greenhub general cross disciplinary glossary of Controlled Environment Agriculture (CEA)

https://greenhub.eu/docs/greenhub-general-cross-disciplinary-glossary-of-controlled-environment-agriculture-cea/

for greenhouse growers, indoor farm managers, students, professors, breeders and industry tech providers, a step towards a common language.

1. Core CEA Systems & Methods

- **Controlled Environment Agriculture (CEA)** — Crop production under fully controlled conditions of light, climate, and nutrients.
- **Greenhouse** — A structure with transparent or translucent materials plastic or glass for controlled or semi-controlled crop growth.
- **High-Tech Greenhouse** — Greenhouse with advanced automation (climate, fertigation, energy) fully automatically adapting to the outside climate.
- **Indoor Farm** / **Vertical Farm** — Multi-layered growing inside buildings, typically with LEDs, usually without the use of daylight.
- **Hydroponics** — Growing without soil, roots in nutrient solutions, can be supported with substrate or a structure.
- **Aeroponics** — Roots suspended in air, misted with nutrient solution.
- **Aquaponics** — Combination of aquaculture (fish) and hydroponics (plants) in one closed loop system.
- **NFT (Nutrient Film Technique)** — Thin film of water/nutrients flows past roots.
- **Deep Water Culture (DWC)** — Roots suspended in oxygenated water with nutrients.
- **Propagation** — The process of starting plants from seeds, cuttings, clones, or runners.
- **Mother Plant** — Selected plant used as source of cuttings or runners.
- **Runner** / **Stolon** — Horizontal shoot forming clonal offspring (e.g., strawberry).

- **Cuttings** — Vegetative plant parts used for propagation.
- **Tissue Culture** / **Micropropagation** — In vitro plant propagation under sterile conditions.
- **Cropping Cycle** — Full timeline from seeding to harvest.
- **Cultivation Recipe** — Crop-specific setpoints for irrigation, fertigation, light, and climate.
- **Batch** / **Lot** — A group of plants treated as a unit for production and traceability.

2. Growing Media & Rootzone

- **Substrate** — Medium supporting roots (coco coir, rockwool, perlite, peat).
- **Rootzone Management** — Monitoring water level, oxygen, EC, pH in root environment.
- **Drainage Fraction** — % of irrigation water drained; indicator of over/under-watering.
- **Electrical Conductivity (EC)** — Concentration of dissolved salts in solution.
- **pH** — Acidity/alkalinity of nutrient solution.
- **Buffering Capacity** — Medium's resistance to pH changes.
- **Root Oxygenation** — Oxygen supply in hydroponics/soil affecting root health.
- **Dissolved Oxygen (DO)**- The concentration of oxygen molecules (O_2) available in a liquid solution, usually measured in milligrams per liter (mg/L). In CEA, DO is critical for root health in hydroponic, aeroponic, and aquaponic systems. Adequate DO supports root respiration, nutrient uptake, and overall plant vigour, while low DO can lead to root stress, anaerobic conditions, and increased risk of pathogens such as *Pythium*.
- **Rhizosphere** — Root–soil (or root–substrate) interaction zone.
- **Drip Irrigation** — Targeted delivery of water and nutrients through tubes with emitters at the plant base.
- **Ebb & Flood Table** — Hydroponic system where plants are periodically flooded with nutrient solution and then drained.
- **Pump System** — Device that moves water/nutrient solution through irrigation or recirculation systems.
- **Filtration System** — Removes particles and microbes from nutrient or irrigation water to protect crops and equipment.
- **Flow Rate** — Volume of water or nutrient solution delivered per unit time.
- **Pressure Sensor** — Device measuring hydraulic pressure in irrigation or fertigation lines.

- **Water Quality** — Parameters such as pH, EC, dissolved oxygen, ions, and contaminants that affect crop growth.

3. Plant Science & Physiology

- **Assimilation** — The net incorporation of absorbed carbon (from CO_2) into plant biomass through photosynthesis, minus respiratory losses. Assimilation represents the gain of sugars, starches, and structural compounds that fuel plant growth.
- **Dry Weight (DW)** — The weight of plant material after all water has been removed (usually by drying at 70–80 °C). Dry weight reflects the accumulated biomass and assimilates.
- **Fresh Weight (FW)** — The weight of plant material including its water content. Often used for harvest measurements but more variable than dry weight.
- **Yield** — The total amount of crop produced per unit area, typically expressed in kilograms per square meter per year ($kg \cdot m^{-2} \cdot year^{-1}$).
- **Harvestable Product** — The portion of crop biomass that meets quality standards and can be sold (e.g., marketable fruits, leaves, spears). Distinguished from total biomass or waste fractions.
- **Harvest Index (HI)** — The ratio of harvestable product to total plant biomass (DW or FW). A key measure of production efficiency.
- **Photosynthesis** — Conversion of CO_2, water, and light into sugars.
- **Respiration —** Metabolic process in which plants convert sugars into energy (ATP) to support growth, maintenance, and repair. Occurs continuously but is the sole energy source during non-light periods.
- **Transpiration** — Water loss through stomata.
- **Stomatal Conductance** — Gas exchange capacity of stomata.
- **Leaf Temperature** — Actual surface temperature of leaves.
- **Vapor Pressure Deficit (VPD)** — Difference between actual and saturated humidity; controls transpiration.
    - **Transpiration** — Water loss from plant leaves through stomata. Controlled by **leaf VPD**, stomatal conductance, and available soil/substrate water. Directly influences cooling, nutrient transport, and water-use efficiency.
    - **Stomatal Conductance** — Measure of the rate at which CO_2 enters and water vapor exits the leaf via stomata. Influenced by **leaf VPD**, light intensity, CO_2 concentration, and plant

stress.

- **Leaf Temperature** — Surface temperature of the leaf, affecting **leaf VPD**, photosynthesis, and transpiration. Can differ from air temperature, especially under high radiation or low airflow.
- **VPD (Air & Leaf)** — Determines **transpiration rates, stomatal behavior, and plant cooling**. Leaf VPD depends on air VPD and leaf temperature; both are critical inputs for climate computer control and digital twin simulations.
- **Irrigation & Fertigation Timing** — Managed using **VPD, leaf temperature, and transpiration data** to optimize water and nutrient delivery, avoid stress, and maximize growth.
- **Climate Setpoints** — Air temperature, RH, CO_2, and lighting are controlled to maintain **optimal air and leaf VPD** for target crop development.

- **Leaf Area (LA)** — Total surface of leaves.
- **Projected Leaf Area** — 2D visible area from imaging.
- **Leaf Area Index (LAI)** — Total leaf area relative to ground area.
- **Phenology** — Plant growth stages (seedling, vegetative, flowering, harvest).
- **Bolting** — Premature flowering (e.g., in lettuce or spinach).
- **Senescence** — Natural aging and decline of plant tissues.
- **Abiotic Stress** — Stress from non-living factors (heat, salinity, drought).
- **Biotic Stress** — Stress from pests/pathogens.
- **Nutrient Deficiency** — Lack of essential nutrients; visible as chlorosis, necrosis, poor growth.
- **Nutrient Toxicity** — Excess nutrients causing damage.
- **Red:Blue Ratio (R:B)** — Ratio of red to blue light affecting morphology and growth.
- **Green:Blue Ratio (G:B)** — Ratio affecting canopy light penetration and morphology.
- **Shoot-to-Root Ratio** — Distribution of biomass between shoots and roots.
- **Fruit Partitioning Model**— Carbohydrate allocation to fruits vs. vegetative growth as published by heuvelink a staple in plant sciences.
- **Plant Balance** — Concepts of assimilation, respiration, source–sink dynamics, and growth balance.
- **Phenotypic Plasticity** — Ability of plants to adapt traits to environment.
- **Harvest Index** — Ratio of edible yield to total biomass.

4. Genetics & Breeding

- **Genotype** — Genetic makeup of a plant.
- **Phenotype** — Observable traits (size, color, yield).
- **Allele** — Variant form of a gene.
- **QTL (Quantitative Trait Locus)** — Genome region linked to trait expression.
- **Polyploidy** — Multiple sets of chromosomes.
- **Heritability** — Proportion of trait variation due to genetics.
- **Germplasm** — Genetic material for breeding.
- **Artificial Selection** — Human-directed breeding.
- **Backcrossing** — Breeding method to recover parent traits.
- **Hybrid Breeding (F1)** — Crossing inbred lines to produce hybrid vigor.
- **Open-Pollinated Varieties (OPVs)** — Maintained by natural pollination.
- **Self-Pollination** — Fertilization within the same plant.
- **Cross-Pollination** — Fertilization between plants.
- **Single Seed Descent (SSD)** — Rapid generation advance by selecting one seed per plant.
- **Doubled Haploids (DH)** — Fully homozygous lines in one step.
- **Marker-Assisted Selection (MAS)** — DNA markers used to select traits.
- **Genomic Selection (GS)** — Genome-wide predictions used in breeding.
- **CRISPR-Cas9** — Precision gene-editing tool.
- **Gene Editing** — Targeted DNA modification technologies.
- **RNA Interference (RNAi)** — Gene-silencing method.
- **Transgenic Plant** — Plant modified with foreign DNA.
- **Cisgenic Plant** — Plant modified with same-species DNA.
- **Mutation Breeding** — Induced variation via chemicals or radiation.
- **Homozygosity** — Genetic uniformity across alleles.
- **Heterozygosity** — Genetic diversity across alleles.
- **Elite Line** — Advanced breeding line with desirable traits.
- **Seed Bank / Germplasm Bank** — Storage of plant genetic resources.
- **Plant Breeder's Rights (PBR / UPOV)** — Legal protection of new varieties.
- **Species** — Broad genetic category of a crop (e.g., *Lactuca sativa* for lettuce, *Solanum lycopersicum* for tomato). Determines **basic growth requirements** and environmental

tolerances.

- **Variety (Cultivar)** — Distinct plant group within a species, selected for traits like **growth speed, leaf size, disease resistance, fruit quality, and photoperiod response**. Determines **how you set up your cultivation recipe** (light, temperature, nutrient targets).
- **Hybrid Variety** — Offspring of two genetically distinct varieties or lines, often showing **faster growth, uniformity, or stress tolerance**. Important for predicting yield and uniformity in production cycles.
- **Maturity Class / Days to Harvest** — Expected number of days from planting or transplant to harvest. Guides **cropping cycle scheduling**.
- **Plant Habit / Growth Habit** — Description of plant architecture (compact, upright, sprawling). Influences **plant density, pruning, interlighting, and shelf spacing**.
- **Leaf Type / Fruit Type** — Morphology of the edible part (e.g., romaine vs. butterhead, cherry vs. beefsteak tomato). Helps **adjust light, nutrient, windspeed and support strategies**.
- **Stress Tolerance / Resilience** — Varieties rated for **heat, salinity, drought, or pathogen resistance**, informing **climate setpoints and fertigation**.
- **Vigor / Growth Rate** — Relative speed of plant growth; affects **spacing, top lighting, DLI requirements, and fertigation schedules**.
- **Uniformity** — Consistency of growth and morphology across a batch; critical for **harvest planning and automation setup**.
- **Yield Potential / Harvestable Fraction** — Expected total production per plant or area; guides **energy use, light allocation, and economic forecasting**.
- **Photoperiod Sensitivity** — How the variety responds to day length; relevant for **flowering induction, vertical farms, and light recipe adjustments**.
- **Rooting Ability / Root System Architecture** — Determines substrate choice, irrigation method, and transplant handling.

5. Environmental Control & Technology

- **Climate Control** — Automated control of temperature, humidity, light, CO_2.
- **Heating System** — Boilers, geothermal, or radiant heat.
- **Cooling System** — Ventilation, fogging, evaporative cooling, shading.
- **CO_2 Enrichment** — Supplementing CO_2 to boost growth.
- **Grow Lights** — HPS, LED, hybrid systems.

- **Light Spectrum** — Different wavelengths (blue, red, far-red, UV).
- **Daily Light Integral (DLI)** — Total light received per day ($mol \cdot m^{-2} \cdot day^{-1}$).
- **Photoperiod** — Hours of light per day.
- **Energy Use Efficiency** — Biomass per unit of energy input.
- **Joules per m²** — Light/energy unit used by growers to manage input.
- **Integrated Pest Management (IPM)** — Combining biological, cultural, and chemical control.
- **Light Intensity (Irradiance / PPFD)** — The amount of photosynthetically active radiation (PAR) reaching the crop surface per second, expressed as $\mu mol \cdot m^{-2} \cdot s^{-1}$. Determines photosynthetic rate.
- **Light Quality (Spectrum)** — The distribution of wavelengths (blue, red, far-red, green, UV) provided by natural or artificial light. Different ratios influence morphology, flowering, and assimilation.
- **Light Penetration** — The depth to which light reaches inside the crop canopy. Key for uniform photosynthesis and avoiding shaded lower leaves.
- **Light Distribution / Uniformity** — The evenness of light across the growing area. Poor distribution causes uneven growth and yield variability.
- **Top Lighting** — Overhead fixtures (HPS or LEDs) illuminating plants from above. The traditional greenhouse and indoor farming setup.
- **Interlighting (Intra-canopy Lighting)** — Supplemental lighting placed between crop rows or within the canopy to improve light penetration to lower leaves (often LED strips).
- **Layer Lighting / Multilayer Lighting** — Lighting applied at each shelf level in a vertical farming rack system.
- **Hybrid Lighting Systems** — Combining natural sunlight with supplemental artificial light (HPS or LED).
- **Dynamic Lighting Control** — Adjusting light intensity and spectrum in real-time based on sensor data, daylight levels, or crop growth stage.
- **HVAC (Heating, Ventilation, and Air Conditioning)** — Integrated systems that regulate greenhouse or indoor farm climate, including temperature, humidity, and air circulation.
- **Heating System** — Boilers, combined heat & power (CHP), geothermal, or radiant pipes delivering heat into the greenhouse.
- **Pipe Rail Heating** — Hot water pipes that run along the greenhouse floor, doubling as rails for carts.

- **Overhead Heating Pipes** — Pipes positioned above crops for radiant heat distribution.
- **Unit Heater / Air Heater** — Fan-driven systems blowing heated air into the greenhouse.
- **Cooling System** — Technologies for reducing excess heat, including ventilation, evaporative cooling, pad & fan, fogging, and mechanical chillers.
- **Ventilation** — Exchange of air through roof vents, side vents, or fans to control temperature, humidity, and CO_2 levels.
- **Air Distribution Systems** — Polyethylene tubes or ducts distributing conditioned air uniformly through the crop canopy.
- **Fogging / Misting System** — High-pressure nozzles creating fine mist for evaporative cooling and humidity control.
- **Pad & Fan Cooling** — Cooling by pulling air through wetted pads (common in hot climates).
- **Dehumidification System** — Condensation-based or desiccant systems to remove excess humidity from greenhouse air.
- **Air Handling Unit (AHU)** — Centralized unit for controlling temperature, humidity, and CO_2 of incoming air.
- **Heat Recovery System (HRS)** — Captures and reuses waste heat from greenhouse or CHP systems.
- **Thermal Storage Tank / Buffer Tank** — Stores heated water for later use, balancing energy peaks.
- **Chiller** — Machine that removes heat from water or air for cooling applications.
- **Heat Pump** — System that transfers heat from one medium to another for heating or cooling efficiency.

6. Sensors, Imaging & Digital Systems

- **RGB Imaging** — Standard color imaging for plant monitoring.
- **Infrared (IR)** — Thermal radiation used to assess stress.
- **Near-Infrared (NIR)** — Assesses water status.
- **Multispectral Imaging** — Captures narrow light bands for vigor/stress.
- **Hyperspectral Imaging** — Dozens of spectral bands for detailed analysis.
- **Chlorophyll Fluorescence** — Measure of photosynthesis efficiency.
- **NDVI** — Vegetation index from NIR/red reflectance.

- **Environmental Sensors** — Measure temp, humidity, CO_2, PAR, VPD.
- **Rootzone Sensors** — Measure pH, EC, oxygen, moisture.
- **Sap Flow Sensors** — Plant-based water use monitoring.
- **IoT (Internet of Things)** — Network of connected sensors/devices.
- **Edge Computing** — Local data processing.
- **Cloud Services** — Off-site data storage/analytics.
- **Digital Twin** — Virtual crop/farm simulation.
- **Decision Support System (DSS)** — Software guiding management.
- **AI & Machine Learning** — Predictive models for yield and stress.
- **Computer Vision** — Image-based crop analysis.
- **Software as a Service (SaaS)** — Subscription software model.
- **Research as a Service (RaaS)** — Outsourced trials and analytics.
- **Automation** — Reducing manual work via machines.
- **Robotics** — Harvesting, scouting, or transplanting machines.
- **Autonomous Vehicles** — Self-driving platforms in greenhouses.
- **Light Intensity (PPFD Sensor)** — Measured in $\mu mol \cdot m^{-2} \cdot s^{-1}$ using PAR or quantum sensors. Logged continuously in climate computers and used to calculate DLI.
- **Daily Light Integral (DLI)** — Computed value from PAR sensor integration over 24h. Used as a KPI for crop assimilation.
- **Light Quality (Spectral Data)** — Measured via multispectral or quantum sensors, reported as ratios (e.g., red:blue, far-red fraction). Stored for steering morphology and flowering.
- **Light Penetration Models** — Simulated or sensor-based models that estimate canopy light distribution. Input for digital twins.
- **Light Distribution / Uniformity Index** — Derived KPI comparing light levels across multiple sensors/zones.
- **Top Lighting (Digital Control)** — Actuator setpoints in % dimming, intensity steps, or $\mu mol \cdot m^{-2} \cdot s^{-1}$ targets. Logged as “lighting on-time” and “lighting energy use.”
- **Interlighting (Digital Control)** — Independent control channel in climate software for intra-canopy LEDs, logged separately for energy and effect.
- **Layer Lighting (Rack Lighting)** — Controlled per shelf in vertical farms, often linked to recipe management (growth phase-specific).
- **Dynamic Lighting Control** — Software routines adjusting light in real-time:

- **Daylight Integration Mode** — Lights dimmed when solar radiation is sufficient.
- **Spectral Tuning Mode** — Actuator values set for red:blue ratio or UV pulses.
- **Photoperiod Control** — Digital timer defining day/night cycle.
- **Lighting Energy KPI** — Energy consumption (kWh/m²) linked to yield, assimilation, and ROI.
- **System Integrator** — A company or professional that **designs, installs, and connects multiple CEA systems** (climate computers, sensors, actuators, lighting, fertigation, ERP) into a fully operational and automated farm. Ensures hardware, software, and communication protocols work together seamlessly.
- **Hardware-Software System** — Combination of **physical components** (pumps, sensors, lighting, fans) and **software control** (climate computers, dashboards, digital twins) that together manage crop growth and farm operations.

7. Operational Growing Terms

- **Germination Rate** — % of seeds that sprout.
- **Seed Vigor** — Strength of seeds to germinate under stress.
- **Transplant Shock** — Temporary growth slowdown after transplant.
- **Retarded Growth** — Slowed growth due to suboptimal conditions.
- **Vegetative Stage** — Period of leaf and stem growth.
- **Reproductive Stage** — Flowering and fruit set stage.
- **Pruning** — Removing shoots/leaves to optimize growth.
- **Pinching** — Cutting shoot tips to induce branching.
- **Harvest Index** — Ratio of harvestable yield to total biomass.
- **Postharvest Physiology** — Study of quality/shelf life after harvest.
- **Crop Turnover** — Time between consecutive harvests.
- **Uniformity** — Consistency of growth and yield.
- **Yield** — Harvested crop per unit area.
- **Harvestable Product** — Portion of crop suitable for market.
- **CO_2 Application** — Management of enrichment timing and levels.
- **Uptime / Downtime** — System availability.
- **QMS (Quality Management System)** — Protocols ensuring standardization (e.g., Delphy tools).

- **ERP (Enterprise Resource Planning)** — Integration of production, sales, and inventory management.
- **Pest** — Organism (insect, mite, or nematode) that can cause damage to crops.
- **Pathogen** — Disease-causing organism (fungus, bacteria, virus) affecting plant health.
- **Biocontrol Agent** — Natural predator, parasite, or microorganism used to control pests or diseases.
- **Integrated Pest Management (IPM)** — Strategy combining biological, cultural, mechanical, and chemical controls to minimize pest damage sustainably.
- **Scouting / Monitoring** — Regular inspection of crops for early detection of pests, diseases, or physiological disorders.
- **Resistance Management** — Practices designed to delay or prevent pests/pathogens developing resistance to chemical or biological controls.

8. Sustainability & Food Systems

- **Food Miles** — Distance food travels from farm to consumer.
- **Circular Agriculture** — Closing loops by recycling inputs/wastes.
- **Life Cycle Assessment (LCA)** — Environmental footprint analysis.
- **Carbon Footprint** — Greenhouse gas emissions per product unit.
- **Water Use Efficiency** — Yield per liter of water.
- **Energy Use Efficiency** — Yield per joule of energy.
- **Resource Use Efficiency** — General input/output efficiency.
- **Energy Meter** — Device measuring electricity, gas, or thermal energy consumption in the farm.
- **Energy Use Efficiency (EUE)** — Ratio of biomass or yield produced per unit of energy input.
- **Renewable Energy Integration** — Use of solar, wind, geothermal, or other renewable sources to supply greenhouse or indoor farm energy needs.
- **Thermal Storage** — Tanks or materials that store heat or cold to balance energy demand peaks.
- **Peak Shaving / Demand Response** — Adjusting energy use during high-demand periods to reduce costs and stress on the grid.

9. Industry & Operations & Markets and & Sales

- **Input** — Any material or resource used in production.
- **Output** — Product or biomass harvested.
- **Scaling Up** — Moving from pilot to commercial production.
- **Standard Operating Procedure (SOP)** — Protocol for consistent operations.
- **Key Performance Indicator (KPI)** — Performance metrics (yield, energy, uptime).
- **Return on Investment (ROI)** — Profitability measure.
- **CapEx** — Capital expenditure (infrastructure, equipment).
- **OpEx** — Operational expenditure (labor, energy, consumables).
- **Benchmarking** — Comparing performance to industry peers.
- **ERP System** **(Enterprise Resource Planning System)** — Integrated software platform that **manages and connects all core business processes** in a greenhouse or indoor farm, including crop planning, inventory, procurement, labor, production scheduling, harvest data, and financials. ERP systems often interface with **climate computers, dashboards, and sensors** to provide a holistic view of operational performance, resource use, and ROI.
- **Embedded System** — A **dedicated computer or microcontroller built into CEA equipment** (e.g., sensor nodes, actuator controllers, dosing pumps) that runs specific software for real-time monitoring and control, often interacting with the main climate computer or cloud service.
- **IoT Node** — Individual sensor or actuator connected to a network, often an embedded system, that **collects or executes data** for monitoring, automation, or cloud integration.
- **Digital Twin** / **Virtual Model** — Virtual representation of the physical farm, integrating **embedded systems, sensors, actuators, and software** to simulate crop growth, energy use, and climate response.
- **Wholesale Market** — Centralized market where growers sell crops in bulk to distributors, retailers, or food service companies. Prices are often determined by supply, demand, and quality grades.
- **Retail Market** — Outlets where crops are sold directly to consumers, either fresh (supermarkets, farmers' markets) or packaged.
- **Food Service** / **Horeca** — Market segment supplying restaurants, hotels, and catering businesses. Crop specifications may differ from retail or wholesale (size, uniformity, packaging).

- **Distributor / Broker** — Entity that buys crops from growers and sells them to retailers, restaurants, or other buyers. Often handles logistics, storage, and quality verification.
- **Market Class / Grade** — Standardized classification of crops based on size, appearance, or quality, affecting pricing and sales channels.
- **Contract Farming / Forward Sale** — Agreement where growers commit to deliver a specific quantity and quality of crops to a buyer under pre-agreed conditions, providing financial predictability and market access.

10. Growing System Types & Infrastructure

Irrigation & Rootzone Systems

- **Ebb and Flood Table (Flood & Drain)** — Benchtop system where trays are periodically flooded with nutrient solution and then drained.
- **Drip Irrigation** — Controlled delivery of water/nutrients directly to the root zone via drippers.
- **NFT (Nutrient Film Technique)** — Roots exposed to a thin, recirculating nutrient film.
- **Deep Water Culture (DWC)** — Plants suspended with roots in oxygenated nutrient solution.
- **Vertical Towers** — Upright columns where plants are stacked vertically, maximizing space efficiency.
- **Vertical Walls (Living Walls / Green Walls)** — Plants grown on vertical surfaces, often with integrated irrigation.
- **Shelve System (Multilayer / Rack System)** — Tiered growing racks used in vertical farms.
- **Rolling Benches / Mobile Tables** — Movable benches to optimize space and workflow.
- **Germination Chamber / Germination Room** — Climate-controlled environment for uniform seed sprouting.
- **Propagation Tray / Plug Tray** — Multi-cell trays used for raising seedlings.
- **Mist Bench** — Propagation bench using fine mist to maintain high humidity for cuttings.
- **Capillary Mat Irrigation** — Plants absorb water from a moist mat placed under pots or trays.
- **Aeroponic Tower** — Vertical system where roots are suspended in air and misted with nutrients.
- **Hybrid Systems** — Combinations of hydroponics, aeroponics, and substrate-based growing.
- **Direct Air Capture (DAC)** — Technology that extracts CO_2 directly from ambient air for use in greenhouse or indoor farm enrichment. DAC allows farms to supplement CO_2 sustainably,

improving **photosynthesis**, **assimilation**, **growth rate, and yield** while reducing carbon footprint. Can be integrated with climate computers to maintain **optimal CO_2 setpoints**.

- **Direct Ion Measurement** — Sensors that measure individual ion concentrations (e.g., NO_3^-, K^+, Ca^{2+}) in nutrient solutions in real time. Enables **precise fertigation, dynamic nutrient dosing**, and prevention of deficiencies or toxicities, improving crop yield, quality, and resource efficiency.
- **Nanobubbles / Microbubbles** — Extremely small gas bubbles suspended in water that enhance **dissolved oxygen, CO_2 delivery, and nutrient absorption**. Used in hydroponic and aquaponic systems to improve **root respiration, water quality, and pathogen suppression**. Can be integrated with digital sensors for monitoring and optimization.

Greenhouse Structures & Drainage

- **Gutters (Rain Gutters / Drainage Gutters)** — Channels under greenhouse roofs to collect rainwater or irrigation runoff.
- **Growing Gutters (Crop Gutters)** — Elevated channels holding substrate slabs (rockwool, coco) for root-zone management.
- **Hanging Gutter Systems** — Suspended gutters allowing vertical flexibility and airflow.
- **Mobile / Movable Gutter Systems** — Adjustable gutters for crop rotation or density optimization.
- **Drainage Floors** — Sloped or porous floors to collect and recycle runoff water.
- **Sub-irrigation Floors** — Floors that supply water/nutrients from below (ebb-and-flood style).
- **Concrete Floors with Drainage Channels** — Easy-to-clean hard floors with integrated drains.
- **Raised Benches** — Crops lifted above floor level for climate control and ergonomics.

Greenhouse Mechanics (Ridder, Priva, Hoogendoorn systems)

- **Climate Screens / Energy Screens** — Retractable screens that manage light, energy loss, and humidity (e.g., Ridder screen systems).
- **Shading Curtains** — Screens or fabrics that reduce incoming sunlight and protect plants from heat stress.
- **Thermal Screens** — Screens designed to reduce night heat loss and save energy.

- **Ventilation Windows** — Roof or side vents that open/close to control airflow and temperature.
- **Window Actuators** — Automated mechanical systems (Ridder drives) for precise vent/window operation.
- **Light Deprivation Curtains** — Blackout curtains used to control photoperiod and crop flowering.
- **CO_2 Distribution Tubes** — Polyethylene tubes placed along the crop rows to distribute enriched CO_2 evenly.
- **Drain Water Collection Tanks** — Tanks for capturing and recycling nutrient runoff.

Material Handling & Automation

- **Overhead Cranes** — Greenhouse cranes for crop handling, transport, and sometimes pipe rail maintenance.
- **Pipe Rail Systems** — Heating pipes that double as rail tracks for carts, scissor lifts, and cranes.
- **Crop Work Carts** / **Scissor Lifts** — Mobile platforms used for pruning, harvesting, or installing screens.
- **Automated Transport Systems** — Conveyor belts, shuttle systems, or trolleys for moving plants/products.
- **Internal Logistics (ILS)** — Integrated movement of crops and materials, linking greenhouse to packhouse

11. Data, Control & Actuator Points

Sensor & Measurement Data

- **Air Temperature** — Climate variable, measured at canopy and reference levels.
- **Relative Humidity (RH)** — % water vapor in air.
- **Vapor Pressure Deficit (VPD)** — Driving force for transpiration.
- **Leaf Temperature** — Measured by IR sensors, indicates plant stress.
- **Photosynthetically Active Radiation (PAR)** — Light available for photosynthesis.
- **Daily Light Integral (DLI)** — Sum of PAR per day ($mol \cdot m^{-2} \cdot day^{-1}$).
- **CO_2 Concentration (ppm)** — Key driver of photosynthesis.

- **EC (Electrical Conductivity)** — Nutrient concentration in irrigation/drain water.
- **pH** — Acidity/alkalinity of nutrient solution.
- **Drain Percentage** — % irrigation not absorbed by crop.
- **Substrate Moisture** — Water content in rockwool, coco, perlite.
- **Sap Flow** — Direct measure of plant transpiration.
- **Stem Diameter** — Used to detect water stress (shrink–swell cycles).

Actuator Control Points

- **Vent Opening %** — Position of roof or side vents.
- **Screen Position %** — % closed/open for energy, shading, or blackout screens.
- **Heating Pipe Temperature** — Setpoint for pipe rail heating.
- **Boiler Output / CHP Output** — Heat energy supplied by boilers or cogeneration.
- **Fogging / Misting Rate** — % capacity for evaporative cooling.
- **Irrigation Event** — Triggered watering cycle, defined by volume, duration, or EC/pH.
- **Drip Frequency** — Number of irrigation pulses per hour/day.
- **Lighting Intensity ($\mu mol \cdot m^{-2} \cdot s^{-1}$)** — Instantaneous light delivered by LEDs/HPS.
- **Photoperiod Setting** — Hours per day lights are on.
- **CO_2 Dosing Rate** — Flow of CO_2 to distribution tubes.
- **Fan Speed** — % airflow generated by circulation or extraction fans.

Digital Control & Software Metrics

- **Setpoint** — Target value for climate variable (e.g., 22 °C, 70% RH).
- **Deviation / Overshoot** — Difference between measured and setpoint value.
- **Control Strategy** — Algorithm linking sensors and actuators (PID, model-based).
- **Actuator Duty Cycle** — % of time an actuator is active.
- **Energy Balance** — Calculation of heat inputs vs. losses in greenhouse.
- **Water Balance** — Inflow vs. uptake vs. drain.
- **Nutrient Balance** — Delivered vs. absorbed nutrients.
- **Crop Registration Data** — Yield, fruit size, quality per week/season.
- **Labor Registration Data** — Worker hours, task efficiency, OEE (overall equipment effectiveness).

- **Alarm / Event Logs** — Records of deviations, failures, or warnings.
- **Heating Pipe Setpoint** — Desired pipe water temperature, controlled via boiler/CHP.
- **Boiler Output %** — Real-time actuator point showing boiler load.
- **Vent Opening %** — Percentage of vent window opening, automated by Ridder/Priva drives.
- **Fan Speed %** — Output signal controlling circulation or extraction fans.
- **Fogging Capacity %** — Percentage of fogging system activation.
- **Dehumidifier Duty Cycle** — Time fraction a dehumidifier is active.
- **Pad & Fan Differential Pressure** — Measurement of airflow through cooling pads.
- **Air Temperature Setpoint** — Target air temperature value.
- **Humidity / RH Setpoint** — Target humidity for crop steering.
- **ΔT (Temperature Differential)** — Difference between inside and outside air temperature.
- **Remote Sensing** — Use of sensors, imaging, or drones to **collect data on plant health, growth, climate, or nutrient status** without physical contact. Enables monitoring of large or dense crop areas efficiently.
- **Remote Control** — Capability to **adjust or manage climate, irrigation, lighting, and other systems** in a greenhouse or indoor farm from a distance using software or mobile devices.
- **Dashboard** — Visual interface displaying **real-time data, KPIs, and alerts** from sensors, climate computers, or other farm systems. Helps growers make informed operational decisions quickly.
- **Climate Computer** — Centralized digital system that **controls and monitors greenhouse or indoor farm climate**, including temperature, humidity, CO_2, ventilation, heating, cooling, and lighting. Integrates with sensors and actuators.
- **Windows XP / Legacy Software** — Older operating system platforms sometimes still used in **climate computers or control systems**, highlighting the importance of software updates and modern integration.
- **Communication Protocol** — Standardized method for **digital devices and sensors to exchange data**, e.g., Modbus, KNX, OPC-UA, or proprietary greenhouse protocols. Ensures interoperability between controllers, climate computers, and IoT devices.
- **Linear / Statistical Model** — A mathematical model that predicts outputs (e.g., crop growth, transpiration, nutrient uptake) as a **direct, proportional function of one or more inputs** (e.g., light intensity, temperature, nutrient concentration). Linear models are simple,

interpretable, and often used for **small datasets or controlled experiments**, but they may not capture complex, nonlinear interactions in a greenhouse.

- **Machine Learning (ML)** — Computational approach where algorithms **learn patterns from data** without being explicitly programmed with fixed equations. ML can model **nonlinear relationships**, detect subtle correlations, and improve over time as more data is collected. In CEA, ML is used for **predicting yield, optimizing fertigation, detecting stress, and anomaly detection**.
- **Artificial Intelligence (AI)** — Broader concept where systems **simulate human-like decision making**, often using ML as a core component. AI can **autonomously adjust climate, irrigation, or lighting**, integrate multiple datasets (sensors, imaging, weather forecasts), and provide actionable recommendations. In practice, AI is applied when **decision-making goes beyond prediction and requires dynamic adaptation**.

12. Statistics & Experimental Design

- **Plant Batch** — A group of plants grown under the same conditions and treated as a unit for experiments or production. Often used in yield and uniformity assessments.
- **Biological Replicate** — Independent samples of the same treatment, grown under similar conditions, to account for natural biological variability.
- **Technical Replicate** — Multiple measurements of the same sample or plant to account for measurement or instrument variability.
- **Randomization** — Experimental design method to assign treatments randomly to plants or plots, reducing bias.
- **Blocking** — Grouping experimental units with similar characteristics to reduce environmental variability in analysis.
- **Factorial Design** — Experiment where multiple factors (e.g., light intensity, nutrient concentration) are tested simultaneously.
- **Statistical Model** — Mathematical representation linking independent variables (treatments) to dependent variables (growth, yield, physiology).
- **Analysis of Variance (ANOVA)** — Test to determine if differences among treatment means are statistically significant.
- **Post Hoc Tests** — Follow-up analyses (Tukey, Bonferroni) after ANOVA to identify which groups differ.

- **Regression Analysis** — Statistical method for modeling relationships between variables (e.g., light intensity vs. assimilation rate).
- **Correlation** — Measure of the strength and direction of a relationship between two variables.
- **Standard Deviation (SD)** — Quantifies variability within a dataset.
- **Standard Error (SE)** — Estimate of how precisely the mean of a sample represents the population mean.
- **P-value** — Probability that observed differences occurred by chance; used to assess significance.
- **Confidence Interval (CI)** — Range within which the true mean or effect likely lies, with a given probability.
- **Replicate Block** — Set of experimental units treated as replicates within a block to account for local environmental effects.
- **Experimental Unit** — The smallest division of the experiment to which a treatment is applied.
- **Data Normalization** — Adjusting measurements to a common scale for comparison across batches or treatments.
- **Outlier Detection** — Identifying data points that deviate significantly from expected trends, often for quality control.