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Research Needs and Research Requirements in the Context of Sustainable Agriculture

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Abstract: *The goal of sustainable agriculture is to meet society's food and textile needs in the present without compromising the ability of future generations to meet their own needs. Practitioners of sustainable agriculture seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Every person involved in the food system—growers, food processors, distributors, retailers, consumers, and waste managers—can play a role in ensuring a sustainable agricultural system. This paper deals with Research Needs and Research Requirements in the Context of Sustainable Agriculture. It outlines the indicators of bio resource use efficiency, research strategies on plant production system, diversification of plant production system, research needs in plant production system, plant health promotion, research needs and strategies in quality food production and research needs and requirements in non food production. This paper concludes with some interesting findings along with policy suggestions.*

INTRODUCTION

Sustainable agriculture is farming in sustainable ways based on an understanding of ecosystem services, the study of relationships between organisms and their environment. It has been defined as "an integrated system of plant and animal production practices having a site-specific application that will last over the long term". Sustainable agriculture is the efficient production of safe, high quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species. Agriculture should ensure the economic viability of farming systems at the local farm level. An adequate net farm income is necessary to support an acceptable standard of living for farmers and to ensure the annual investment needed to improve progressively the productivity of soil, water and other resources.

Sustainable agriculture also aims to explore how farmers can benefit from, Cost saving in terms of from forms of zero or conservation tillage, Increased yields from increased soil fertility, Market mechanisms that favour production of quality raw materials, Making a positive contribution to the public good in the form of landscape, availability of farming infrastructure, resources & renewable inputs and access to global markets.

The success of sustainable agriculture depends on research and innovation. Hence there is a need to promote research in bio resource use efficiency, plant production system, plant health promotion, production of quality food and production of non food crops. These aspects of research needs and research solutions are discussed here.

RESEARCH STRATEGIES IN BIO RESOURCE USE EFFICIENCY

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 man aging more

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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 bio economy, 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. These 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". 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.

INDICATORS OF RESOURCE USE EFFICIENCY

Resource use efficiency has many different definitions. Agronomic resource use efficiency is often defined as the ratio of output often yields 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 with respect to 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.

There is a need to improve the utilization 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.

The success of agricultural bioresource use efficiency depends on reduction of the environmental footprint in 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 Asia and 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.

The proper utilization of bioresource depends on Biodiversity Promotion 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 macroscopic and micro scopic 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 num ber 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 com munities.

The success of agricultural bioresource use efficiency depends on conservation and utilization of 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 agriculture in developing countries. 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.

AGRICULTURE RESEARCH ON RESOURCE USE STRATEGIES

1. 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 underutilized resource to be tapped into and made available for projects improving plants for sustainable production. To tackle this huge task adequately, all omics and phenoty ping technologies need to be developed beyond today's focus on the major commodity crops.
2. 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.
3. The actual yield performance of plants in the agricultural environment is strongly dependent on the species; cultivar, developmental stage and specific environ mental 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.
4. Plant phenotyping has been identified as a crucial bottleneck in knowledge growth, as well as in application-oriented research.
5. 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 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 infra structure network allowing standardised testing of germplasm would allow basic research as well as provide a significant competitive advantage for European breeders.

AGRICULTURE RESEARCH IMPLICATIONS

Improving resource use components for water and nutrient utilisation by breeding for root traits and 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 environ mental 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 plat forms 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.

RESEARCH STRATEGIES ON PLANT PRODUCTION SYSTEM

Germplasm enhancement, breeding programmes and ecophysiology including novel production practices, have all contributed to substantially increased yield in world agriculture and forestry in past decades. This has been the basis for a secure supply of both food and non-food products to the world 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.

Extreme weather conditions are expected to become more frequent in many regions in developing countries 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.

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 Asian 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.

RESEARCH SOLUTION ON PLANT PRODUCTION

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 focused 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.

ENVIRONMENTS 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 environ mental 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. In addition, agricultural technology, including the use of sensors and predictive models, must be further developed to respond rapidly and effectively to fluctuating conditions.

DIVERSIFICATION OF PLANT PRODUCTION

In the past, 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 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.

INTEGRATED PLANT PRODUCTION

The regional diversity of agricultural production in throughout the world 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. Hence the 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. There is a long tradition of agricultural extension services across in many countries. This existing system of driving innovation will benefit from knowledge exchange at the National 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.

PLANT PRODUCTION RESEARCH STRATEGIES

1. 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.
2. 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 under utilised 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.
3. 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.
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.
5. As crop species are cultivated for various specific purposes around the world,

understanding and manipulating key traits to develop optimal geno types 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.

6. 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 organ isms. This will provide the basis for future development of beneficial interactions useful for sustainable production.
7. 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. Fund mental 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.
8. 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.

BIOECONOMIC RESEARCH SOLUTION ON PLANT PRODUCTION

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 com pounded 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

RESEARCH STRATEGIES ON PLANT HEALTH PROMOTION AND RESILIENT PRODUCTION

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 plant production pesticides 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. 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 plant production pesticides and (iv) monitor and respond to resistance development by pests, diseases and weeds.

RESEARCH FOCUS ON IMPROVED TOLERANCE AND RESISTANCE OF PLANTS TO PESTS AND DISEASES

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 resist ant/tolerant varieties will improve both food security (grain production) and food safety, improving the competitiveness of both the agriculture and livestock sectors in the area of adoption. 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.

RESEARCH STRATEGIES TO DEVELOP PRACTICAL ALTERNATIVES TO PESTICIDES

1. 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.
2. 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.
3. More targeted plant production pesticides 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.

4. 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 inoculums detection such as automated air samplers using biosensors to detect spores and wireless reporting of results.
5. 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).
6. 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 har vest 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.

RESEARCH SOLUTION ON PEST MANAGEMENT

1. Understanding the key mechanisms in crop disease and resistance would provide the essential insights needed to develop novel resistance pathways and improve their durability.
2. An understanding of the interactions between plants, microbes and fungi is essential for developing pathogenomic approaches as well as plant health treatments.
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 inter action, which can be used as a basis for future development of resistance.
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.

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.

RESEARCH STRATEGIES ON QUALITY OF FOOD PRODUCTS

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 Organization (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 physicalactiv ity and, perhaps most importantly, the increasing cosumption 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.

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.

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.

RESEARCH NEEDS IN QUALITY FOOD

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 countries.

PLANT RAW MATERIALS TOWARDS 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 com pounds, 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.

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.

1. 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 aqua culture.
2. 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.
3. 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.
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.
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.
6. 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.

RESEARCH SOLUTION FOR QUALITY FOOD

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 bio markers 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.

RESEARCH STRATEGIES FOR NON FOOD PRODUCTS

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 specialty 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.

IMPROVING 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 com pounds, 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.

NON FOOD CROPS DEVELOPMENT STRATEGIES

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.

This has shown that there is no universal production system that can guarantee the proper expression of all recombinant pharmaceuticals or bioactive com pounds 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.

RESEARCH NEEDS

1. 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.

2. 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 plat forms 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.

3. 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.

4. 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.

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 bio mass and valuable secondary products.

6. 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-glycosylaion, 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.

7. 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.

RESEARCH SOLUTIONS

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 bio mass crops on marginal lands to ensure their economic and social sustainability. The eventual mining of germplasm or the genetic modification of bio mass 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 com parative 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 approache 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/fun gus associations under challenging conditions (e.g.drought) are required. Conservation and management strategies for fungal resources are also necessary.

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.

RESEARCH STRATEGIES ON ENVIRONMENT

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.

RESEARCH 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.

RESEARCH SOLUTION

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, eco system services and sustainable intensification. Generating a European Forum for Sustainable Bio economy – 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.

CONCLUSION

It could be seen clearly from the above discussion that the success of sustainable agricultural practices depends on research and innovation. In this paper many research strategies and research solutions and implications are discussed in the direction of sustainable agricultural practices. In order to promote the research and research requirements in sustainable agriculture, the following policy suggestions can be considered.

1. The government should allocate more funds for research in organic farming and sustainable agriculture practice.
2. The government should promote bio fertilizer industry by the way of providing more subsidies and concessational finance
3. The government should encourage research and development in proper utilization of bio resources by the way of providing research grant
4. Efforts should be made to develop research solutions towards organic farming and sustainable agricultural practices
5. The government should initiate new research programs on production of quality food products by the way of encouraging research in organic farming
6. Efforts should be made to protect the environment and life support system by the way of promoting research on production of eco friendly food products
7. The implications of bio science research should reach all the regions and different parts of the country through effective dissemination mechanism.

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