ABSTRACT

This volume illustrates the main research issues for the development of an environmental and economical sustainable primary production. An interdisciplinary collaboration between several scientific areas has allowed the study of the future evolution of agriculture, livestock and food production. The first chapters analyze the proper balance between productivity and environmental goals in agriculture and how to reduce its impact on ecosystems. Subsequently, the following chapters discuss the improvement of livestock and aquatic systems. Besides, new approaches in plant health, plant biotechnology and plant breeding are also described according to a future sustainable production. To conclude, the final chapters suggest the novel and future approaches in food production and food safety.

KEYWORDS

ecosystem services | biodiversity | agroecology | circular bioeconomy | animal health and welfare | aquaculture | plant health | pests | genome-editing | synthetic biology | functional food | food industry 4.0 | emerging risks | food safety

EXECUTIVE SUMMARY

The current model of development and consumption generates a high environmental impact, in some instances difficult to reverse. Sustainable primary production is a respectful manner to adapt to the new conditions and act as mitigators of Climate Change and protect biodiversity. It is essential to find solutions by seeking harmony, restoring human-nature relationships, through optimal, respectful and sustainable management of agro-ecosystems and livestock production promoting basic and applied research.

In this book we summarize the most relevant challenges that must tackle in the coming years to achieve a more efficient and respectful use of natural resources, including land and marine agricultural inputs. These challenges are covered into 7 chapters:

1. Agriculture ecosystem services
2. Agroecology and circular bioeconomy
3. Comprehensive improvement of livestock and aquatic systems
4. Plant health. Resistance to pests and diseases
5. Biotechnology and plant breeding
6. Sustainable production in the food industry
7. Food safety

PREFACE

It is difficult to imagine a world today without agriculture and livestock. However, until the last glaciation (≈11,000 years ago), human social groups were made up of hunter-gatherers who lived from hunting, fruit gathering and fishing and were distinguished by their capacity for mobility. About 10,000 years ago, a turning point in human history took place. Progressively, these groups became sedentary with the creation of the first settlements, coinciding with the development of the first domesticated species of plants and animals that allowed them to be producers of their own food. In the following millennia, the progressive development of agriculture, livestock and fishing took place in different parts of the world allowing the increase of the world population in parallel. From the end of the 19th century and the beginning of the 20th century, industrialization and the development of chemical fertilizers and pesticides gave an important impulse to the increase of agricultural and livestock production in the world, allowing the population to multiply by seven in the last 200 years. Never in the history of mankind have had access to such amount of high quality food. However, we cannot ignore the high environmental costs of development, known in numerous impacts, from the decrease of biodiversity in large areas, the eutrophication of aquatic ecosystems due to the excessive input of nutrients in hydrological and sedimentary flows, to the proliferation of the use of food packaging systems, as well as production and distribution chains, with a high environmental footprint.

The Earth's resources are adequate to meet the current demand for food. However, as the human population continues to increase, and historical consumption patterns change and expand, as a result of increasing economic wealth, the need for more demand-driven, waste-free production is inexorable. Under current pressures, according to the United Nations, the world's population will be approximately 9,7 billion by 2050, and according to FAO, an increase of more than 70% in current food production will be required to feed this population. Therefore, in the next 50 years we must produce as much food as it has been produced in history (Megan Clark, former director of the CSIRO).

Considering that the planet's resources are finite and there are limits based on the planet's capacity to renew them, and to absorb impacts without catastrophic changes, research is needed to develop strategies for sustainable development in agriculture. The concept of "sustainable development" was presented by the World Commission on Environment and Development (WCED)

in 1987 —known as the Brundtland Report— as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Sustainable development is based on the acceptance that development is both possible and necessary; that it must be made sustainable, enduring and achievable over time; and that it must fulfilled a threefold function: economic growth, social equity and environmental problems.

The current model of development and consumption —including the current agricultural systems— generates, in its great majority, a high environmental impact through different processes of land degradation, which have led in several occasions to changes in biodiversity of difficult reversibility. This situation is complicated both by regional aspects (in terms of primary production, processing and supply chain to the end user) and by greater global fluctuation in the demands of a specific food. In addition, in a global context, enormous challenges appear associated with a changing climate scenario, which forces us to continue producing, consuming fewer resources, adapting practices and technology to new environmental conditions and generating mitigation scenarios in the face of the climate emergency. In addition to producing quality food in a respectful manner in the face of growing demand, agricultural systems are challenged to adapt to the new conditions and have the opportunity to act as mitigators of Climate Change and protect biodiversity. The protection of biodiversity, with its buffer and dilution effect, is also a key factor in the face of another global challenge, namely the prevention of pandemics, with the unprepared and global scourge of the current COVID-19, which we must incorporate into our current range of threats. Finally, there is the continuing dilemma of having a finite amount of land available for agriculture and livestock.

Awareness of the global nature and the impact of our actions force us to proceed to avoid the irreversible effects. All of these factors point to the need for more efficient production of crops with optimized traits intended as a whole for primary products and co-products. It is essential to find solutions by seeking harmony, restoring human-nature relationships, through optimal, respectful and sustainable management of agro-ecosystems and promoting basic and applied research. With this approach, innovative responses, the implementation of decentralized systems adapted to local situations, the use of appropriate technologies, new production processes can achieve a more efficient and respectful use of natural resources, including land and marine agricultural

inputs. We summarize below the research challenges proposed for the achievement of sustainable primary production.

(i) Sustainable agricultural and food systems, which combine preservation of the natural environment with food production, in addition to producing food for society, generate many ecosystem services that are essential to its well-being. Our society today faces the challenge of valuing these ecosystem services from natural and agricultural systems that will enable us to improve the health, economy and quality of life of people today and in future generations. It is not sustainable to deplete resources and degrade ecosystems in order to produce food, agriculture and biodiversity cannot be opposed but complementary, co-working for food production and the generation of ecosystem services. Even so, the conversion of natural areas, or traditional agricultural systems, into areas of intensive agricultural monoculture is advancing unstoppably, causing various processes of ecosystem degradation and loss of biodiversity, directly affecting climate change and deteriorating numerous ecosystem services. Thus, a key objective now is the imminent evolution towards a sustainable intensification of agricultural and livestock systems, where sustainable agricultural and livestock practices and management are compatible with the production of sufficient and quality food, without impairing fundamental ecosystem services for other socio-economic sectors (e.g. tourism, provision of common household goods) and for social welfare (e.g. flood regulation, erosion and pollution control, human health, quality of life, recreation). Various studies show that it is possible to combine sustainable agricultural practices that preserve the optimal quality and functions of soils and vegetation on a small scale, without negatively affecting or even increasing productivity. Experiences with agro-ecosystem management need to be tested, validated and extrapolated to a larger scale in order to develop sustainable extensive and intensive agriculture. All this can only be done by knowing the impacts of agriculture on the socio-ecological systems, from the most updated research hand in hand with social acceptance and consensus of the actors involved, with agro-ecological keys.

(ii) The multidisciplinary approach to agroecology can provide healthy food by maintaining productivity, increasing soil fertility and biodiversity, and at the same time reducing the footprint of food production. Agroecology takes into account the hybridization of scientific knowledge with farmers' knowledge and integrates three dimensions: (i) one of a technical-productive nature, where ecology and agronomy converge in the design of agro-ecosystems;

(ii) a second dimension oriented to the cultural and socio-economic analysis of local agro-food systems from a territorial vision; (iii) a political dimension, whose priority objectives are to reinterpret the analysis of power in the agro-food system and to achieve food sovereignty. In order to respond to the scientific challenges, the paradigms inherent to the Circular Bioeconomy, product of a symbiosis between Ecology and Economy, are part of the guiding principles of Agroecology: to use renewable resources, to maximize efficiency in the use of biological resources. Within this, in particular, organic agriculture has great potential for farmers and consumers, minimizing, re-using and recycling waste as much as possible.

(iii) Both chemical fertilizers and pesticides have contributed to the pollution of soil, water and air, affecting the loss of biodiversity, harming non-target plants, birds, mammals, insects and amphibians. In addition, we must add the undoubted effect of climate change which has gradually led to an increase in the average global temperature, which together with the human impact on unsustainable practices and management of the environment, has considerably exacerbate desertification risk across the planet. For all these reasons, in order to ensure food supply and to adapt or protect ourselves from the effects of climate change, it is necessary to seek more efficient production systems benefiting natural resources and environmentally sustainable models that favour the saving of resources and have the lowest possible environmental impact. We must consider increasing organic agriculture, reducing the use of chemical fertilizers, decreasing the current dependence on pesticides and antimicrobials, improving animal welfare and reducing the loss of biodiversity that is taking place. We must also integrate new approaches provided by biotechnology and genetic improvement that allow a better use of plant and animal resources.

(iv) The greatest challenges currently facing biotechnology and plant breeding are climate change and population growth and both of them require the development of new plant varieties. While traditional improvement goals are still valid, i.e. higher yields, healthier products and resistance to multiple pests, new ones need to be added, such as adaptation to higher CO2 levels or high temperatures. To meet this challenge, advances in the biological sciences have provided us with powerful data collection techniques, high-throughput "omics" technologies supported by bioinformatics approaches of unprecedented capacity, and innovative biotechnology tools, in particular genome editing and synthetic biology. Using these technologies in model and crop plants, and exploiting

the untapped local genetic variability, will allow us to boost Biotechnology and Plant Breeding for the generations to come. The development of these new technologies must focus on obtaining new products to maintain food security and promote sustainable industrial uses of photosynthetic organisms.

(v) Each year, different harmful organisms (pests and pathogens) reduce the potential yield of agricultural crops by about one third and threaten the sustainability of the world's forests. The current scenario of progressive decrease of cultivable surface and increase of temperature and global CO2 of the planet contribute to the emergence and re-emergence of different invasive species of pests and pathogens with negative effects on forests, crops, biodiversity of these ecosystems, and animal and human health. It is essential to generate new knowledge and technologies for a more efficient control and management of strategic diseases and pests that are a threat in key productive sectors into the world economy and in particular the Spanish one.

(vi) On the other hand, animal production, both terrestrial and aquaculture, is key from an economic, social and environmental point of view. Moreover, it supports a powerful agro-food industry. Although its main objective is to produce food for human consumption, the sector faces important challenges: to increase the efficiency of production of food with high nutritional value and safe for human consumption; to ensure animal health and welfare; to reduce the environmental impact of animal production; to improve the quality of animal products and their traceability; to adapt production systems to the available resources and production purposes and to increase their resilience to social, economic and environmental changes on a global scale.

(vii) Population pressure and climate change are forcing food industry to use more sustainable processes to increase productivity and minimise environmental impact. In addition to the sustainability of primary production, there is a need to support these sustainable food systems by assessing the safety and effectiveness of innovation in the food chain. The food industry can find innovative ways to reduce the overexploitation of multiple species by optimising raw materials and promoting the use of waste and by-products. In addition, this industry must also be prepared to provide innovative products in a fast and reliable manner, flexible and even customizable to meet new consumer demands, such as specific health and even lifestyle requirements. This requires multidisciplinary studies on raw materials, waste recovery, efficient green technologies, new products and intelligent biodegradable packaging. Likewise, the globalization of food markets in the 21st century has posed new

food safety challenges. The persistence and emergence of conventional and emerging primary food risks such as viruses, bacteria, parasites, allergens, harmful algae, fungi, toxic contaminants, among others, and the patterns of their corresponding foodborne diseases have become globalised, as in the recent pandemic caused by the severe acute respiratory syndrome coronavirus 2 virus (SARS-CoV-2). Successful initiatives to manage emerging risks must identify, assess and prioritize potential risks, as well as respond with sustainable strategies capable of reducing threats. This requires the development of accurate, sensitive and rapid detection methods for real-time process control. Quality, security and authenticity will depend on powerful process analytical tools, multiple sensors and advanced computing and digitizing systems.

Thus, this theme will work to address the main research issues for the development of environmentally and economically sustainable and socially accepted agricultural ecosystems, from the incorporation of the main technologies and results of basic and applied research in different fields of agricultural sciences, in close interdisciplinary collaboration with other scientific areas that address the study of natural resources and socio-economic processes and factors.

Therefore, this topic, responsible primary production, has been divided into 7 chapters that aim to describe the most relevant challenges in the medium and long term:

- Chapter 1: Agriculture and ecosystem services
- Chapter 2: Agroecology and circular bioeconomy
- Chapter 3: Comprehensive improvement of livestock and aquatic systems
- Chapter 4: Plant health. Resistance to pests and diseases
- Chapter 5: Biotechnology and plant breeding
- Chapter 6: Sustainable production in the food industry
- Chapter 7: Food Safety

Addressing the different challenges proposed will require not only the participation of the different CSIC research groups but also international collaboration and the creation of networks that will make it possible to develop common strategies when addressing these challenges. The CSIC has research groups of recognised international prestige that could lead the different initiatives that may arise from the implementation of these challenges. The incorporation of young postdocs and doctoral students should allow the

renewal of new ideas in a CSIC staff that presents a high level of ageing. Similarly, we must make the CSIC attractive in order to attract researchers from other countries by facilitating the mechanisms of incorporation into our research system.

In this area, it is essential to have the collaboration of the different social and productive actors, farmers, aquaculturists, livestock breeders and the agrofood industry, in participatory processes that lead to consensual decisions that can favour the successful transfer of research results. Although the CSIC has long and extensive experience in collaborating with the Spanish food production sector, it will be necessary to increase interaction at different stages of the research process, in order to implement the scientific results obtained. The approach to the challenges proposed in this manuscript is in line with the European strategies for 2030 "*Biodiversity*" and "*Farm to fork strategy for sustainable food*" as part of the "*Great European Green Agreement*". The new "Climate Change and Food Security" programme is an ambitious response to the challenges of climate change in the food chain by proposing a transformation of primary food production towards more sustainable systems that allow the conservation of biodiversity.

76 researchers from 30 CSIC research centres have participated in the preparation of this book, with the collaboration of three universities and a private institution:

Instituto de Economía, Geografía y Demografía (IEGD)
Instituto de Recursos Naturales y Agrobiología (IRNAS)
Instituto de Agricultura Sostenible (IAS)
Instituto de Ciencias Agrarias (ICA)
Misión Biológica de Galicia (MBG)
Instituto de Ganadería de Montaña (IGM)
Instituto de Lengua, Literatura y Antropología (ILLA)
Centro de Edafología y Biología Aplicada del Segura (CEBAS)
Museo Nacional de Ciencias Naturales (MNCN)
Instituto de Ciencias del Patrimonio (INCIPIT)
Instituto de Historia (IH)
Instituto de Agricultura Sostenible (IAS)
Instituto de Ciencia y Tecnología de Polímeros (ICTP)
Instituto de Biología Molecular y Celular de Plantas (IBMCP)
Estación Experimental de Aula Dei (EEAD)
Instituto de Hortofruticultura Subtropical y Mediterránea (IHSM)
Centro de Investigación Agrogenómica (CRAG)
Estación Experimental del Zaídin (EEZ)
Instituto de Ciencias Marinas de Andalucía (ICMAN)
Instituto de Investigación de Recursos Cinegéticos (IREC)
Instituto de Acuicultura Torre de la Sal (IATS)
Instituto de Ciencias del Mar (ICM)
Instituto de Investigaciones Marinas (IIM)
Centro de Investigaciones Biológicas (CIB)
Instituto de Agroquímica y Tecnología de Alimentos (IATA)
Instituto de Productos Lácteos de Asturias (IPLA)
Instituto de Ciencia y Tecnología de Alimentos y Nutrición (ICTAN)
Instituto de la Grasa (IG)
Instituto de Investigación en Ciencias de la Alimentación (CIAL)
Instituto de Microelectrónica de Barcelona. Centro Nacional de Microelectrónica (IMB-CNM)
Instituto de Química Orgánica General (IQOG)
Universidad Pablo de Olavide (UPO)
Universidad Politécnica de Madrid (UPM)
Universidad de Córdoba (UCO)
Red de Municipios Agroecológicos TERRAE
Estación Biológica de Doñana (EBD)