbioses with soil microorganisms may also dramatically improve plant root efficiency.

How far can we go? From the development of basic principles, transfer into practical plant breeding can be quick (3-5 years) for traits controlled by major loci (genes/QTLs). It may take up to 10 years for optimising traits for single resources but more complex optimisation for multiple efficiencies, such as improved phosphate and water use efficiency, may require up to 20 years. Interactions among geneticists, breeders, physiologists, agronomists and modellers will be needed to achieve progress in this area, as will the development of improved technologies for root phenotyping and a better understanding of the mechanisms that control root architecture.

Action 2 – Enhance yield and yield stability for increased resilience in dynamic and adverse environments

Description

Germplasm enhancement, breeding programmes and ecophysiology (including novel production practices), have all contributed to substantially increased yield in European agriculture and forestry in past decades. This has been the basis for a secure supply of both food and non-food products to the European population, export of agricultural commodities, and rural income generation. However, it is unlikely that this trend of increasing yields can be accelerated or even continued into the future with current agricultural production techniques. Moreover, new challenges have become apparent that are likely to constrain crop production and forest management in the EU.

Extreme weather conditions are expected to become more frequent in many European regions in the near future. This will require the development and introduction of new, improved cultivars in cultivation systems giving a high resilience to both abiotic and biotic constraints, making good use of resources in favourable conditions while withstanding periods of drought, flooding, late frost, cold or heat. These cultivars must be able to achieve acceptable yields despite multiple constraints on production. Both germplasm and crop management techniques will have to be adapted to more dynamic and adverse environments.

It is also clear that, in most European regions, the needs of the urban population and environmental consciousness are high priorities for society. Urban greening and even urban food production have become a recognised aim of some European societies. On the other hand, urban waste and residues from renewable energy systems (such as biogas residues) are expected to be incorporated into nutrient fluxes of agricultural systems. Subsidies for agricultural production are likely to decrease in Europe in the medium term. At the same time, consumer preferences determine market success for agricultural and horticultural products, with product safety and quality being key priorities. Safety and quality have to be controlled throughout the production chain, while the environmental impact of agricultural production has to be minimised, and for many consumers the use of pesticides and even synthetic fertilizers appears questionable.

Other important new challenges will also dictate the use of resilient plant production systems with high flexibility. The food sector is very dynamic and consumer demands can vary quickly and with regional preferences. Plant production systems must be able to adjust rapidly to these demands. Moreover, large numbers of European citizens play a part in the agricultural and food supply chain, as small producers, traders or consumers. Tradition and embedded knowledge are part of existing plant production systems, and should be taken into account when developing modified or new systems with increased resilience.

All these requirements have to be met without losing European agriculture's global competitiveness. This requires new solutions based on improved plants and production systems in both agriculture and horticulture. The required production resilience can be achieved only with the help of a systematic biological, ecological and technological understanding.

Objectives

To meet the overall challenges, research and innovation have to take into account fast changing agricultural environments, as well as the diversity of European regions and agricultural systems. Since there is little possibility of increasing agricultural acreage, setting up tools and systems to improve yield and yield stability at farm level is key. Research and innovation have to increase yield potentials under good growth conditions, but also be focussed on improved yield stability in sub-optimal and constantly changing environments, where multiple, time-dependent variable stresses are likely to occur more frequently and with greater intensity.

Match environment and genotypes: providing an improved understanding of ecological, physiological and genetic requirements

Agricultural and horticultural producers have always attempted to create a suitable environment for plant growth, where resources for growth are delivered to plants at high rates and homogeneously in both space and time. Today´s most widely used plant varieties perform well under such conditions. However, large-scale irrigation and optimal supply of nutrients may be too costly in economic and environmental terms, particularly in light of the increasing scarcity of resources and cost of energy. To address these issues, plant production systems in controlled environments will become more important including, for example, protected horticultural systems. Under open field conditions, fluctuations in resource supply may become even more frequent in the future, so that plants must sometimes cope with sub-optimal conditions, which differ by season and region.

New, specifically adapted germplasm must be developed that is able to acclimatise rapidly and effectively to these diverse conditions or that is not vulnerable to environmental constraints, so that it produces increased yields and better product quality. Rapid acclimatisation responses to abrupt environmental changes are of particular importance for crops with a long growing period, including novel perennial types (see also Action 1). In addition, agricultural technology, including the use of sensors and predictive models, must be further developed to respond rapidly and effectively to fluctuating conditions.

Diversify plant production: more plants with higher yield potential, yield stability and quality

In the past, European farmers used a wide range of different crop species and varieties. Farmer and consumer preferences have contributed to a significant decrease in the number of species and cultivars under cultivation, which means that European agriculture now uses a much narrower range of plant types. The use of traditional (but neglected) crops and local genotypes with stable yields, good quality and competitive prices must be promoted and crops with novel properties and improved yield potential need to be developed. Novel breeding methods will help to increase the range of varieties available to farmers, and efficient and environmentally safe production methods must be developed for these crops. Mixed cultivation systems (for example, of cereals and associated legume crops) or mixing several cultivars of one species may also help to diversify plant production, and thus increase resilience.

Detailed analysis of a wide range of quantitative genetic traits, of the epigenomic control over plant traits, and more comprehensive phenotyping are needed for a thorough understanding of the potential for improved plant adaptation and actual yield resilience.

Improve understanding of management systems and integrated plant production (agriculture and horticulture) in different regions of Europe

The regional diversity of agricultural production in Europe has decreased in recent decades. Partly this is due to market demands or the dominance of large retail chains and also the focus on high-performance seeds and only a few crop species. This increased uniformity across regions may have made European agriculture more vulnerable to the consequence of changing environmental conditions, which vary by region. European research should help to develop production systems that are adapted to regional conditions. This should include the development of locally adapted germplasm that gives higher yield potential and yield stability under these specific local conditions, keeping in mind the economics of seed supply.

All these objectives can be achieved only by active participation of innovative small and medium enterprises (SMEs). There is a long tradition of agricultural extension services across Europe. This existing system of driving innovation will benefit from knowledge exchange at the European level and the use of new technologies. Food production and consumption are important societal activities that link rural and urban areas, and traditionally connect societal groups with very different educational levels. Resilient production systems for high quality food can thus also be central to the development of resilient and inclusive societies. Plant production systems that are resilient to environmental changes are therefore vital to achieve several goals of the Horizon 2020 programme.

Basic research and infrastructure to be developed

Complete the sequencing of cereal genomes and identify diversity at the genome level in relevant European crops (Action 1, 2, 3, 4 and 5). Sequencing and understanding the genomes of major crops will be an essential tool in the future. Today many of the major crops are still not fully sequenced or require significantly better understanding of their genetics and genome development. This will provide new insights into how modern crops evolved and how they can be further improved.

Omics platforms for poorly-studied crops and crop wild relatives to unlock the potential of seed banks (Action 1, 2 and 3). A large number of seed samples are preserved and stored in global seed banks. This global heritage and treasure needs to be analysed and developed into a valuable resource for plant breeding. In the mid- and long-term this will allow this hitherto underutilised resource to be tapped into and made available for projects improving plants for sustainable production. To tackle this huge task adequately, all omics and phenotyping technologies need to be developed beyond today's focus on the major commodity crops.

Improving the understanding of the potential of new technologies for gene modification in crop species (Action 2, 3, 4 and 5). Novel methods to generate improved genetic resources aim for more targeted approaches for plant improvement. Proof-of-principle studies need to be undertaken to identify the potential and the limitation of these novel tools for crop improvement.

Study the quantitative genetics of complex, agronomically important traits (e.g. root traits) (Action 1, 2, 3 and 4). Knowledge about these highly important traits is still very limited. Integrated approaches need to be developed in order to understand quantitatively the heritability and impact of development and environment of these traits, which are very important in determining crop yield.

Environmental stress and biomass candidate crops (Action 1, 2 and 5). As crop species are cultivated for various specific purposes around the world, understanding and manipulating key traits to develop optimal genotypes suited to the environment becomes more important. There is a clear need to study the underlying mechanisms that connect abiotic stress and the environment to flowering and biomass production, in order to reduce yield loss and select genotypes adapted to local environments.

Understanding the synergistic relationships between plants and other biological systems (Action 1, 2, 3, 4 and 5). The interaction between plants, microbes and other organisms in the soil is an essential field of research that can provide many novel insights in the food and interaction web as well as the signalling between organisms. This will provide the basis for future development of beneficial interactions useful for sustainable production.

Integration of environmental and developmental signals in growth and yield formation (Action 1 and 2). The actual yield performance of plants in the agricultural environment is strongly dependent on the species, cultivar, developmental stage and specific environmental stresses. These interactions are highly dynamic and depend on the potential of the plant genome. Fundamental research to elucidate the mechanisms and systematic strategies of a wide range of plants in these complex interactions will be essential to move towards knowledge-based development of crop adaptation strategies.

Infrastructure for plant phenotyping in pre-breeding (Action 1, 2, 3 and 4). Plant phenotyping has been identified as a crucial bottleneck in knowledge growth, as well as in application-oriented research. Recently developed and emerging national platforms for plant phenotyping and the European Plant Phenotyping Network (EPPN), a European infrastructure network, require further expansion of capabilities for European scientists and breeders to maintain their global competitive advantage.

Example for a research solution to Action 2

Development of Stress Cross-Tolerance in crop plants

Crops grow in a dynamic environment and are continuously challenged by a range of abiotic/biotic factors acting alone or in combination that compromise any potential yield gains that might be exploited for enhancing productivity (resulting in yield gaps). Modern agriculture may have compounded the inability of crops to deal with dynamic situations through a range of management interventions and because breeding programmes do not specifically address selection for stress cross-tolerance. Cross-tolerance to environmental stresses is a common phenomenon in plants, whereby exposure to one type of stress confers a general increase in resistance to a range of different stresses through synergistic co-activation of non-specific stress-responsive pathways that cross biotic–abiotic stress boundaries. In the future, the predicted weather volatility and more extreme environmental conditions argue for the selection of crops with multiple stress resistance. Also, given the difficulty associated with accurately predicting future conditions, enhancing stress cross-tolerance would act as a fail-safe approach to uncertainties surrounding future climate projections. Only by enhancing stress cross-tolerance will we be able to develop true all round resilience in crops. Importantly, the evidence indicates that stress cross-tolerance can be developed without any yield penalty

How far can we go? Short term ~5 years: There is a vast range of genetic material available for examining stress cross-tolerance, including existing cultivars, land races and ancestral varieties. The identification of stress cross-tolerance in one wheat variety and Arabidopsis will be important 'tools' for examining the traits required for enhancing this trait. This will be aided by new phenotyping platforms that have the capacity to screen large amounts of genetic material. The goal would be to identify breeding lines/traits that could be used in cultivar development. Long term ~10-years: development of flexible crop genotypes adapted to a wider range of abiotic/biotic conditions. Development of specific cultivars suited for particular or problematic edaphic or environmental conditions.

Action 3 - Improve plant health for resilient production

Description

Pathogens and other biotic factors, such as pests and herbivores, are major contributors to yield losses in crop plants (including cereals, vegetable and fruit), as well as forest tree and ornamental species. Some also have an important impact on quality due to the production of toxins. As a consequence, one of the major uses of PPPs is to protect crops against pathogens and pests. Plant protection and agri-chemical weeding have contributed to increased productivity of crops and there is little chance that we will be able to do without them in the foreseeable future. However, there is an urgent need to reduce undesirable side effects like potential residues, toxicity towards non-target organisms, pollution of surface and ground water or the loss of efficacy as a consequence of the development of resistance in target organisms.

European farmers have to meet tight restrictions on their use of chemical control methods and it is becoming more and more difficult for them to meet, for instance, EU mycotoxin standards in cereals, especially when climatic conditions favour development of hard-to-fight fungal diseases. Weed populations, fungal pathogens and insect or animal pests are able to respond and adapt to changing environmental conditions and to develop resistance against PPPs.

The future challenges for crop protection are to (i) ensure high quality production, (ii) maintain and increase productivity, (iii) reduce the risks related to the use of PPPs, and (iv) monitor and respond to resistance development by pests, diseases and weeds.

At the cropping system level this requires a holistic approach towards establishing systems which are more resilient, both for individual crops and within the rotation. Pests, diseases and weeds show variable distribution pattern within fields, whereas most farmers use PPPs based on the assumption of homogeneity within fields. From both an ecological and economic point of view this kind of PPP application is undesirable and exceeds the amount necessary for effective use. Following EU policy, numerous Member States recently developed National Action Plans (NAPs) in order to reduce the overall use of PPPs in agricultural ecosystems. Additional research is needed to achieve the ambitious objectives set in these NAPs without jeopardizing yield stability. Pest and disease resistance have to be treated as priority traits in plant breeding. Interactions between pests/diseases and host plants have to be studied in detail in order to establish economic intervention thresholds. Alternative pest and disease control strategies have to be developed based on non-chemical approaches such as biological or bio-technological control. Biodiversity has to be fostered, in particular for the ecosystem services it provides, including regulating and stabilizing functions. Forecasting tools and Decision Support Systems (DSS) have to be developed in order to optimize the use and combination of the most promising control measures. In view of the complexity of integrated pest and disease management (IPM) systems, international collaboration and coordination is urgently needed. A new source of concern is global warming. There is already evidence that this process is having detectable effects on agriculture, through alterations in pathogen and herbivore evolution and changes in the global distribution of pests.

Objectives

Improved tolerance and resistance of plants to pests and diseases

Reduce and optimize the environmental impact of agriculture

Plant genetic improvement could provide new opportunities for adapting plant protection systems, combining improved efficiency with a lower impact on the environment. The detrimental effects of chemical crop protection can be drastically reduced as plant breeders succeed in further improving the plants' own resistance to pathogens, pests and other biotic stresses. Completely new avenues of opportunity will open as we expand our knowledge of beneficial biotic factor interactions.

Improve tolerance and resistance to pathogens and other biotic factors

An obvious alternative to chemical protection is the exploitation of naturally occurring resistance mechanisms. The identification of plant defence or resistance genes is very likely to improve with a better understanding of the factors influencing virulence and pathogenicity of pathogens and pests. The development of resistant/tolerant varieties will improve both food security (grain production) and food safety, improving the competitiveness of both the agriculture and livestock sectors in the EU. In particular, major advances can be expected from an understanding of the ways in which pathogens manipulate the physiological processes of their host plants to shut off defence reactions and provide a suitable growth environment. Further breeding efforts will also be needed to increase resistance, so providing a comprehensive set of resistance mechanisms. In order to make resistance to pathogens more durable, the molecular basis of non-host resistance needs to be further elucidated. Breeding efforts can be supported by molecular methods such as QTL analysis, marker-assisted breeding and genomic tools.

Characterizing major plant pathogens and their natural antagonists

Major plant pathogens affecting key European crops – genetic resources and biodiversity

In addition to the sequencing of crop genomes, the genomes of all major plant pathogens that affect important European crops need to be determined. Genome sequencing of all major European pests will greatly benefit our understanding of plant defence mechanisms, contribute to a reduction in the use of PPPs and help the development of disease-resistant plants. A better knowledge of the biodiversity of pests and pathogens is needed to develop optimal crop protection strategies.

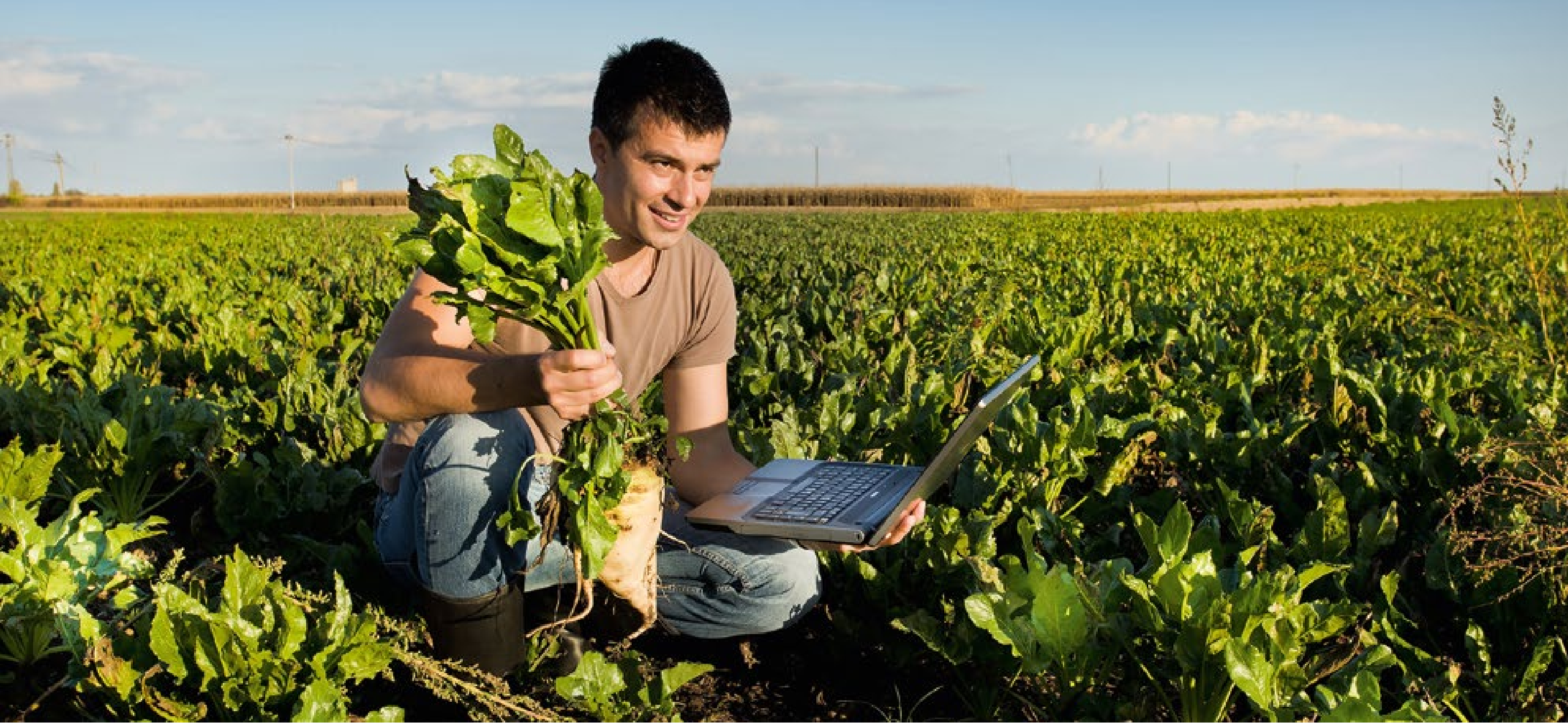
Biologicals and chemicals for plant protection

Develop practical alternatives to pesticides

As the Sustainable Use Directive (2009/128/EC) is being implemented there is a real need to provide farmers with effective alternatives. There is a range of promising new approaches but they have not yet been introduced either because of lack of information, a need to improve efficacy or because they are too complicated, expensive or time consuming to use. Translational research is needed to transform them into viable options that farmers can use. Options to develop include (but are not restricted to), the following: resistant crops, biological control, entomopathogenic fungi, improved understanding of ecological interactions, phytochemicals, pheromones and other semiochemicals, activating plant defence signalling, crop management, mechanical weeding, improved formulations and application methods and rationalising pesticide use with decision support.

Improve the interaction of beneficial biotic factors based on an improved knowledge of beneficial microorganisms

Crop plants in the field are part of a complex network of biotic interactions. A better understanding of all the species and interactions in agricultural and forestry ecosystems will be useful in two ways. On one hand, they can help to stabilize or even improve the complexity of affected ecosystems and the associated biodiversity. On the other hand, biotic interactions can also positively



influence the crop plants themselves. Symbiotic or associated microorganisms in the rhizosphere are the most prominent example. A milestone in this respect would be an inventory of beneficial microorganisms, together with an analysis of their impact on crop production and protection against pathogens.

Improving methods and management of farming and production systems

Improve methods of precision farming

More targeted PPP application requires improvements in pest diagnostics, forecasting, risk assessment and application technology. New targeted application technologies, such as detection of biomarkers for volatile organic compounds given off by pests or plants under stress, image recognition algorithms for pest and weed species detection and ICT and robotic control solutions will allow us to treat individual fields heterogeneously, with varying dose rates according to the actual occurrence of pests. This would lead to lower environmental impact and reduced application rates. Essential requirements for improved, better targeted application techniques are (i) high spatial resolution, (ii) short delay times, and (iii) switching on or off of spraying equipment during application.

Integrated Pest Management (making use of a range of well-targeted biological and chemical interventions in a flexible way to control pests with minimum impact on non-target species), and using optical sensing for early detection of plant diseases and also new technologies for inoculum detection such as automated air samplers using biosensors to detect spores and wireless reporting of results.

Improve cropping systems combining plant-host resistance and agronomic management practices

Plant science has greatly improved our knowledge about pathogens, insects and weeds and the underlying mechanisms of host-pathogen interactions. Nevertheless, many of these research findings have yet to be applied at the farm level. Future cropping systems need to combine new resilient varieties which guarantee high quality and yield with novel management approaches using synergistic effects within the rotation (e.g. for weed management) and within plant communities (e.g. mixed varieties within a field, or planting a number of varieties in neighbouring fields).

Improve post-harvest protection

Pests, diseases (fungi, bacteria) and rodents cause considerable losses of crops and plant-based products, and have a significant impact on quality. As a result, the European Commission has introduced maximum limits for harmful substances such as mycotoxins, which are relevant for the protection of stored products. Losses of grain crops can be as much as 30%, and not only in developing countries. Much greater losses – even total loss – are common in root crops, fruit and vegetables along the process chain (harvesting, transport, processing, and storage). Therefore, sustainable methods for post-harvest protection are urgently needed. The focus should be on environmentally friendly methods for prevention as well as on methods for early detection and control. These methods should not cause unacceptable changes in the treated product.

Basic research and infrastructure to be developed

Understanding the molecular basis and potential gene-transfer of non-host resistance, the role of sRNA signalling, effector gene action and host-induced gene-silencing (Action 3). Understanding the key mechanisms in crop disease and resistance would provide the essential insights needed to develop novel resistance pathways and improve their durability.

Understanding the synergistic relationships between plants and other biota (Action 1, 2, 3 and 4). An understanding of the interactions between plants, microbes and fungi is essential for developing pathogenomic approaches as well as plant health treatments.

Studying the (co-)evolution and diversity of pathogens based on pathogenomic approaches (Action 1, 2 and 3). Important insights into the development of pathogen-host interactions will be gained by analysing the development of the interaction between pathogens and their hosts during evolution and domestication. This will allow the identification of the principles governing interaction, which can be used as a basis for future development of resistance.

Study the quantitative genetics of complex, agronomically important traits (e.g. root traits) (Action 1, 2, 3 and 4). Knowledge about these highly important traits is still very limited. Integrated approaches need to be developed in order to understand quantitatively the heritability and impact of development and environment of these traits, which are very important in determining crop yield.

Example for a research solution to Action 3

New emerging plant diseases in scenarios of global climate and trade change

Specific challenge: Diseases substantially reduce plant productivity and reduce the quality of food, feed and forest products. In addition, plant diseases affect the balance and dynamics of natural ecosystems, to the detriment of people's quality of life. Under the present constraints of limited availability of cultivable land, climate change, increased seasonal weather instability, and intensive global trade, the threat posed by plant diseases to mankind will most likely become even more serious, particularly because these conditions favour the emergence of new diseases, which may have a particularly high impact. Examples of recent introductions of particularly harmful pathogens in Europe are Xilella fastidiosa in Italy and tomato torrado virus (ToTV) and tomato spotted wilt virus in Spain. ToTV was first reported in Spain and later on in Poland, Hungary, France and Italy. Other recent examples are citrus greening (Huanglongbing), caused by the bacterium Candidatus Liberibacter asiaticus in Brazil and in Florida, which has resulted in the loss of millions of trees. This disease is an extremely serious threat for the citrus industry of the Mediterranean Basin, unless preventive measures like those implemented in California, are adopted.

Scope: Globally, societies and economies must anticipate, prevent and control new emergent diseases to avoid major social, economic and ecological crises. We should aim at understanding the phenomenon of emergence itself. Epidemiological theory predicts that the emergence of a new disease may result from the complex interaction of a variety of factors, often leading to changes in the host range and/or distribution of pathogens. These factors include genetic changes in the pathogen and/or hosts and vector organisms, and changes in the size, density, structure and connectivity of host and vec-

Improving the understanding of the potential of new technologies for gene modification in crop species (Action 2, 3, 4 and 5). Novel methods to generate improved genetic resources aim for more targeted approaches for plant improvement. Proof-of-principle studies need to be undertaken to identify the potential and the limitations of these novel tools for crop improvement.

Infrastructure for plant phenotyping in pre-breeding (Action 1, 2, 3 and 4). Plant phenotyping has been identified as a crucial bottleneck in knowledge growth, as well as in application-oriented research. Recently developed and emerging national platforms for plant phenotyping and the European Plant Phenotyping Network (EPPN), a European infrastructure network, require further expansion of capabilities for European scientists and breeders to maintain their global competitive advantage.

Infrastructure for testing crops in future climate scenarios (Action 1, 2 and 3). Crops will have to perform well in the field with higher CO2-concentrations, increased and more variable temperatures and uncertain water availability. The capacity to test plants under these future environmental scenarios is not available today. For example, free-air carbon dioxide enrichments sites (FACE) have been the main facilities used for assessing the impact of global change, but such sites are not readily available. The development of a European-wide infrastructure network allowing standardised testing of germplasm would allow basic research as well as provide a significant competitive advantage for European breeders.

tor populations, which to a large extent are influenced by human activity. Research work should analyse those aspects of the evolution of plant pathogens most relevant to emergence, such as estimation of the parameters needed for meaningful modelling, adaptation to new environments, virulence evolution, biogeography and molecular epidemiology as well as the host-range determination and host-range modification through molecular and systems analysis of virus multiplication. This will increase understanding of the mechanisms underlying host-switch and host-range expansion and to evaluate the risks of virus emergence in a changing environment. Analysis of these factors requires collaboration between scientists with expertise in widely different fields: from the molecular genetics of the interactions between pathogens and their hosts and vectors determining host and vector ranges, to the genetic variations of pathogens, plant and vector populations, and to the ecology of these populations and their interactions.

Expected impact: *(1)* Development of models describing the population dynamics of viruses and other plant pathogens, hosts and vectors under different scenarios, and of protocols for rapid response against new outbreaks that could assist policy makers. (2) Knowledge of the durability of commercially available resistance genes/varieties against emerging pathogens and transfer of this knowledge to seed companies and the agricultural sector. (3) Development of different approaches (practical solutions) for preventing and combating the damage caused by viruses and other emerging plant pathogens and thus reduce their impact on crops. Aspects like transmission by vector organisms (including important insect pests, such as aphids and whiteflies) can result in data relevant for a changing environment (in the context of a climate change scenario). Regarding resistance traits, a major interest of seed companies is to know how their current and future products will perform in the face of new infections. Collaborations between research consortia and the industry are essential.

Actions for quality of food, feed, and non-food products

Action 4 - Develop plants with improved composition for human and animal nutrition and health

Description

Improvements in our knowledge of plant genetics, physiology and agronomy have underpinned significant increases in crop productivity over the last 50 years, and these have provided better access to food on a global scale. But new challenges are arising from the continuing need to increase food and feed output while at the same time improving nutritional quality and assuring safety at the point of consumption. To address these challenges, we need to focus on the development of diversified and affordable high-quality, nutritious plant raw materials for food and feed products. A major priority should be optimizing their nutritional quality as well as their processing characteristics, shelf life and sensory properties.

A major challenge in human health over the next fifty years will be chronic, non-communicable diseases including heart disease, cancers, type-2 diabetes and obesity. In 2005 the World Health Organisation (WHO) projected that mortality from chronic disease would increase by 17% world-wide over the following decade, due to longer average lifespan, tobacco use, decreasing physical activity and, perhaps most importantly, the increasing consumption of unhealthy diets. Because socio-behavioural risk factors contribute significantly to the incidence of (and mortality from) chronic disease, 36 million of the 388 million premature deaths predicted for 2005-2015 could be avoided if health, science and public policies were re-oriented towards prevention rather than cure. In 2007 the Oxford Health Alliance published a grand challenge document in Nature (Daar et al., 2007), outlining how such a reorientation of policies and priorities might occur. One of the five major objectives was to modify the risk factors for chronic disease, and it is in this area, particularly in identifying and understanding the health-promoting components of food, that new multidisciplinary approaches could contribute significantly to addressing this grand challenge.

The past thirty years have seen the development of an enormous body of evidence on the importance of plant-based foods in preventing or reducing the risk of chronic disease. A new phase of research is now required to lay the foundations for understanding the relationships between diet and health and to reduce the burden of chronic disease. This new field should combine research on plants, including analytical phytochemistry, marker-assisted selection, and metabolic engineering of plants, nutritional research including both intervention and epidemiological studies with well-defined dietary materials and experimental medicine to define the mechanisms of action of dietary phytonutrients in promoting health and ameliorating the impacts of chronic diseases. Similar objectives apply to improvements in animal feed, both for optimised nutrition for animals through improvements of feed and for forage plants used both in agriculture and aquaculture. Such multidisciplinary approaches should contribute significantly to advancing understanding of the complex relationships between diet and health and underpinning public information campaigns and health initiatives to improve diets, reduce the impact of chronic diseases (particularly their economic burden) and improve the quality of life of Europeans.

Objectives

The FAO definition of food security requires that all people at all times have adequate access to enough safe nutritious food for an active and healthy life. This challenge is focussed on the elements of nutrition, health and quality of life, within the broader challenge of food security. Food and feed security and safety, the competitiveness of the European agri-food industry and the sustainability of food production and supply must be addressed, covering the whole food chain and related services from primary production to consumption. This approach would contribute to (a) reducing the burden of food- and diet-related diseases on societies by promoting healthy, nutritious and sustainable diets, (b) achieving adequate nutrition and good levels of food safety and security for all Europeans, (c) eradicating hunger in the world (see above), and (d) reducing the currently accelerating incidence of chronic disease.

Develop and produce sufficient, nutritious and affordable plant raw materials for food products

We will need to improve our understanding of the key factors affecting the quality of plant raw materials and plant foods, focussing on European crops and providing improved varieties using variation within germplasm collections, breeding for nutritional traits and state-of-the-art engineering technologies. We will need to pursue an integrated approach which will require close collaboration between all stakeholders in the agri-food chain, from breeders to consumers. This will involve identification and quantitative assessment of beneficial compounds from plants. Such an approach should not be limited to the main field crops, but should also cover a broad range of horticultural crops, including vegetables, fruits, herbs and spices, all of which are essential for a nutritious, varied and tasty diet. We need to ensure access for all to healthy nutritious food, by ensuring that improved production and transportation methods result in affordable fresh fruit and vegetables being available throughout Europe.

Provide tailored plant raw materials for specific health benefits

We will need new plant raw materials tailored to prevent chronic diseases by providing more plant-derived, health-promoting bioactives. These will help prevent the onset of major chronic diseases, including obesity, diabetes, cardiovascular and neurodegenerative diseases and ameliorate their impact once contracted. Model foods, designed to test the impact of individual plant compounds, can be used to establish the mechanisms of action of bioactives (and their synergistic interactions) in promoting health. Model foods could also assist in the design of customized diets. New nutritionally-enhanced products that do not require additives such as sugars and trans-fatty acids should be developed to improve the diet.

Develop and produce sufficient, nutritious and affordable plant raw materials for feed

Plant raw materials may also have an indirect impact on food products as feed for animals. The increasing demand for animal products should be met by ensuring the sustainable production of sufficient high-quality, nutritious and affordable feed. Approaches could include the development of new European protein crops, including research on effective yield increase and improvement of protein quality of pea, faba bean, alfalfa and soybean, improved oil seed for feed, exploring the possibilities of increasing the ratio of omega3: omega 6 fatty acids in cattle feed and developing new sources of oils to increase the sustainability of fisheries. The composition of feed could be optimised for both macro- and micro-nutrient content for nutritional quality and efficiency in both agriculture and aquaculture. Palatability and digestibility of raw materials for feed will also constitute an important objective for feed improvement.

Reduce or eliminate potentially harmful compounds to improve safety of food and feed
We need to assure the safety of plant raw materials in the food chain and ensure safe practices in organic farming by reducing or eliminating the content of non-beneficial compounds; for example, plant toxins, allergens, toxic metals, microbial pathogens, neurotoxins, acrylamide precursors, pesticide residues and mycotoxins. Removal of toxic components from animal feed for optimised nutrition is also desirable for both agriculture and aquaculture.

Basic research and infrastructure to be developed

Complete the sequencing of cereal genomes and identify diversity at the genome level in relevant European crops (Action 1, 2, 3 and 4). Sequencing and understanding the genomes of major crops will be an essential tool in the future. Today many of the major crops are still not fully sequenced or require significantly better understanding of their genetics and genome development. This will provide new insights into how modern crops evolved and how they can be further improved.

Improving the understanding of the potential of new technologies of gene modifications in crop species (Action 2, 3, 4 and 5). Novel methods to generate improved genetic resources aim for more targeted approaches to improve the genetic basis for plant improvement. Proof-of-principle studies need to be undertaken to identify the potential and the limitations of these novel tools for crop improvement.

Study the quantitative genetics of complex, agronomically important traits (e.g. root traits) (Action 1, 2, 3 and 4). Knowledge about these highly important traits is still very limited. Integrated approaches need to be developed in order to understand quantitatively the

heritability and impact of development and environment of these traits, which are very important in determining crop yield.

Understanding the synergistic relationships between plants and other biological systems (Action 1, 2, 3 and 4). The interaction between plants, microbes and other organisms in the soil is an essential field of research that can provide many novel insights in the food and interaction web as well as the signalling between organisms. This will provide the basis for future development of beneficial interactions useful for sustainable production.

Infrastructure for chemical plant phenotyping (Action 1, 2, 3 and 4). Plant phenotyping has been identified as a crucial bottleneck for progress in knowledge growth as well as in application-oriented research. Specifically, chemical phenotyping systems can be developed to support improving plant composition.

Example for a research solution to Action 4

Model Foods for comparative nutrition

A major challenge in human health over the next fifty years will be in the area of chronic, non-communicable diseases, including heart disease, many cancers, type-2 diabetes and obesity. Because socio-behavioural risk factors contribute significantly to the incidence of and mortality from chronic disease, science and public policies need to be re-oriented towards prevention rather than cure.

The importance of plant-based food components in promoting health and ameliorating the impact of chronic diseases has been recognized for some time. However, currently, recommendations are unable to identify specific fruit and vegetables that confer the greatest health benefits, meaning that official recommendations are vague and that dietary improvement campaigns are untargeted and largely unsuccessful. It is therefore important to define the action of phytonutrients through a multidisciplinary approach.

It has been well recognized that food components need to be studied in the context of complex foods and not as purified compounds, since other metabolites, enzymes, fibre etc with which they are normally ingested may modify the bioavailability and bioactivity of specific phytonutrients. Hence there is a need to design a limited number of model foods (near-isogenic plant-based foods that vary only in the quantity of the bioactives under analysis), which can be used in all research activities on bioactives to establish scientifically the relationship between food and health.

A number of well-defined and designed model foods can be used to feed animals under simplified and controlled conditions. Such model foods should be used to ascertain the preventive effect of bioactives against chronic diseases, to define the molecular mechanisms underlying the observed effects and finally to determine novel potential biomarkers useful for early identification of pre-clinical onset of diet-related diseases. The robustness of such biomarkers should then be verified in human intervention studies using the same model foods. These activities will deliver tools for early diagnosis of diet related-diseases and for science-based formulation of appropriate nutritional interventions to prevent/reverse disease progression.

Action 5 – Improve composition and performance of plants for non-food products

Description

Recent investment in full-scale integrated biorefineries already allows the competitive production of high value bio-based products. By 2030, biorefineries will play a very important role in Europe: it is expected that 30% of all chemicals will be bio-based, 25% of Europe's transport energy will be supplied by biofuel and 30% of Europe's heat and power generation will use biomass. The production of recombinant proteins is also a growing area, and has a high market value. More than 150 recombinant pharmaceuticals are now approved by regulatory agencies in the USA and EU, and hundreds more are undergoing clinical trials. Recombinant proteins are the largest category of biopharmaceuticals and account for over half of global sales. Plants and plant cell cultures will both be important production routes both for these biopharmaceutical products and also for small molecules. The production of therapeutic molecules in plants also has significant potential to improve health in developing countries by allowing low-cost access to modern medical treatments.

The economic viability of processes based on plants depends on how the break-even selling price compares to the market price. Market price is dependent on demand and is very different for those products that are considered commodities (such as bulk chemicals and fibres) and those considered as speciality goods (such as fine chemicals, enzymes and recombinant proteins). These are two quite different categories; plants grown for commodity products must necessarily be grown on an agricultural scale whereas those grown for speciality products are likely to satisfy market demand even if the scale of production is low. Even so, there is a degree of overlap between the categories which must be considered. For example, certain antibodies (such as those envisaged as topical microbicides and even components of cosmetics) are now regarded as 'bulk' products with annual demand on the multi-tonne scale. The economic perspective of added-value non-food plants therefore needs to encompass these 'crossover' products and their implications in what has traditionally been a highly segmented market.

Boosting the yield of non-food crops

The selection of high-yielding, high-quality European crops and the development of efficient and sustainable agricultural and forestry practices are essential prerequisites for the development of a sustainable supply chain for European bio-based industries. However, to avoid serious negative social and economic consequences, the cultivation of plant biomass must be designed to avoid competition with food and feed production. Therefore, biomass crops need to achieve high yields with minimal inputs, even under unfavourable climatic and soil conditions (in marginal or water-limited environments, for example). Such plants can also be selected to reduce net greenhouse gas emissions on either a local or global scale, further contributing to environmental sustainability. Because many non-food crops have yet to be considered for research and intensive crop improvement, the potential for rapid gains is high. Research on model species has identified potential strategies to improve both feedstock yield and quality and to increase the positive impact of these species on the climate system. Likewise, fundamental research aiming at optimising plant architecture and photosynthetic efficiency, so enhancing the capture and conversion of solar radiation into biomass, could readily be applied to many non-food crops. This knowledge must now be transferred to species that are commercially relevant in Europe.

Many low-cost, non-food or multi-use plants also produce a range of additional high-value natural products that maybe recovered, providing further economic justification for their development. Cultivation for high-volume, low-price products such as bioenergy and biofuels can be made more economically competitive if combined with the extraction of high added-value compounds, such as agrochemicals, drugs, cosmetics, lubricants and safe dietary supplements. We therefore also need to develop efficient and environmentally beneficial technologies for the extraction of these compounds, and tailor the composition of non-food plants to maximize their yield. Alongside this, there is also a need to develop new and efficient processes to reduce chemical and energy use, as well as the cost of pre-treatment and waste management.

Production of chemicals and proteins in plants

Biotechnology and the life sciences more generally have been identified as essential components of the EU Knowledge-Based Bio-Economy (KBBE) strategy, which currently accounts for 1.5–2 trillion euro of EU GDP[5]. Plants have a large part to play and cutting-edge science is transforming them into 'green factories' to exploit the direct potential of plant-derived products and provide a link between the conventional agrochemical/seed industries, the pharmaceutical/healthcare sector, the food sector (food ingredients) and the processing industry, creating opportunities for economic growth.

Plants can compete favourably in the safe production of a wide range of important molecules for medical or industrial purposes. This has been established by the production of plant-derived medicines such as paclitaxel (Taxol®), vinblastine, vincristine and morphine, to name just a few. Also, less than 10% of the plant kingdom has been chemically and biologically characterised and many new discoveries are therefore expected when plant biodiversity is explored fully. In addition, the production of pharmaceutical proteins (e.g. vaccines and monoclonal antibodies) in plants is currently one of the most attractive opportunities in medicine. The advantages of plant-based factories for the production of pharmaceutical proteins include the vast production potential, the low risk of contamination with pathogens, and the inexpensive manufacturing process, which is also accessible to developing countries. Drawbacks include low expression yields in many cases and the lack of efficient and inexpensive downstream processing steps. One major challenge for plant science is the development of suitable expression platforms for the production of diverse recombinant proteins, taking into consideration all the factors contributing to economic feasibility, such as regulatory issues and purification costs.

Objectives

Improved yield, composition and processability of non-food and multi-use crops

We should expand the genetic and genomic characterization of diverse non-food crops to tailor their composition for use in the non-food chain and for the extraction of bioactive compounds. The goals should include yield enhancement, yield stability, input reduction and the introduction of specific traits to reduce the environmental impact of cultivation, enhance the positive impact of these crops on greenhouse gas emissions, and reduce the energy inputs required for processing (focusing on cascade processing for the extraction of multiple added-value products). Because some of these crops are vegetatively propagated, the development of efficient transformation and regeneration technologies and the application of new breeding technologies would be very useful for the genetic improvement of these species. In addition, the development of phytosanitary certification schemes would be desirable to guarantee the distribution of healthy propagation material.

5 http://www.bio-economy.net/reports/files/KBBE_2020_BE_presidency.pdf

Develop photosynthetic systems for the sustainable production of bioenergy

Efficient ways to make biological use of solar energy conversion systems for sustainable bioenergy production should be developed. Optimisation of photosynthetic capacity may take two forms. Firstly, the optimisation of plant architecture (including leaf cuticular waxes and leaf angle for maximised solar interception) and the efficiency of the photosynthetic machinery at the enzymatic level (RuBisCo processing, CO2 pumps etc) in crops to increase the capture and conversion of solar energy, respectively. Secondly, the development of cellular photosynthetic systems should be pursued, combining photosynthetic organisms (algae or plant cell cultures) with synthetic biology and other appropriate technologies to develop novel photosynthesis systems (the "artificial leaf") as energy-efficient solutions for sustainable bioenergy production.

Optimise plant-based platforms for commercial recombinant protein production

Plants (including higher plants, mosses, cyanobacteria and algae) are convenient expression platforms for the production of many recombinant non-food proteins, such as biopharmaceuticals and industrial enzymes. Such recombinant proteins will play an increasingly important role in the bioeconomy, and the identification of low-cost platforms for their production would make a significant contribution to the development of bio-based industries. However, high protein yields are required to achieve economic competitiveness, and highly variable expression levels have, thus far, been obtained using stable and transient expression strategies (e.g. nuclear, chloroplast and viral transformation systems) across multiple species and platforms (e.g. higher plants, plant cell culture, mosses and algae). Downstream processes influencing the correct folding and extractability of the protein, e.g. targeting the endomembrane, secretion, chloroplast or cytosolic systems, have enjoyed variable degrees of success. This has shown that there is no universal production system that can guarantee the proper expression of all recombinant pharmaceuticals or bioactive compounds in high yield. In many cases, the functionality of the heterologous protein could also be improved, by engineering plants to introduce specific co-translational and post-translational modifications. This latter point is critical for the generation of a cost-effective platform for protein production. Efforts are therefore needed to optimise and develop multiple transformation systems and expression platforms to provide a set of alternatives, allowing the most suitable platform to be chosen for each target protein.

Develop plants and plant cells for the production of high value molecules

Plants synthesize valuable natural products that are used as pharmaceuticals, agrochemicals, fragrances, flavours and fine chemicals. Such compounds are often synthesized in minute amounts or are constituents of endangered and/or slow-growing species, making them a scarce and expensive resource. Moreover, many valuable plant-derived compounds remain to be discovered. Only a small portion of known plant species have been screened for bioactive compounds; yet this has already led to the isolation of a large number of drugs. It is therefore necessary to characterise the metabolomes of underexploited and rare plant species and to develop methods that detect metabolites that are synthesized in small amounts, in specific tissues or at specific developmental stages.

We need an integrated and comprehensive effort including bio-discovery and bio-prospecting to identify bioactive compounds. This must be established within the framework of international agreements that address biopiracy. The use of next-generation sequencing technologies has dramatically increased our ability to discover genes and describe genetic variation within and between plant species as well as elucidating the biochemical machinery leading to the desired end products. These and other approaches should be combined with metabolomics to further characterise the corresponding metabolic pathways. Tremendous progress has been made in this field in recent years for non-model plant species e.g. medicinal plants. This information can then be used to increase the yield of each product using conventional breeding, molecular breeding and genetic modification as well as developing true green factories using engineered plant cell cultures or expressing a part or even the whole pathway in microbial production hosts.

Basic research and infrastructure to be developed

Omics platforms for poorly-studied non-food crops (Action 1, 2, 3, 4 and 5). The basic mechanisms underlying plant growth and development as linked to biomass yield and processability in poorly-studied non-food crops should be defined using state-of-the-art approaches (-omics technologies, collections of mutants). It is also necessary to characterise the plant genetic diversity for specialised high-value phytochemicals and the biosynthetic pathways leading to their accumulation.

Transformation and expression platforms for non-food crops (Action 1, 2, 3, 4 and 5). Fundamental research is required to develop transformation tools in a wide variety of non-food crop species, where to date these resources have not been developed. This will enable both forward and reverse genetics strategies to be applied, underpinning traditional plant breeding programmes and enabling transgenic approaches to be considered. Likewise, optimisation of the expression platforms used for chemical and protein production in non-food crops requires significant effort to ensure that economically and environmentally sustainable solutions are delivered across multiple plant species.

Optimisation of photosynthetic capacity and efficiency and plant architecture (Action 1, 2, 3, 4 and 5). Significant yield gains may be achieved by characterising the fundamental physiological, genetic and chemical processes in non-food crops associated with plant architecture and photosynthesis, to enable more efficient interception, capture and processing of solar radiation into fixed carbon (biomass). This kind of research is a current focus for several cereal crops; a similar effort is required for non-food crops.

Sustainable yield improvement of biomass crops through beneficial interactions (Action 1, 2, 3, 4 and 5). The root-associated microbiome greatly influences plant nutrition and health and can also improve resistance to environmental stresses. Key pathways and elements of the transcriptional response induced by beneficial microorganisms in non-food crops, with and without environmental stress, need to be identified.

Environmental stress and biomass candidate crops (Action 1, 2 and 5). Many biomass crop species are cultivated globally under a wide range of environmental and agronomic conditions. Understanding and manipulating key traits to choose optimal genotypes suited to particular environments and resilient to specific stresses is therefore a high priority. There is a clear need to study the underlying mechanisms that connect abiotic stress and environmental factors to flowering, fertility and biomass production, in order to maximise yield gains, both of biomass and valuable secondary products.

Protein folding and quality control machinery (Action 4 and 5). In plants, relatively few molecular chaperones and other components that facilitate protein folding have been characterized in terms of their targets and protein folding activities. Moreover, unlike the situation in animals, these plant proteins are often encoded by multigene families and the precise functions of individual members are largely unknown. Likewise, optimising key cellular functions e.g. phosphorylation, N-glycosylation, codon usage, post transcriptional modification etc. to maximise the production of high yields of structurally correct recombinant proteins in non-food crops is essential, and we need to fill these gaps in knowledge to provide the tools required to improve the necessary folding of recombinant proteins.

Mechanisms and recognition properties of protein turnover (Action 3, 4 and 5). The turnover rates of recombinant proteins are difficult to predict. We need to improve our understanding of the mechanisms that control protein stability in the different compartments of plant cells (e.g. cytosol, plastid, endoplasmic reticulum). Characterising the main production and degradation pathways and identifying the principles that regulate the selection of substrates for degradation is a fundamental issue that has to be addressed for the development of high-yielding recombinant protein production systems in plants.

Example for a research solution to Action 5

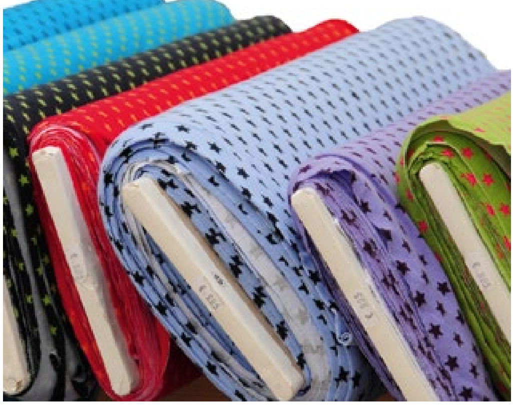
Improving biomass yield, composition and processability for the production of bioenergy/biofuel and biomaterials

Work on model species has led to substantial progress in our understanding of plant physiology and metabolism at the genomic, proteomic and metabolomic levels. This knowledge can now be used to design strategies to increase biomass yield while improving biomass composition and processability, facilitating its transformation into bioenergy/biofuel and biomaterials. Genes, pathways and regulatory networks that influence biomass generation/carbon accumulation (under low input/stress conditions) and processing-relevant characteristics (e.g. lignin content and composition) have been identified in model species. This information can now be used to identify genetic loci that modulate the accumulation and quality of the biomass in related lignocellulosic biomass feedstock candidates.

As competition between food/feed and biomass crops increases, there is more pressure to grow biomass crops on marginal lands to ensure their economic and social sustainability. The eventual mining of germplasm or the genetic modification of biomass candidate species for xerophytic and halophytic lifestyles would significantly reduce competition between food/feed and biomass production. Extremophiles, particularly model systems, provide the resources for the basic understanding of tolerance and will unlock the potential in other species.

Contributions from genetics, functional and comparative genomics, plant breeding, genetic and metabolic engineering, physiology, biochemistry and agronomy will therefore be required to exploit the potential of non-food/multi-use crops for industrial and energy uses.

How far can we go? Yield improvements could be achieved by translating current knowledge on the role of yield components, such as photosynthetic efficiency and plant architecture, into undomesticated biomass species (4–5 years for herbaceous species, 10–15 years for tree species). There is likely to be significant genetic variation for stress tolerance traits in biomass crops, which in the short term (2–3 years) could be incorporated into breeding programmes to improve biomass yield in limiting environments. Lignocellulosic biomass crops that propagate vegetatively will require dedicated approaches


for genetic transformation and the engineering of relevant metabolic pathways, so that considerable progress could be achieved in the medium term (5–7 years).

We also need to investigate how and to what extent symbiotic organisms and pathogens affect the performance of non-food crops. Biomass crops can form associations with mycorrhizal fungi, which improve water and nutrient uptake. Mycorrhizae and/or fungal endophyte colonization could be used to enhance biomass production, particularly under drought conditions. A survey of fungal biodiversity in host plants and the dynamics of plant/fungus associations under challenging conditions (e.g.drought) are required. Conservation and management strategies for fungal resources are also necessary.

How far can we go? The selection of the most effective symbiotic fungi can be achieved rapidly (3–5 years) but will require extensive interactions between plant physiologists, mycologists, geneticists, cellular and molecular biologists. The transfer of these results into large-scale practical applications may take up to 10 years.

Clonal propagation is required for some biomass crops, which may carry over intracellular pathogens (viruses and virus-like agents) that cannot be later controlled by chemicals. In addition, limited information is available concerning intracellular pathogens infecting biomass/energy crops because these plants were not considered to be crops until recently, or were even regarded as weeds. A combination of breeding (when possible), good agronomic practices and phytosanitary certification of the propagation material has been applied in other clonally-propagated species, such as fruit trees and grapevines, improving both yield and quality.

How far can we go? For biomass/energy crops, a primary goal will be to identify viruses, viroids and phytoplasmas present in accessions, followed by the development of diagnostic tools, as well as phytosanitary protocols and certification procedures to be used in the production stages of mother-plants (this could be achieved in 3 years). Five to ten years will be required to develop transformation methods allowing the engineering of specific traits.

Actions for a vibrant research environment

Action 6 – Develop and implement horizontal actions

Description

The complexity and urgency of the challenges facing the human population calls for a rapid and effective response. Financial and human resources are already limiting factors and therefore combining resources and developing synergies between the different stakeholders is of key importance. A European Research and Innovation Area is needed now more than ever, to respond efficiently to society's need to address European and global challenges and generate innovative solutions that can be applied in the field and by industry.

Human resources and education are increasingly important in the global scenario. Making the most of these requires long-term and proactive approaches. The challenges ahead demand a flexible, well-educated and open-minded scientific workforce. They also require better career options that allow balanced approaches to knowledge transfer as well as a focus on implementation. Innovation needs to be supported, but today´s systems do not allow easy cooperation or openness between the academia and industry. Specific key actions for the plant sector on education and innovation are outlined in the Education Action Plan and Innovation Action Plan, respectively. Both are as well as the Research Action Plan essential parts of an integral strategy of the plant sector to boost research, build innovation leadership and educate the next generation in the sector.

We also have to realize that many global challenges will directly affect us in Europe. On the one hand new economic opportunities develop from such challenges, on the other hand we also have to take a responsible approach to addressing the most pressing issues in developing countries. If not, we will indirectly import developing social and economic problems into Europe. Thus we need to use our technological and human resources to deliver solutions to global challenges, even if they are generated outside our region. It must also be recognized that the 'old' solution to our lack of self-sufficiency in food production in Europe, to import what we need, poses ethical, economic and ecological problems. As the world population grows to 9 billion, we cannot simply export our problem to other parts of the globe, just because we can afford to do so. Each EU Member State will need to make its own contribution to food production, and this will require sustainable intensification. The alternative reduced-intensity model proposed by some effectively asks other (poorer) countries to absorb the consequences of our needs for food, feed and fibre.

Openness and the involvement of society is the key to gaining support in democratic systems. This requires not only an awareness of the problems ahead, but also an open-minded approach to addressing solutions by both decision makers and society. Discussions of policy in Europe often neglect the consequences in other parts of the globe. This runs the risk that we cannot apply the most useful technologies to address problems, that we do not make the best use of opportunities that can provide the basis for a prosperous future, and that we do not act according to our ethical values.

Objectives

A special focus on human resources

Currently, a shortage of specialists (e.g. plant breeders) is hampering progress in key areas of the bio-based innovation process. However, even when specialists and appropriate programmes have been developed, the need to coordinate the activities of scientists still has to be kept in mind. While there is a strong need for junior scientists, we also urgently need the experience of senior scientists from academia and industry and the practical knowledge of farmers to be properly applied and exchanged. Thus increasing efforts need to be put into the support of careers for today's young scientists, using a life-long learning approach that crosses sectors and disciplines.

Strengthening European competiveness

European agricultural industries and farming communities face major changes. While increased production at a competitive cost is key, the requirements for a smaller environmental footprint and the delivery of ecosystem services by agricultural production systems have to be fulfilled at the same time. Exchange of ideas and options for collaborative experimentation as well as greater interaction of the science sector with business have to be major objectives in the process of boosting innovation in the European agricultural sector.

European solutions in a globalised world

The global nature of the current challenges calls for global solutions, and Europe has to help deliver these, for the sake of fairness, job opportunities and wealth generation in Europe and in an increasingly connected world. European plant sciences and industry therefore need to tackle food and nutrition, feed, material, energy and sustainability issues and contribute solutions to developing countries across the globe.

International and development sector cooperation is required for research into resilience under changing conditions, with particular attention to smallholder farming in developing countries. An increasing number of international commitments recognise the important role this has in contributing to solutions. Increased research efforts are required to provide a sound knowledge base for measures to adapt current production systems to expected changes as well as to fully exploit the development potential of the agricultural sector.

Open dialogue with all stakeholders

Support by society is required if the tasks for plant sciences, industry, farmers and forest managers are to be completed effectively. In order to enhance the support and appreciation of plant sciences and agriculture by the general public it is important to establish a better understanding of economic and ecological reality, of global interrelations and the basis of technical solutions currently limits their willingness to support plant sciences and agriculture. Thus an open and rational discussion with society is required, together with direct involvement in societal and political decision making.

To address each of the key actions described above, "horizontal actions" have to be developed and implemented.

Example for a research solution to Action 6

Open discussion with society and decision makers – Towards a European Forum for Sustainable Bioeconomy

While this has been a major goal for some time, more action is needed to develop fruitful and required long-term support for plant sciences in Europe. Overcoming knowledge deficits and limitations, often leading to uneducated fears is a central issue in the acceptance of European bio-based sectors. Open discourse and discussion with the society at large is supported, for instance, by activities like the *Fascination of Plants Day* in which aspects of research, infrastructure and innovation and their interaction are shown. Here discussion should also address issues that are controversially discussed, due to limited popular understanding, like e.g. novel breeding technologies, GMO, ecosystem services and sustainable intensification. Generating a European Forum for Sustainable Bioeconomy – based on the collaboration of national academies, European Technology Platforms and other stakeholders - could deliver a strong message to the public by providing an open discussion forum in the member states, as well as joint statements or discussion papers.

Action 7 – Strengthen basic and applied research and research infrastructure to secure innovation

Description

Basic research in plant science underpins innovation based on scientific knowledge and understanding in the sector and, therefore, must remain a high priority for research programmes in individual as well as collaborative projects at both the European Union and Member State level. Stimulating basic research from applied challenges (and vice versa), and supporting both branches of research are key requirements for the development of products for the plant sector. The development and use of scientific infrastructure and enabling technologies in plant and agricultural sciences and the innovation framework need to be part of comprehensive solutions to maintain and to increase the innovation capacity of the sector in Europe.

Objectives

Strong basic as well as applied research in the plant sector

In order to inspire, drive and sustain the bioeconomy it is key to strengthen the knowledge base for innovation. Both, basic as well as applied plant research must be supported by strong programmes in individual European Research Council – ERC as well as collaborative Societal Challenges – SCs projects at the European level and similarly at the national and international level, with a strong European contribution or lead as appropriate. This should include both sectorial and multi-disciplinary research.

Integrated programmes and projects beyond national, sectorial and disciplinary borders

Fragmentation is a central disadvantage of Europe in the global marketplace. While on one hand it allows for diversity (a strength that should not be lost), uncoordinated action potentially causes a wasteful doubling of activities (and cost) in Member States. The plant and agricultural sciences of today are closely linked to other sectors, including the food, pulp and paper, chemical and even energy industries. However, these links will become increasingly strong as these industries (and the novel ones created) become key parts of the future bioeconomy. Therefore projects and programmes have to be set up that are integrated across value-chains and form value networks. Here, plants and agriculture go beyond the simple delivery of feedstock, providing the quality characteristics (i.e. nutritional, pharmaceutical) needed in the end product, forming the central component that allows recycling of nutrients and carbon into the continuing processes that make the (bio)economy sustainable.

Cooperative efforts

Cooperative efforts within and between academic institutions in the plant sector, various industry sectors and farmers need to be strengthened to address the grand challenges for European and global society.

Integrated technology platforms and networks

Real technical and economic progress needs advanced technologies and centralized resources available for research, development and transfer of technology to the market place. However, developing technologies often require significant investment, and special structures to facilitate developing scientific as well as technology transfer expertise. Given the economic risks of these investments and the central role of these infrastructures, coordinated action is required, and these large scale networks and technology platforms require adequate long-term funding in order to fulfil their role. While this has been achieved in other science sectors, the plant and agricultural sciences are not adequately resourced yet, having little experience in mobilizing such resources.

Example for a research solution to Action 7

European integrated technology platforms in genomics, phenotyping and experimental farms

In recent years, significant progress has been made with national platforms for plant genomics, phenotyping and farm-scale experimental platforms utilising systems approaches. However, this is a very fragmented development and not all Member States have reached a sufficient level of integration of these, often expensive, platforms and technologies. A process should be put in place to develop integrated, Europe-wide, networks in the relevant technological fields that support exchange, reduce double investment and ensure long-term funding of cornerstones of the European plant research and innovation area.

About Plant ETP

The ETP 'Plants for the Future' is a key stakeholder in the agri-food chain, representing those organisations which are active in plant science research, companies investing up to 20% of their annual turnover in plant research and innovation, and farmers keen to access the latest technology adapted to their needs.

The Technology Platform calls upon the European Commission and Member States to take on board the integrated Innovation, Research and Education Action Plans that aim at enhancing plant-based innovation potential and the societal support needed to implement innovation. The Technology Platform is highly committed to assist in bringing stakeholders together (from industry, academy and farming communities), and participate to the development of a sustainable leadership of European Agriculture.

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All the experts have participated in three different workshops organized during the development of this Research Action Plan.

Name of experts highlighted have directly contributed to draft this Research Action Plan.

Glossary

Abiotic Stress
Non-living environmental factors (such as drought, extreme cold or heat, high winds) that can have harmful effects on plants.

Agri-Food-Sector
The sector of the economy that produces agricultural and food products.

Agricultural Extension Services / Advisory Services
Agricultural extension services are organisations helping to expand the application of scientific research and new knowledge to agricultural practices through farmer education.

Agricultural Supply Industry
The agricultural supply industry encompasses seed breeders, biotechnology and trait specialists, crop protection manufacturers and suppliers and other companies providing material or knowledge inputs to farmers.

Biomass
Renewable biomass encompasses any biological material (from agriculture, forestry, fisheries and aquaculture) as a product in itself or to be used as raw material.

Bioeconomy
The bioeconomy encompasses the sustainable production of renewable resources from land, fisheries and aquaculture environments and their conversion into food, feed, fibre, bio-based products and bio-energy as well as the related public goods. The bioeconomy includes primary production, such as agriculture, forestry, fisheries and aquaculture, and industries using and/or processing biological resources, such as the food and pulp and paper industries and parts of the chemical, biotechnology and energy industries.

Biotic Stress
Living environmental factors (such as viruses, bacteria, fungi, insects etc.) that can have harmful effects on plants.

Classical Plant Biology
Classical plant biology includes the traditional plant science disciplines, for example plant breeding, agronomy, taxonomy, physiology, genetics, plant science, agricultural and horticultural subjects needed by industry.

European Technology Platform (ETP)
ETPs are industry-led stakeholder fora that develop short to long-term research and innovation agendas and roadmaps for action at European Union and national level, to be supported by both private and public funding.

Food Security
Food security encompasses the availability of sufficient, nutritious, safe and affordable food.

Forestry
Cultivation of trees and the management of forests and woodland. Related sectors include paper and pulp industry.

Horticulture
Horticulture can be defined as the branch of Agriculture concerned with plants that are used by people for food, either as edible products, or for culinary ingredients, for medicinal use or ornamental and aesthetic purposes.

New Plant Biology
New plant biology includes modern biological disciplines, for example bioinformatics, molecular biology, various –omics and mathematical biology. These are essential for plant breeding and improvement programmes at the molecular level.

Plant Sector
The plant sector is composed of the public sector - universities and research institutes working on plant science - and the private sector with arable farming, horticulture, forestry and agro-chemistry, plant breeding, seed and plant biotechnology industries. The sector is characterised by activities enhancing and stabilizing yield, food production and nutritional security, environmental benefits and the non-food use of plants and plant biomass for bulk as well as high value products.

Small And Medium Enterprises (SMEs)
Small enterprises have fewer than 50 employees. Medium enterprises have fewer than 250 employees and have an annual turnover not exceeding 50 million euro. In 2012, in the EU-27, some 20 million SMEs provide approximately 86.8 million jobs.

Sustainability
This is an economic, social and ecological concept. A sustainable (bio)economy is one that meets the economic and social needs of the present while minimising the impact on the environment, and without compromising the ability of the future generations to meet their own needs.

Annexes

Annexes (only available on the website www.plantetp.org)

Annex I: Research solutions to the key actions

Annex II: Headings of Strategic Research Agenda of the ETP 'Plants for the Future'

Annex III: Headings of Horizon 2020 Specific Programme proposal by the EC

Annex IV: Focus areas of Horizon 2020 Strategic Programme for the WP 2014-15 proposal by the EC

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This Research Action Plan , as well as the Innovation Action Plan, the Education Action Plan and the Summary of Action Plans, which outlines the key elements of all three action plans, can be downloaded from the website **www.plantetp.org**.

Disclaimer

This Research Action Plan has been drawn up through the collaborative effort of a group of experts representing the various stakeholders of the European Technology Platform 'Plants for the Future' (Plant ETP) (industry, academia and farming communities). Whilst the Research Action Plan represents the outcome of a series of open workshops and discussions, it is neither exhaustive nor comprehensive and covers only selected aspects of broader issues. This Research Action Plan is a living document and will be updated regarding new developments and based on experiences from its implementation.

Views and information expressed in this document do not necessarily reflect the opinions of any single member, their organisations, or of the European Commission.