Horticultural Science Focus

› Future direction and opportunities for horticultural research

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This paper was inspired by an invited plenary lecture at the occasion of the Annual Spring Conference of the Korean Society for Horticultural Science (KSHS), May 22-25, 2019 at Gyeongsangbuk-do. The original contribution was supplemented to provide a comprehensive overview to include current challenges of horticulture as well as perspectives of horticultural research and role of the ISHS. The content reflects the personal view of the authors.

Abstract

Horticulture is the art and science of the culture of plants such as fruits, nuts, berries, vegetables, ornamentals and medicinal and aromatic plants for food, beauty, utility, comfort, health and therapy. The history of horticulture dates back more than 10,000 years. The contribution of horticultural production and the related value chain to economy is considerable and growing. Horticultural export values are increasing. Horticulture is critical to the health and quality of human life and society at large. It has gained particular recognition in recent years due to the positive effects of its commodities on balanced nutrition and human well-being. Horticultural production combats hidden hunger. Marketable fruits and vegetables contribute decisively to a healthy life and high quality living standard. Their sustainable production and successful marketing require highly specialised technologies managed by competent value chain actors. In the past, applied research often concentrated on individually defined problems, usually without taking a system view into account, and thus made possible problem solutions that led to impressive gains in plant production. But now holistic solutions are required, because in the globalized world the decisive importance of the complex relations of individual problems with their context has become increasingly evident and tangible. Solutions must be developed while involving stakeholders and keeping the entire value chain context in mind. Thematically, major goals must continue to address sustainability, and the resilience and agility of production systems while drastically increasing the efficient use and re-use of the ever more limited resource base. To reach these ambitious goals, transdisciplinary problem solving in multi-actor settings is needed, which requires appropriate practicable methodologies. These methods must be developed to enable researchers and directors to cope with the requirements of the systems-based approach. Our Society is a global network that promotes and encourages research and education for all branches of horticultural science. We facilitate cooperation and knowledge exchange. We advocate for the changes needed to achieve the sustainable development goals of the United Nations (SDG). The ISHS makes a positive contribution to the SDG.

Introduction

The word "horticulture" is the combination of two Latin words, *hortus* (garden) and *cultura* (culture). Horticulture is the art and science of the culture of plants such as fruits, nuts, berries, vegetables, ornamentals and medicinal and aromatic plants for food, beauty, utility, comfort, health and therapy.

The history of horticulture and that of agriculture have been closely linked for the past 10,000 years. Humans began as hunter-gatherers, scavenging, collecting, and hunting wild animals before initiating a revolution by shifting to agriculture (Janick, 2007). The emergence of agriculture occurred in seven to nine major centers, mainly in the river valleys of the Tigris-Euphrates, Indus and Nile, and in China, Mesoamerica, and East and West Africa. The domestication of our major food crops (such as turnip, onion, carrot, lettuce, apple, pear, quince, banana, peach, citrus, and almonds from Asia; cabbage, cauliflower, and broccoli from the Mediterranean; corn, beans, tomato, cacao, squash, sweet potato, avocado, and potatoes from Mesoamerica) goes back to 3000 BCE (Von Baeyer, 2014). Grapevine is the first plant manipulated in 6000 to 4000 BCE. The writings of a tablet dating from the 7th century BCE in Babylon (Sumerian civilization) listed the vegetables and herbs of the gardens of Babylonian. Egyptians used technologies such as irrigation that were most probably invented by Sumerians, incorporating with a network of canals, dikes, sluices, and basins. A wide range of food (garlic, onion, radish, lettuce, parsley, beans and lentils, melons and gourds, dates, figs, grapes, and later pomegranate, olive, apple, peach and pear), herbs, spices and medicinal plants were cultivated by Egytians. Also centers of horticultural development were found in South America (Aztec, Maya, and Inca) between 8000 and 2000 BCE, and in China and Japan at least until the 10th century. Greek civilization by 1600 BCE influenced the Romans (7th century BCE to 5th century CE) who inherited the knowledge of grafting, budding, and rotation with legumes (Von Baeyer, 2014).

Agriculture and horticulture continued to evolve jointly until the Middle Ages when horticulture became formally recognized as a discipline distinct from agriculture (Von Baeyer, 2014).

Recent production history of horticulture

Horticulture contributes to the health and quality of life. In particular, horticulture has gained more importance in recent years due to the recognition of health-related effects of horticultural products in our diet, and their importance for a healthy human nutrition and well-being. In addition, horticultural production is beneficial in combating hidden hunger (Grubben et al., 2014).

Horticultural crops require high professional skills and intensive care, and are considered high value crops. They deliver higher financial returns per production unit as compared to agricultural crops. Horticultural production has become particularly important for income generation and food production in developing and emerging economies. Horticultural crops are instrumental for development not only because of their high economic and nutritive value, but also, because they are important for small landholders in terms of their contribution to agricultural and economic diversification (USAID, 2005).

In the 1950s, comparatively more resources were assigned to the improvement of staple grains than to improving horticultural crops. Between 1960 and 2000, the land resources needed for horticultural crop production more than doubled worldwide (Weinberger and Lumpkin, 2005) and continue to increase. The contribution of the horticultural sector to economies being an important source of employment and provider of industrial raw materials is significant (Singh et al., 2015). Among fruits, nuts, berries, vegetables, ornamentals and medicinal and aromatic plants and other food crop sectors, the fruit and vegetable sector compares favourably for employment and income generation (Joosten et al., 2015). Therefore, fruits and vegetables are of priority importance on future directions and opportunities.

Global production trends of fruits and vegetables exhibit an increase, with Asia providing the highest proportion among all continents (Figure 1). Also with regard to per capita supply of vegetables, Asia takes the lead, while with fruits, America, Africa and Europe delivered more per capita (Figure 2).

Challenges and opportunities

Around 10.6% of world population is undernourished (FAO, IFAD, UNICEF, World Food Program, WHO, 2019). The majority (more than 256 million people) live in Africa.

The world population is projected to reach 9 billion by 2050, which will mean an increased food requirement of at least 70% (Marondedze et al., 2018). For 2100, the global population is projected to reach even more than 11.2 billion, increasing food demand enormously.

Horticulture plays an important, multifaceted role in this context in industrialized as well as in developing countries. Horticulture may offer the best alternatives for increased food self-sufficiency, improved nutrition and ensuring the generation of increased incomes and employment (Irungu, 2011). Also, horticulture forms an integral part of food, nutritional security and poverty alleviation, and is an essential ingredient of economic security (Singh et al., 2015).

Horticulture is globally undergoing significant changes impacting production technology and priorities for research and development (Warrington, 2011). Selected aspects related with the important drivers of this change or with the need to respond to challenges for assuring a sustainable progress are addressed in the following sections.

Globalization and trade

The globalization of societies and markets is represented by intensified trade. Export values of fruits and vegetables increase globally (Figure 3) and horticultural products increase their share of the total agricultural product export value (see Figure 4 adressing selected countries in each continent).

Fresh fruit and vegetable marketing have undergone significant changes due to globalization and an increasing demand for safe and high quality products (Nicola and Fontana, 2010). Food supply chain demands change consequently in response to changing consumer preferences, a need for product diversity, progress in technologies from farm to fork, easy accessability of markets and increased levels of international investment, resulting in globally changing wholesale and retail markets in delivering horticultural crop products to consumers year-round (Wu Huang, 2004). The global fruit and vegetable consumer expenditure dynamics changed by geography and will further change with a significantly increasing global share of Asia and Oceania in the future (Figure 5). Super- and hypermarkets began playing an important role in the marketing of horticultural products and have replaced small markets and/or fruit-veg sellers. International retailers have become known globally for their brand names buying power (Warrington, 2011). The marketing channel dynamics will further change, however, after the rising importance of hyper- and supermarkets in the recent past towards increasing shares of out-of-home and convenience channels in the future (Figure 6).

The concentration of the food supply power may continue at the same pace and drivers such as digitalization or changing consumer demands will further intensify or even reverse this concentration of buying and marketing power and provide new significant opportunities for local delivery and supply settings.

Horticulture has a particular role in the globalization context, due to its particularities

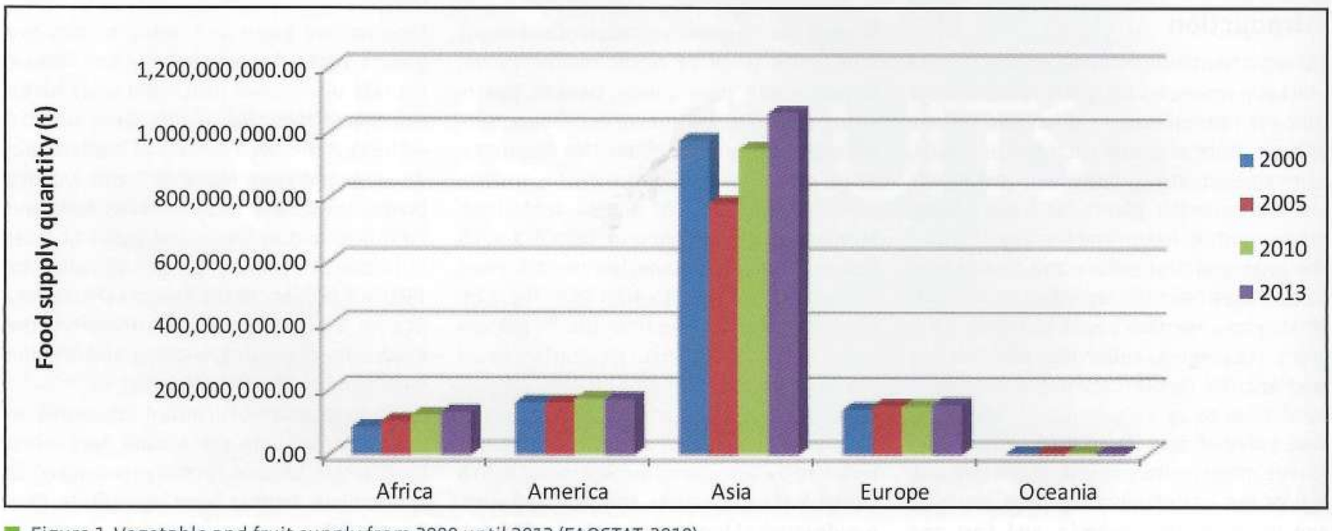

Figure 1. Vegetable and fruit supply from 2000 until 2013 (FAOSTAT, 2019).

in the societal global and local settings. Horticulture and its products play in these settings often a significant role in rural development, innovating production systems and contributing to a healthy, safe nutrition while also representing cultural values and identification.

Food demand and food waste

Coping with increasing food demand

The increased food demand (see above) refers not only to an increasing global population but also to a changing diet. The global diet has changed due to demand differences as a result of shifting demographics (Warrington, 2011; De Clercq et al., 2018).

Horticulture must play a significant role in responding to these demands. For instance, fruit intake (Figure 7) does not meet the World Health Organization (WHO) standards. This may relate to consumer trends that horticulture cannot influence. However, value chain actors have an opportunity to anticipate and/or respond to such trends with appropriate technology and communication to meet dietary targets and also capitalize on this challenge for their own benefit.

Avoiding food waste

Food waste is a global phenomenon. About one third of the food produced in the world for human consumption every year (approx. 1.3 billion t) gets lost or wasted. Almost half of the fruit and vegetable production is wasted. This would be enough to feed 2 billion people. In industrialized countries, losses and waste value around $680 billion per year, while in developing countries, around $310 billion. With 45% of waste and loss, fruits and vegetables along with roots and tubers exhibit the highest amount of waste among any food products. In some continents, the horticultural production process accounts for the highest contribution to waste, while in others it is processing (FAO, 2019a).

Food loss and waste can be utilized or avoided. This is a multifaceted challenge and must be fastidiously addressed for each setting. For instance, while some processes for waste utilization are used in developed countries, they may not be adopted easily in others due to economics. Cost effective technologies must be developed to convert waste into value added products (Garg, 2014). Waste contains good sources of potentially valuable bioactive compounds that could be used in different industries (Sagar et al., 2018). Also, practicable methods and made improvements in value chain management are needed to avoid waste.

Demand vs. waste

Meeting the increasing food demand and dietary change could be satisfied at least partially by avoiding and utilizing food waste.

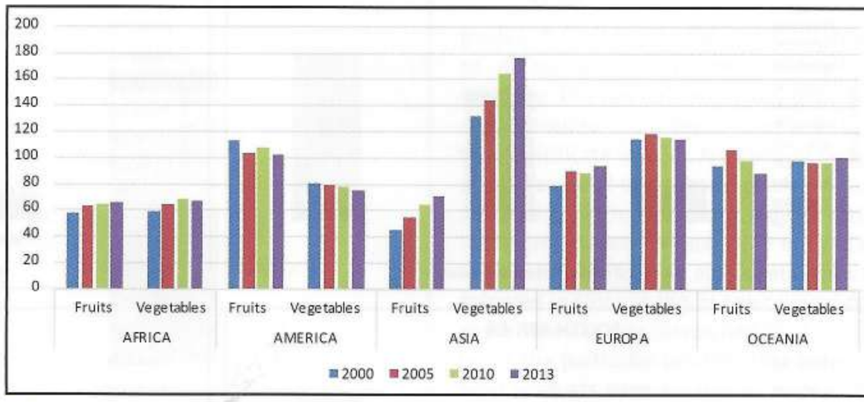

Figure 2. Vegetable and fruit supply per capita (kg capita^{-1} year^{-1}) from 2000 until 2013 (FAOSTAT, 2019).

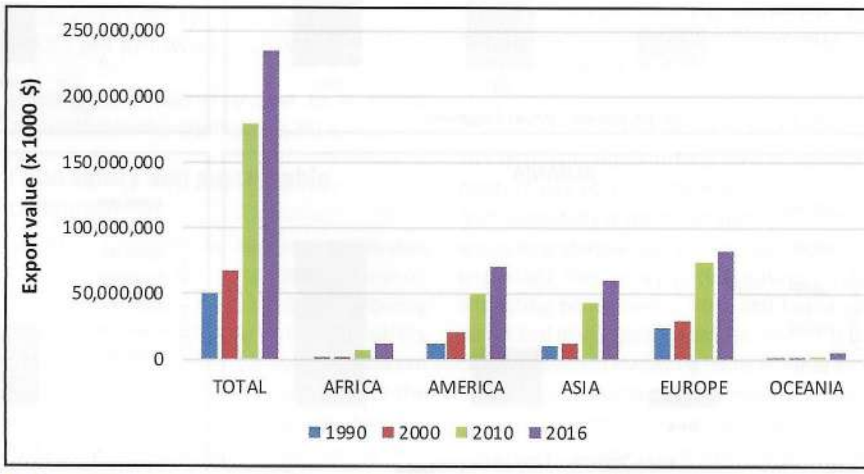

Figure 3. Export value of fruits and vegetables in the world and different regions from 1990 until 2016 (FAOSTAT, 2019).

Also, by finding ways of avoiding food loss and waste, the pressure on horticulture to produce more as well as more efficiently could be alleviated. But realities are more complex. Loss and waste avoidance and reutilization are particularly challenging for fresh horticultural products in view of their particular role for health and well-being and the fact that waste and loss are a consequence of combined circumstances of the value chain. Therefore, a systems approach is needed to identify the key drivers of demand and waste in a particular value chain and to conceptualize and test solutions. Context specific targets must be defined and appropiate procedures and technologies be developed for addressing food demand, the production and market response, and food waste in a concerted way. The different drivers and effects at the value chain level as well as at the macro economical level must be balanced. Sustainable horticultural food systems would be the result.

Need for a more efficient use of natural resources

Global material use will double to 190 billion t (from 92 billion) by 2060, with an increase of 110%. This will result in a reduction in forests and habitats of over 10 and 20%, respectively, and an increase in greenhouse gas emmissions of 43%. Rapid growth in extraction of materials is the main reason of climate change and biodiversity loss (Global Resources Outlook, 2019), deteriorating the resilience and long term productivity of agro- and horti-ecosystems.

As a consequence of this resource efficiency challenge, presently used horticultural land resources are globally under pressure. The availability of non-renewable resources used in horticulture, such as water, energy, mineral nitrogen, phosporous, potassium, and other elements, is already becoming scarce while some of these can only be made available again with highly energy intensive industrial processes (e.g., nitrogen: Haber-Bosch Process).

Horticulture represents particularly intensive use of resources such as labor, water, energy and inputs namely fertilizers and pesticides, due to comparatively high production and process intensity. Land resources may be less pressured in horticulture as compared to agriculture due to a particularly high added value per acreage, but this cannot be generalized around the globe. As a result of the high production intensity, exces-

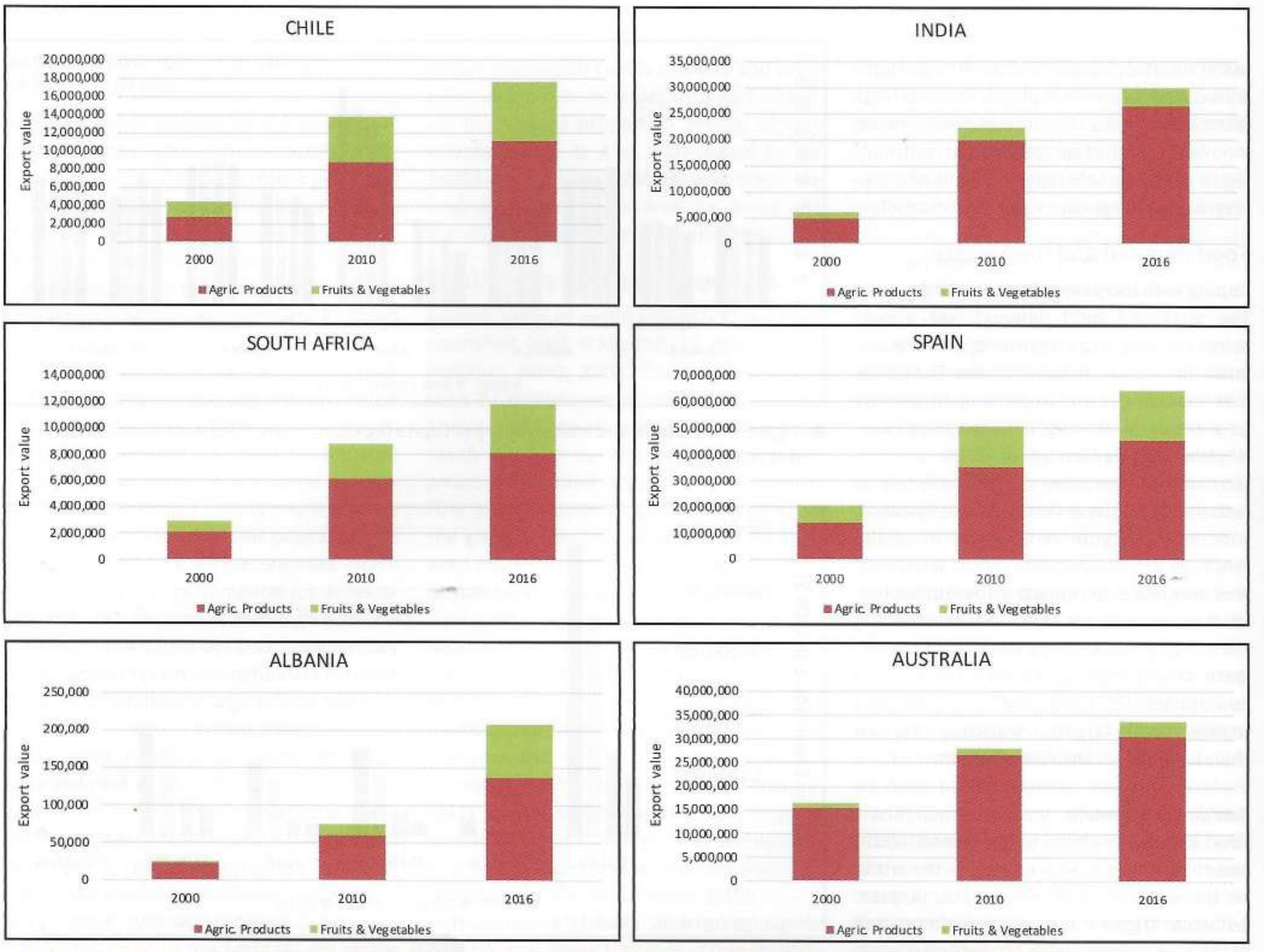

Figure 4. Share of export value of fruits and vegetables in agricultural products in different countries (×1000 $) (FAOSTAT, 2019).

sive use of input resources may have a negative impact on the environment (Wainwright et al., 2014). Societies are increasingly sensitive to pesticide residue and resource inputs into the food system. These old production methods threaten the longterm image and productivity of the horticultural value chain. The increasing food demand and resource efficiency challenges translate into an explicit need of "more" (output) with "less" (input). Horticulture is in the spotlight when strategies and programmes are developed to reduce the dependence on non-renewable resources and negative impact on soils, water, air, organisms, and genomes. Innovative science-based solutions are needed.

Drastical reduction of the dependence on agrochemicals

Pesticides protect crops and their products from insects, mites and nematodes (pests), fungi, bacteria, viruses and viroids, micoplasms (plant pathogens) and weeds. The global cost/benefit of pesticide use (the amount of pesticide use in agriculture and horticulture to produce a certain amount of crop in a year, including insecticides, fungicides, bactericides and herbicides) increased by 22% from 1990 to 2007, and declined since 2007. Pesticide use per ha (total of all categories) developed alike (Zhang, 2018). However, an increased rate of 9% total pesticide use was still noted between 2007 and 2017 (FAO, 2019b). The global pesticide market is expected to further grow from $75 billion in 2017, to $90 billion by 2023 (Mathews, 2018). Pesticide use is distributed unevenly across the globe due to the material and labor cost and availability and due to pest/disease problems for specific climatic/geographic regions (Carvalho, 2017).

Horticulture delivers many fresh, untransformed products to the food market. Their internal and external quality are at risk in function of the prevalent environmental condition and pressure from pests. Protected measures are needed to prevent rapid deterioration of fresh produce. Pesticides offer attractive opportunities. Although specific data is not available for global pesticide use in horticulture, studies on screening fresh fruit and vegetables for residues point to intensive pesticide use (Zorka and Serdar, 2009; Bakırcı et al., 2014). Besides the positive control measures, pesticides negatively affect human health, drinking water, the ecosystem, and biodiversity. Many reports indicate that occupational exposure to pesticides has negative effects on human health (Tsimbiri et al., 2015). Modern horticulture has been proactive in reducing the risk due to marketable product quality. Public concern regarding pesticide use has risen sharply in recent years. A fundamental change of plant protection strategies and production systems are needed but they may go at the cost of profitability while a practicable path for transformation is less than clear. An increasing number of studies claim, however, that change is possible. For instance, data from 946 non-organic arable farms indicated that pesticide use could be reduced by 42% without any impact on productivity and profitability (Lechenet et al., 2017).

Mineral fertilizer is widely used for plant nutrition. Fertilizer use increased by 25% between 2008 and 2018, up to more than 200.5 million t. Nitrogen, phosphate and potash use increased by 1.4, 2.2 and 2.6%, respectively, in 2018 (FAO, 2019c). Fruits and vegetables account for around 16% of world N+P+K consumption (Figure 8). With regard to N, P_2O_5 and K_2O, fruits and vegetables account for 13.5, 18.7 and 19.1% of the global consumption of these nutrients (IFA, 2017). Excessive use of fertilizers (over fertilization) causes serious environmental degradation

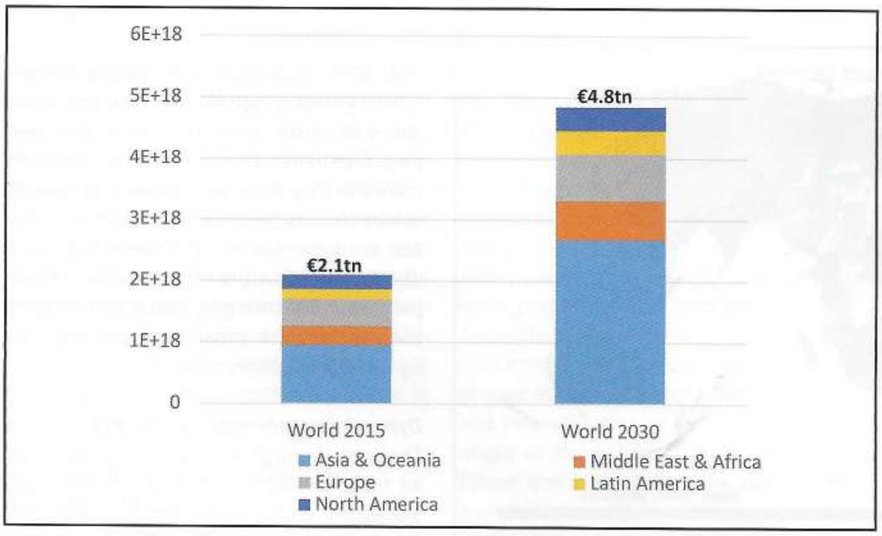

Figure 5. Modeling of fruit and vegetable marketing geography dynamics based on compound annual growth rate (CAGR) between 2015 and 2030 (Wyman, 2018).

and in particular, excessive N application increases the soil nitrate level excessively resulting in groundwater and environment pollution (Rahman and Zhang, 2018).

Consequently, the use of biopesticides and biofertilizers started to increase in the last decade, gradually replacing mineral fertilizers and synthetic pesticides. These are nature identical materials derived from animals, plants, and living micro-organisms. Currently, biopesticides have still a small share of the pesticide market globally amounting $3 billion but accounting for just 5% of the total crop protection market. An annual 10% increase has been estimated for the coming years (Damalas and Koutroubas, 2018). The global biofertilizer market was worth more than $1.5 billion in 2018, growing at a compound annual growth rate (CAGR) of around 10.1% during 2015-2025 (Mordor Intelligence, 2019).

Food safety and sustainable consumption

Scandals triggered by food contaminated with detrimental microorganisms – some on horticultural crops – have led to a growing public concern with regard to food safety (Erickson, 2010; Hussain, 2016). This concern relates to risks for human health and for the environment and it promoted the development of a set of standards to improve production methods, to provide traceability, to control hazards resulting in certificated products and farms (GlobalGAP, ISO22000) and to improve supply chain transparency. Such programs are to ensure that the products are produced according to the standards needed. According to the figures of GlobalGAP, Germany, The Netherlands, Spain and Italy are the leading countries for fruit and vegetable certificate holders. Also, 68% of flower and ornamental certification resides in Germany, The Netherlands, and Italy. In 2018, the largest growth for GlobalGAP Integrated Farm Assurance for fruit and vegetables was recorded in Africa as 68% in non-covered and 46.5% covered crops (GlobalGAP, 2019).

Given the particular position that horticultural products have for human health and nutrition, and given the growing damage potential unsafe food may have in an urbanized mobile and open society, affordable, practical procedures and methods that ensure the safety of horticultural products must be given top priority.

Soil fertility and biodiversity loss

Soil fertility is fundamental for a sustainable productivity of agriculture and horticulture. Soil is not only a source of nutrients and an anchoring matrix for plants, but plays an important role in regulating natural cycles impacting on nutrients, flora and fauna and water and in mitigating climate change. It is a complex system including living components that are destabilized and impoverished easily by unqualified crop management. Intensive industrialized horticulture must not be hazardous for soil fertility jeopardizing sustainable production. Appropriate innovative soil management concepts including crop rotations and care for soil organic matter are needed in intensive horticulture (ecological

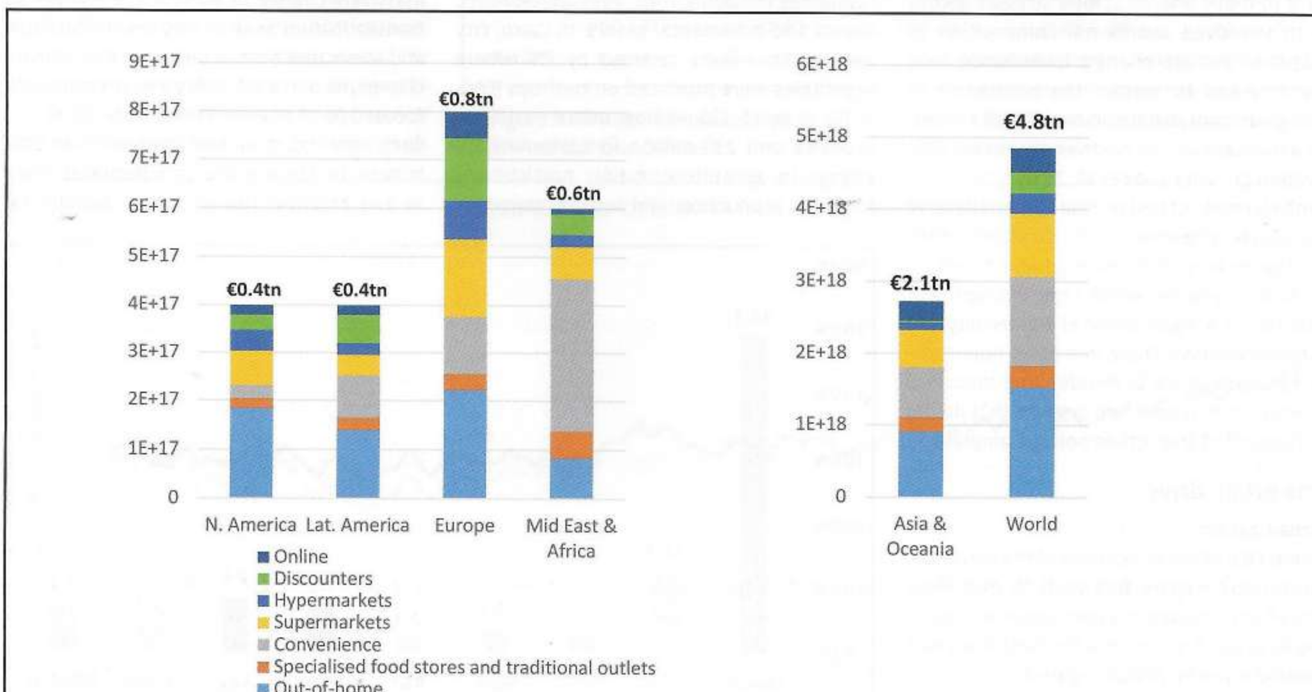

Figure 6. Modeling of fruit and vegetable consumer expenditures (trillion Euro) by geography and channel based on compound annual growth rate (CAGR) between 2015 and 2030 (Wyman, 2018).

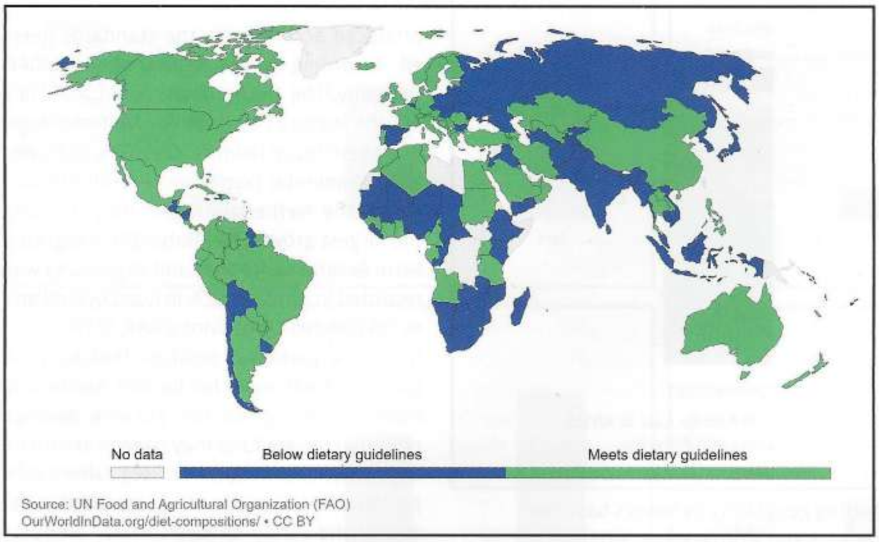

Figure 7. Average per capita fruit intake vs. minimum recommended guidelines, 2013 (blue: intake <200 g; green: intake >200 g; recommended per day intake reference of 200 g according to World Health Organization (WHO); average per capita fruit supply without correction for waste at the household level) (Ritchie and Roser, 2019).

intensification) to prevent soil fertility loss and jeopardising the multifuncional DNA of soil that qualifies for sustainable production. Production systems characterized by a high biodiversity are more resilient, have a better buffering capacity with regard to climate change incidents and may reduce pest and disease pressure due to an antagonistic microbiome and beneficial insects. For instance, apple production systems enriched with cover crops in the alleyways showed a positive effect on beneficial species and soil fertility (Webber, 2017). Furthermore, genetic diversity is an essential source for developing resilient varieties tolerant and/or resistant to biotic and/or abiotic stresses and/or with improved nutritional composition to adapt to climate change, to enhance food security and to sustain the production in marginal lands (Lutaladio et al., 2010). However, a dramatic loss of biodiversity has become evident globally (Díaz et al., 2019).

Both elements of sustainable systems deserve particular attention in horticulture, since horticulture tends to be produced based on intensive systems, while crop management intensity is a major driver of soil fertility and biodiversity loss. There is a great opportunity for horticulture to develop and introduce innovation in production systems that do not endanger but strengthen both parameters.

The urban drive

Urbanization

About 68% of the population of the world will shift from rural to urban areas by 2050. More than half of the world's population will be living in urban areas within the next few years (United Nations, 2019a) (Figure 9).

Urbanization may have several positive effects such as increased employment, modernization, easy accesibility. Some of these effects may turn bad (e.g., loss of employment and increasing poverty). Urbanization is detrimental to the environment, resulting in an increased energy consumption and over population, which calls for the question how urbanization can be made more sustainable.

Greener cities

Opportunities arise in this context for horticulture. Horticulture can help to grow greener, more sustainable cities in the industrialized and developing world. Urban and peri-urban horticulture represent cultivating many crops within cities and in their surroundings including fruit, vegetables, roots, tubers and ornamental plants. In Cairo, city temperatures were reduced by 7°C where vegetables were produced on rooftops (FAO, 2010). Around 130 million urban residents in Africa and 230 million in Latin America engage in agriculture, mainly horticulture, for food production and income purposes (FAO, 2015). In addition, horticulture is essential in greening business places and living zones in urban areas, contributing to people's well-being. Furthermore, local governments in Italy provide allotment gardens to senior citizens because of the socio-cultural and economic functions of gardening (Tei et al., 2010). Horticulture may also educate people through learning by doing and bridging the gap between urban business and rural agrifood production.

Dynamic convenience food market

The progressing global urbanization and related transformation from rural to urban and globalized societies changes food demands for quantity and quality. Modern societies request new types of food. Meat consumption has been increasing with urbanization. Industrialized societies consider it as an indicator of wealth and modern living standards. The modernization of big countries like China and India boosts total meat demand. Unfortunately, industrialized meat production is 3-4 times less resource efficient than plant protein production and contributes up to 40% of the climate change relevant greenhouse gases and carbon dioxide. Food system scenario studies, including dietary changes towards a more plant-based diet and other assumptions, show that the future world population can be fed while respecting the demands of sustainability (Muller et al., 2017; Poore and Nemecek, 2018; Springmann et al., 2018). However, it is hard to predict which societal values and perceptions related with meat production and consumption will globally and massively change to achieve the envisioned transformation even if this seems desirable and inevitable from a public health, climate change, resource efficiency and sustainability focused point of view (Willett et al., 2019).

Such conflicts stimulate innovation to contribute to closing the gap between theory and practice. The increased demand for

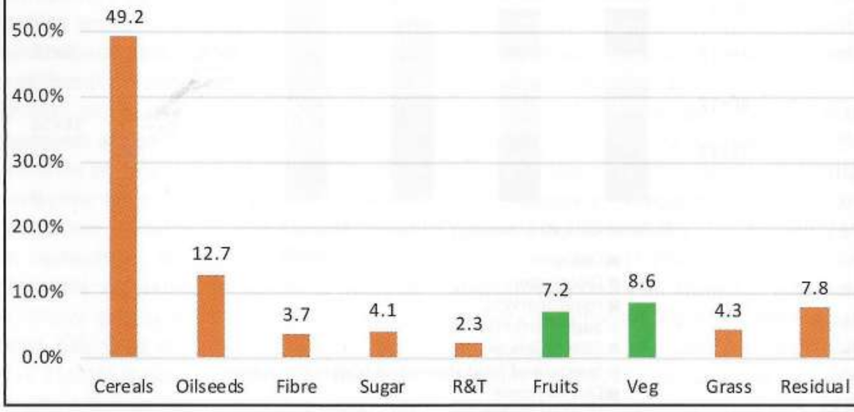

Figure 8. Estimates of N+P+K used by different crop categories in selected countries (%) (2014-2014/15 Campaign) (IFA, 2017).

convenience product innovation to respond to changing urban life styles and consumer behaviours should enroll in this effort (e.g., rising demand for vegetarian dishes for fair trade and regional products). Horticulture can take a lead in this development because its products such as fruits, vegetables, aromatic plants relate ideally to a healthy nutrition, tastiness and convenience. Contributing to a healthy nutrition and taking a leadership role in developing and delivering more sustainable production technologies are in the DNA of horticulture.

The challenge of progressive climate change

Climate change is not new. However, the on-going change is globally challenging humanity with dramatic changes for food production. This is of particular concern for food demand and resource perspectives. Global air temperature is clearly and steadily increasing (Figure 10). Also CO_2 and other greenhouse gases (methane, nitrous oxide, chlorofluorocarbons) are rising. Changes in precipitation (intense floods or severe droughts varying from one region to another) and less fresh water availability are disconcerting for sustainable development (Rather et al., 2015). High temperatures increase evaporation and extend the duration of heat waves, impacting on plant growth, flowering and harvest (Dixon et al., 2014). Climate change also increases the spread and establishment of invasive species (IUCN, 2019).

As with many other sectors of the global economies, horticulture is challenged. Crop productivity is reduced in some parts of the world, while in others, new horticultural production opportunities are opening. For instance, apple productivity has declined in lower elevations in India due to the lack of chilling requirement during winter (Singh, 2010). Jangra and Sharma (2013) reported that the increase in average temperature, long drought period in summer and less snow in winter time resulted in shifting to the cultivation of vegetables such as tomato and peas instead of apples in lower areas of Kullu and Mandi Districts (India) while apple production has moved to the higher altitudes with a yield increase of more than 50%.

Many studies have demonstrated the significant antropogeneous contribution to climate change in the last decades. Industrialization and intensification of agriculture are at the origin of the actual change. Consequently, future horticulture must be able to reduce and mitigate negative effects of intensive horticulture on climate change as well as to adapt to the climate change challenge.

Horticulture will contribute to the mitigation of and adaptation to climate change effects (e.g., by new, resistant varieties, an efficient water and nutrient management, plant architecture). For instance, grape, a temperate fruit, can be grown successfully in tropical regions if changes in plant architecture and production system management are made (Malhotra, 2017). But climate change affects product quality. Productivity perspectives of horticultural crops must be more systematically examined to develop appropriate mitigation and adaptation response. The quality and productivity potential of a crop might be limited by climate change effects or expanded, offering new opportunities. Innovative and effective problem solutions may then be developed in a directed approach.

The opportunities of digitalization

Horticulture 4.0 is seen as revolutionizing production technology involving the use of sensors, robots, machines, and information technology for fostering a sustainable supply chain (De Clercq et al., 2018).

Today the use of smart technologies can be a decisive element in enhancing horticultural crop productivity. For instance an irrigation set allowed for a dramatic yield increase from 50 to 300% by providing micro-irrigation

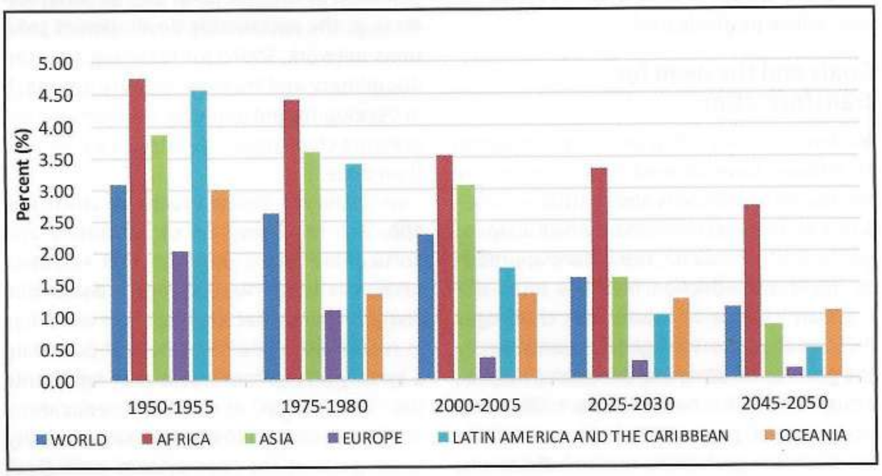

Figure 9. Average annual change rate of population living in urban areas by continent (United Nations, 2019a).

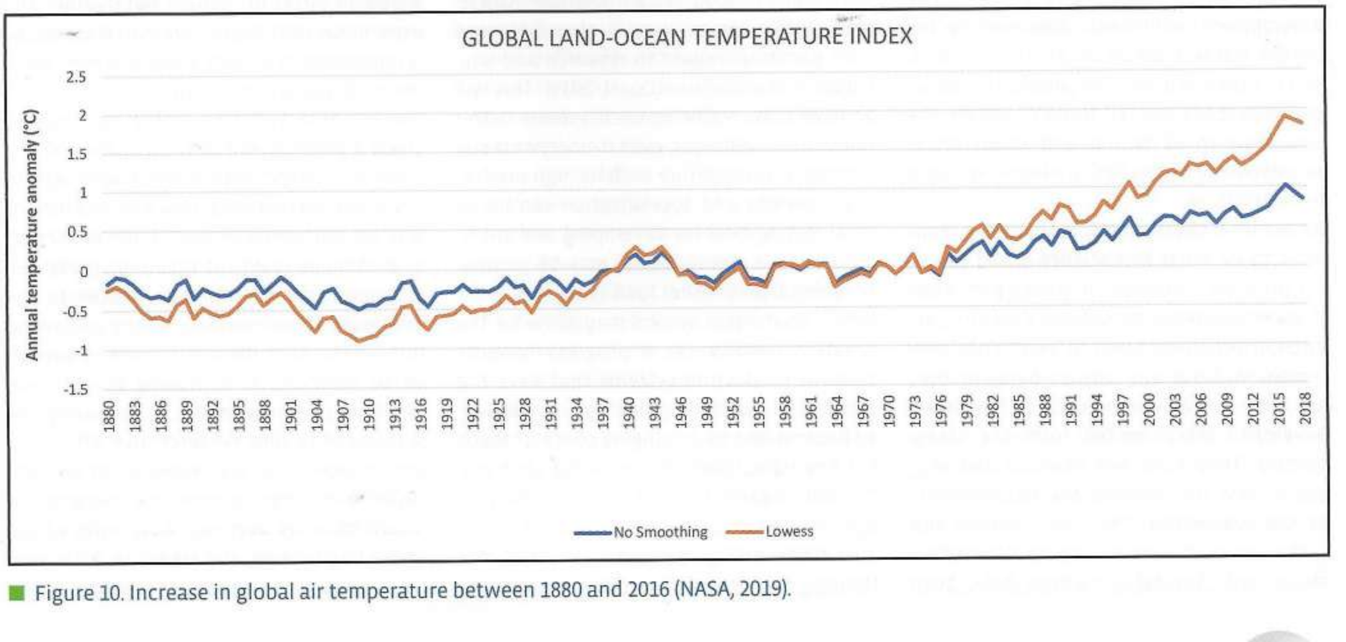

Figure 10. Increase in global air temperature between 1880 and 2016 (NASA, 2019).

systems for local farmers. Different e-learning modules, web applications, mobile apps, and other tools encourage the introduction of smart horticulture (Roy et al., 2019).

Digitalization will increasingly play an important role in advancing the sustainability of horticultural production and processes. Precision horticulture, automation and robotics for different sections of the crop production chain have been developed for assessing seed germination (Ligterink and Hilhorst, 2017), transplant production (Sakaue, 1992), packing (Luna-Maldanado et al., 2012) and/or the sensor use for different purposes (i.e., climate sensors, soil moisture sensors, nutrition) (Sharma and Ashoka, 2015) and/or computer integrated systems in greenhouses and plant factories (Hashimoto, 1991). Machine learning and artificial intelligence will continue to create new opportunites for a more competitive, sustainable and resilient horticulture. This technology should be advantageous in solving some of the challenges mentioned above (e.g., mitigating climate change by reducing greenhouse gases, and reduce pesticide use).

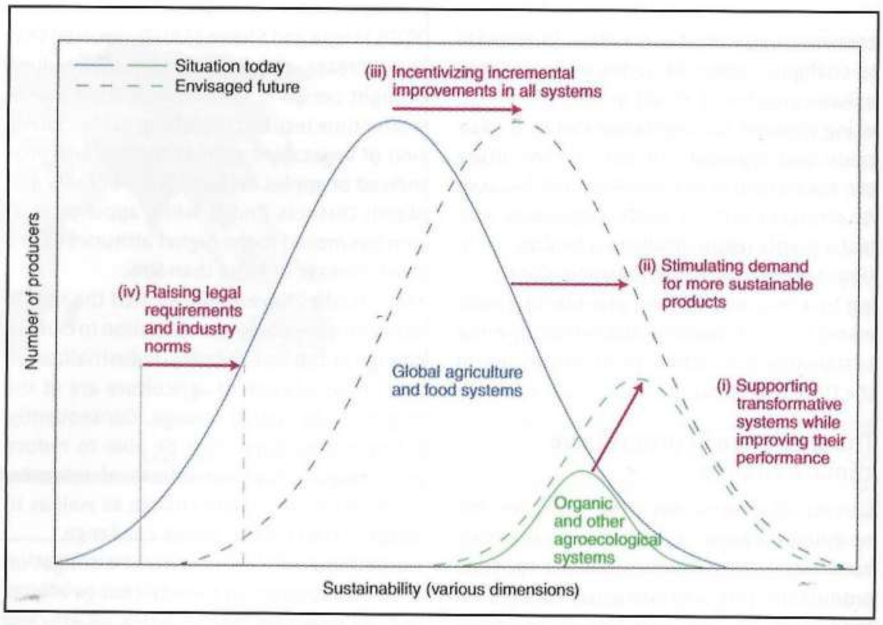

Figure 11. Policy interventions (red arrows) to drive sustainability in agriculture and food systems (Eyhorn et al., 2019).

Goals and the need for transformation

Modern plant breeding and new cultivation techniques have allowed for an impressive increase in productivity and contributed decisively to food security and market adapted food quality. However, our future approach to improve production methods must disruptively change to master the challenges mentioned above. To align forces and specify the goals to be achieved, the United Nations designed on the basis of the millennium development goals (MDGs) the sustainable development goals (SDG; see United Nations, 2019b), which came into force on 1 January 2016 for a period of 15 years. The 17 SDG are the heart of agenda 2030 for a sustainable development, which was approved by the United Nations on 25-27 September 2015, and is a plan of action for people, the planet and prosperity (United Nations, 2019c). The SDG apply to all nations and all sectors of society. Many of the SDG are highly relevant to horticulture.

To achieve these goals, knowledge gaps need to be filled and science-based practical problem solutions be developed. Even if many solutions for solving pressing production problems seem to exist, they may remain without any impact because they are not applicable in practice or have been developed disconnected from the stakeholders. They were not consolidated (e.g., economics) for meeting the requirements of the real world. They are possibly not sustained by the necessary transformative movement. Several initiatives have been launched at international and national levels (e.g., the sustainable development solutions network, SDSN) for fostering an interdisciplinary and transdisciplinary approach in developing and applying solutions for the pressing challenges. The latter is easier said than done.

How can we foster such an inclusive approach for a progress of agriculture and horticulture into a direction that responds to this challenge? 'Agroecology' is a scientific discipline since decades, but the word has in recent years been "re-labelled" becoming a synonym for a movement that represents the "integration of research, education, action and change that brings sustainability to all parts of the food system: ecological, economic, and social. It's transdisciplinary in that it values all forms of knowledge and experience in food system change." (Gliessman, 2018). Agroecology is also discussed with particular regard to research and education in horticulture (Dussi, 2019). This will achieve sustainable agroecosystems better than former concepts, even if evidence is still formative. Horticulture with its high production intensity and specialization can be an ideal testing field for developing and applying inclusive methods that may be groundbreaking also for other food systems.

Which production system may allow for the progress needed, i.e., a progress towards resilient production systems that have the capacity of responding flexibly to unexpected hazards and to a changing context? Much has been discussed whether integrated production, organic farming or any other production system type may provide the suitable frame and guidance for orienting our thinking and action toward the overarching goals. However, the discussion was exclusive while inclusion is needed. The policy intervention concept recently published (Eyhorn et al., 2019) could help to provide the necessary guidance in driving sustainability into the needed direction (Figure 11).

The role of horticultural research

Over the past 150 years science has been a driver of progress of modern societies, and in particular of agriculture and horticulture. Science-based research became an impactful tool to gain scientific understanding of problem contexts and for subsequent problem solving (Bertschinger and Weber, 2019). Such understanding is achieved by testing hypotheses and predictions, which are confirmed or rejected after thorough experimentation (scientific research) and empirical research based on direct or indirect observation and experience. Both types of research are equally important for solving a problem and create impact (DeJong et al., 2019).

The common approach in the past was to study a problem in a defined space and disciplinary context with science-based generally accepted methods. This was an efficient way for addressing distinct issues being part of a complex reality. It required specialized discipline specific expertise related to the addressed topic. Now, our needs go beyond this. In the next decade, science is expected to facilitate: 1) improving the efficiency of production systems, 2) increasing the sustainability and resource use efficiency, and 3) increasing the resilience of cultural systems in order to cover the demands of future societies (National Academies of Sciences, Engineering, and Medicine, 2019). Horticulture with its particular position in the global and regional economies is confronted with complex challenges that can hardly be solved by using a conventional approach in addressing and solving isolated problems in a rational systematic process. We will need breakthroughs in research and development making use of an inter- and transdisciplinary approach for dynamically creating, delivering and applying the sustainable techiques and methods needed. Also, the relatively new discipline of citizen science could be a helpfull research approach particularly for horticultural contexts, representing consumer-related values like health, nutrition and well-being. This could predestine horticulture to play a leading role for other cropping systems in developing problem solutions responding to pressing societal demands and challenges.

Scientfic and empirical research (DeJong et al., 2019) must be the driver of a better understanding of horticultural realities and identify problem solutions and their feasible and affordable adaptation to specific contexts around the globe, and in driving sustainability in the direction needed (Figure 11).

The role of ISHS

Our Society, the ISHS, as a global, large network of scientists, scientific institutions and institutions related to horticulture, effectively facilitates cooperation and knowledge transfer in all branches of horticultural science. Meetings (i.e., symposia, workshops, and congresses), scientific networks, publications and other communication tools provide an ample platform to identify the needs of stakeholders (growers, industry, consumers) and share, exchange and transfer knowledge on horticulture and related problem solutions. ISHS organizes worldwide research and training capacities to strengthen their competences and foster an innovative, science-based spirit.

For this purpose, the ISHS must continue to take an active role in:

- increasing networking opportunities and connecting people,
- improving communication with members,
- developing efficient strategies to network with industry,
- continuing to link with international organizations, national societies, and societies in horticulture related fields,
- encouraging higher participation and submissions to our meetings and publications,
- strengthening the regional relations,
- promoting and celebrating scientific discoveries and empirical advances made,
- in order to promote the further development and use of emerging technologies and systems and progress of horticulture.

The ISHS shall actively draw on the competences of its members and Divisions/Commissions, and both types of research, scientific and empirical (DeJong et al., 2019), equally required for facilitating the making of the needed breakthroughs. The ISHS must align with other societies and bodies in this effort and take an active role in addressing the UN Sustainable Development Goals (SDG) and communicating them to its stakeholders. It should outreach and make clear what horticultural research and horticulture achieve now and in the future and how ISHS supports its members in going along those lines.

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