› Drone monitoring crop growth and health in vineyard. Source: Biological Systems Engineering, Washington State University.

› ISHS Division Precision Horticulture and Engineering: sustaining the future with precision horticulture and engineering

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According to the Food and Agriculture Organization (FAO) of the United Nations, the world's population is expected to grow to almost 10 billion by 2050. This means that food demand will increase by approximately 70%. In addition, the need for ornamental plants will increase given the high demand of people for nature and the necessity of cities to implement nature-based solutions, not only to improve the well-being in urbanized areas, but also to find a way to mitigate the effect of global warming. Furthermore, in the era of climate change, agriculture is currently responsible for 20% of greenhouse gas emissions (including methane and nitrous oxide) due mainly to the use of synthetic nitrogen-based fertilizers, fossil fuel combustion, and electricity used in both field and controlled environment agriculture. During the next decade, horticultural science should be focused on generating fundamental and applied scientific knowledge to contribute to producing more food (increasing productivity) and ornamental plants in a sustainable way, with not only better quality using fewer natural resources but also with zero or reduced emissions of greenhouse gases and much less water. Integrating precision engineering and smart technologies to horticultural practices will be a key as well. One of the most significant resource inputs in a vertical farm system (and also in greenhouse operations) is labor mainly for crop maintenance and produce harvesting.

In the last few years, the precision horticulture and engineering domain has been seeing a technological transition with a focal shift from mechanization to real-time sensing and big-data driven decision support as well as smart actuation with robotic systems both in the field and within controlled environment horticulture, which includes greenhouses and indoor farming. The concept capabilities of digital agriculture have become a reality for precision operations management with futuristic technology infusion. The Internet-of-Things (IoT), compatible soil, in-field climate, and crop variability mapping sensors are becoming rugged, miniaturized, and affordable to increase our understanding of crop stressors, associated plant response traits and quality attributes. Data from such in-field sensor networks can now be supplemented with an overlay of aerial imagery with high spatiotemporal resolution. Apart from drones integrated with optical sensors, the imagery captured by low orbital satellites can now map geospatial variability at a few cm per pixel resolution and at the frequency of a few days. This big-data can now be analyzed either on the edge of the field (edge-compute), or can be transmitted to the cloud for machine learning driven-decision-making (cloud-compute), and real-time actuation of smart in-field systems. The advancement in reliable, economical farm connectivity options and smart decision aid solutions offered via a mobile device friendly application is needed and will further empower growers' capabilities for horticultural applications. Integrated production systems combined with computational modeling and augmented reality (AR) with interactive visualizations of the microclimate and biotic parameters will further advance success in precision horticulture. This information fed into agronomic and horticultural models by integrating biotic

› Organic photovoltaics covered greenhouse. Source: University of Arizona-Controlled Environment Agriculture Center.

› Plant factory with artificial lighting/vertical farm. Source: University of Arizona-Controlled Environment Agriculture Center.

and abiotic stress data will empower growers' decision-making for farm management. Efforts will need to be focused on models to 1) describe the cross-talk among physiological processes at multiple plant scales, 2) diagnose biotic and abiotic stresses based on high-throughput plant phenotyping data, 3) utilize climate-smart, resource use aware production system designs and management practices, and 4) parameterizations.

Machinery utilized in horticulture for inputs management, harvest operations, and phenotyping have become smarter (e.g., intelligent sprayer, efficient harvesting robots) in terms of actuation with either embedded sensor suits or using connected data feeds. They are now being equipped with hybrid energy drivetrains and self-guidance toolkits to make them work independently off-road and for extended hours per day. Overall, state-of-art horticultural crop monitoring and management is seeing a dramatic shift with prototype development of smart, energy, resource use and operation efficient technologies. Plant response-based sensing, monitoring and environmental control of environment is needed for better management of resources such as nutrients, water, and electricity for indoor plant lighting and environmental control. The incorporation of real-time crop data has been gaining interest to be part of environmental controls and will ensure to empower the crops for optimal growth based on current conditions and will provide growers with enhanced production quality and capabilities within controlled environments and in the field of horticulture.

Given a warming planet and a growing global population, conserving and optimizing irrigation water inputs in horticulture will become ever more important, and plant-based methods to determine irrigation needs and schedules will become more commonly used. Currently, many of these methods are still unaffordable for most small growers, often requiring high maintenance and specialized training.

Inexpensive, practical, and reliable sensors are under development and their applications will be adapted by the growers. Future research will continue to advance developments for crop production under controlled and protected environments. Precision horticulture and engineering will help adapting the designs, technologies, and environmental control strategies considering crop specific needs, regional climatic conditions, consumer and market demands, economics, and availability or resources towards more resilient and resource conserving production practices both with greenhouse and indoor vertical farming-based production systems.

During the next decade, horticultural engineering will continue to appreciate the public-private industry partnership-driven research and development efforts to further innovate technological solutions on capturing quality data, artificial intelligence-guided (machine learning and evolutionary computing-based artificial intelligence and fuzzy logic technologies) farm operations, intelligent and smart robotic platforms. Connectivity, smart-links and autonomy of farm operations both in field and controlled environment systems are going to improve drastically. Research and technology development should also focus on supply chain and postharvest technologies as the post-production waste of horticultural products is greater than 50%. Circular and integrated systems approaches must be considered to re-cycle resources and meanwhile better manage waste products converting them into usable inputs within the production system, thereby enhancing resource use efficiency, minimizing environmental footprints, and enhancing sustainability in horticultural production.

Precision horticulture technologies with affordable cost that can benefit growers on a small and local scale will also be needed. Research and development with new crop varieties that are resilient for environmental stressors will allow using resources more effectively both in field condition and under controlled environment systems. The use of local crop varieties and organic horticulture can also be considered. Empowering small farmers worldwide with technology and knowledge will also be an important part

› Crop health monitoring with mobile phone. Source: Biological Systems Engineering, Washington State University.

of the sustainable solution for feeding the world.

Through scientific events such as webinars, workshops, symposia, and conferences, we will advance the understanding of our stakeholders and members of these concepts and emerging technologies. We will continue to embrace multidisciplinary approaches and meetings within and outside the Society. Encouraging and growing private industry participation in ISHS forums and events will enhance discussions, collaborations, and further contribute to innovations in precision horticulture and engineering. Case-specific infusion of brainstorming and learning sessions that meet at the intersection of horticultural science, engineering and emerging technology will play a key role and advance participation, collaborations, and innovations in precision horticulture and engineering. We will continue to harness the opinions and perception of our young minds as new horticulturists, students, and postdocs to ensure that their voices are taken seriously as we continue identifying and implementing future requirements, advancements and innovations in precision horticulture and engineering. Their participation beyond conferences and symposia within the Division and Working Groups activities will play an important role and will continue to be encouraged. It will be critical to enhance our interactions and collaborations with our peer societies such as Institute of Electrical and Electronics Engineers (IEEE), American Society of Agricultural and Biological Engineers (ASABES), International Commission of Agricultural and Biosystems Engineering (CGIR), International Federation of Automatic Control (IFAC) with targeted efforts including organizing joint technical events with webinars, workshops, and with concept papers and thematic/special issue journals. The field of scientific publication is ever changing, and thus are the expectations about publishing for scientists. As open access publishing is on the rise, preprints are becoming a normal and citable mode of publication.

Adaptation to functional changes in the post-COVID-19 world will be needed. As the pandemic challenged many societies with organizing scheduled scientific events, there will be critical need to transition from traditional models of organizing scientific events to hybrid models and to adapt in times of crisis by developing new and innovative ways to inspire, attract, and enable diverse participation and networking from within the ISHS network and other societies. There is also a need to adapt to global changes by continuing to develop and implement action plans, considering the strategic direction of world horticulture "Growing the future while improving the environmental sustainability." Division Precision Horticulture and Engineering, with its working groups, members, partnering industries, under the umbrella of ISHS, will continue to focus on enhancing education, collaboration, innovation, and implementation of precision and digital horticulture both in the field and under controlled environments to contribute to our Society's efforts to help shape the future of horticulture on Earth and beyond.

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