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Greenhouse Innovations in Horticulture

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Horticulture is characterized by a wide range of cultivation systems (i.e., open field, soilless, protected, greenhouse, organic, indoor) and a plethora of fruit, vegetable and ornamental species. Among these, greenhouse horticulture is one of the most intensive agricultural systems, focusing on the production of high-value products. Control of environmental parameters (temperature, light, etc.), higher efficiency of resource utilization (water, fertilizers, etc.) and the use of high-tech systems (hydroponic, automation, etc.) provide opportunities for higher yields, earliness, stability of production and better quality. The value of the global greenhouse horticulture market for 2019 was 30 billion US dollars and it has been projected to increase annually around 9% for the next five years. The world's population increase and adaptation to the adverse environmental effects of future water scarcity and climate change scenarios may be the reasons for the rising demand for greenhouse horticultural crops. With their huge production and use of technology, greenhouses are evolving into sophisticated manufacturing operations. We use cutting-edge systems and sensors to precisely monitor and control business and production activities.

Climate monitoring, water supply, fertigation, energy, crop surveillance, disease scouting, harvesting, internal transportation, sorting, and packing are just a few of the uses for these sensors and systems. The practice of greenhouse farming is becoming increasingly complex and data-driven. Recently, this trend has gained momentum due to the rapid advancements in information and communication technology (ICT), including cloud computing, the Internet of Things, big data, machine learning, augmented reality, and robotics. Instead of relying solely on human labor and on-site direct observation, farmers track and supervise operations virtually in sophisticated and data-driven greenhouse horticulture using real-time digital data. By accessing a detailed digital image of the relevant plants or equipment from their desk or smartphone, users can remotely monitor the greenhouse conditions and receive warnings of any anticipated problems. The more autonomous this intelligent management cycle becomes, the less the farmer will need to be involved manually.

Thus, we may claim that we can remotely operate and virtualize any element of the greenhouse, including the equipment, plants, containers, and greenhouse sections (Natasja *et al*., 2022). T he worldwide greenhouse horticulture industry was valued at 30 billion US dollars in 2019 and is expected to grow at an annual rate of approximately 9% over the next five years. The expanding global population and the need to cope with the adverse environmental effects resulting from potential water scarcity and climate change scenarios

are responsible for the rising demand for greenhouse horticultural crops (Koukounaras, 2020).

New Technologies on Advanced Greenhouse Horticulture

Greenhouse horticulture has been one of the pioneering sectors of agriculture in the use of new technologies. This has increased due to increasing globalization as well as the requirement for more efficient use of resources and more sustainable farming practices. Castro *et al*. (2019) review new technologies such as improved cover materials, light-emitting diode (LED) lighting, alternative nutrient resources, and sensors that are expected to contribute to more digital, automatic, and advanced greenhouse horticultural production. Water and nitrogen deficit stresses are among the most critical growth limiting factors in crop production. Usually quite complex and problematic methods have been used to quantify the impact of water and nitrogen deficit stresses on plants.

Heat pumps : Heat pumps are a multifunctional technology employed in greenhouses to deliver effects of heating and cooling (Mohamed *et al*., 2017). Their function is to regulate relative humidity and sustain the microclimate, typically in collaboration with the ground. The ground-source heat pump (GSHP) has a positive coefficient of performance (COP) ranging from 2.3 to 3.8, enabling indoor temperatures to be maintained between 5 and 10°C. These technologies are specifically engineered to optimize the conditions for plant growth and provide effective protection against pests. Ground heat exchanger pipes can be positioned either vertically or horizontally, with the latter offering superior efficiency. The efficiency of Vertical GSHP (VGSHP) surpasses that of horizontal GSHP (HGSHP), but at a higher cost.

Lighting : Since photosynthesis depends on adequate lighting, it is essential for fruit and vegetable plants in greenhouses. The color and size of fruit are negatively impacted by the lack of PAR wavelengths (Yano et al., 2014). Artificial illumination is used in a variety of ways, including intra-canopy, photoperiodic, and various wavelength combinations, to overcome this difficulty. One important aspect of greenhouse agriculture to take into account is the analysis of lamp types and light wavelengths produced by artificial lighting. LEDs have been found to be an economical and effective replacement for High-Intensity Pulsed Light (HPS) lamps in some applications. Green LEDs have a more noticeable effect on red leaf lettuce development than white FL, according to experimental studies. Additionally, better results are obtained when LED light radiation-such as blue or red LED light or a combination of blue and red is mixed with ambient light. LEDs are a good choice for farmers looking to maximize their greenhouse crops because they are less expensive, last longer, and use less energy.

Control systems : The cost-effectiveness and efficiency of control systems installed in greenhouses are contributing to their growing popularity. By regulating soil moisture, temperature, and humidity, these systems provide ideal growing conditions for crops such as pepper, orchid, edamame, and lemongrass. Furthermore, solar trackers on solar collectors can enhance efficiency by directly optimizing sun radiation. Open source control systems like as ZigBee technology, which function through Bluetooth communication, have the capability to regulate soil water content, temperature, and humidity, as well as monitor carbon dioxide concentration. Furthermore, researchers have investigated remote control techniques, like as Bluetooth technology, that gather data from the greenhouse environment and send it to a central control system. The implementation of this remote-control approach is thought to enhance productivity and decrease dependency on human labor.

Plastic sheets : The materials commonly used for greenhouse cladding are polyvinylchloride (PVC), glass-reinforced polyester (GRP), polymethylmethacrylate (PMMA), and polycarbonate (PC). Typically, these sheets are utilized as either extruded double wall plastic sheets or corrugated single sheets. Nevertheless, they possess drawbacks such diminished light transmission, exorbitant expenses per square meter, and limited resistance to impacts.

Plastic films : Flexible plastics like low-density polyethylene (LDPE) films are used extensively in horticulture due to their affordability and comparable capacity to transmit light from a perpendicular direct incident. PVC films are used in Asian nations like Japan due to

their durability and decreased transmission of far-infrared radiation; however, PVC is difficult to dispose of because it is not as easily recycled or burned as PE.

Conclusion

The future of greenhouse horticulture promises to be an exciting combination of nature and technology. Imagine a world where greenhouses are advanced, self-sustaining ecosystems that transcend their glass and metal construction. These greenhouses are gradually becoming more sophisticated than they were in the past, driven by the urgent need for food security, quality, and sustainability. Food agriculture is being revolutionized by the use of robotics, automation, and data-driven processes. All of the greenhouse's physical characteristics, such as temperature, humidity, soil moisture, and nutrient levels, are continuously monitored by sensors.

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