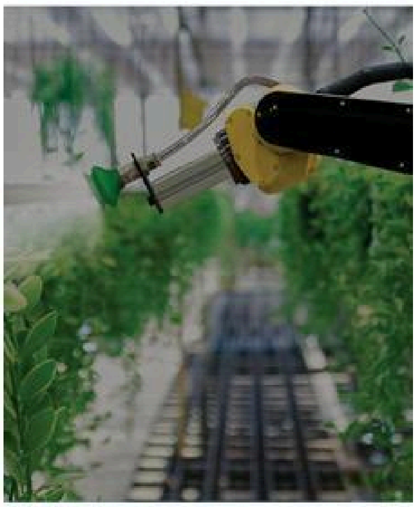
Horticulture 4.0
Vocational Education
for Digital Transformation in Horticulture



SMART GREENHOUSE TECHNOLOGIES

DIGITAL HANDBOOK FOR TEACHERS

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Welcome to Horticulture 4.0!

In the age of digital transformation, horticulture plays a crucial role in providing fresh and nutritious vegetables and fruits to an ever-growing population. The use of smart technologies in greenhouses reduces uncertainty and increases productivity, which is why automated greenhouses are becoming more and more popular. The large-scale advancement **of robots**, **remote control**, **mobile communications**, **the Internet of Things (IoT**), **data analytics**, **decision support systems** and **artificial intelligence (AI)** has also significantly transformed and continues to shape the agricultural sector. The demand for the automation and remote control of greenhouses is increasing in many countries around the world, but **there are few qualified farmers and workforce who can confidently and professionally use these devices,** since vocational education can only keep up with technological developments with a delay of several years.

This handbook **was prepared within the framework of the Erasmus+ project "Horticulture 4.0 – Vocational Education for Digital Transformation"** with the participation of three countries (Hungary, Romania and Serbia), in a partnership of experts from agricultural vocational training institutions and universities. The primary goal of the project was to develop high-quality learning materials for horticultural educators on technologies used in smart greenhouses in three major topics:

1. IT basics of operating smart greenhouses
2. Smart technologies in greenhouses
3. **Innovative teaching methods**

The first topic discusses the essential IT fundamentals required for operating intelligent greenhouses in a clear and accessible manner. The second topic describes the advanced technologies of smart greenhouses across eight chapters, adapting to the physiological stages of plants, with a practice-oriented approach and a special focus on artificial intelligence solutions. The third topic is a methodological guide for teachers of horticultural subjects who want to teach the latest technologies to their students using innovative methods of the 21st century.

Multi-purpose use of the project results means:

- The online training syllabus and program for agricultural vocational educators in three modules in a Moodle environment, with a competency map of the expected learning outcomes of students.
- We published the learning content as a teacher's handbook in digital form, which can be used by teachers of horticulture in their daily work, as a supplement to the available textbooks.
- The independently interpretable chapters of the learning content are continuously published in the form of digital microlearning materials in four languages as free learning material resources, on professional and educational content-sharing platforms.

Horticulture 4.0 Consortium

CHAPTER 1

IT BASICS FOR THE OPERATION OF SMART GREENHOUSES

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1. Communication

1.1 Communication in everyday life

In everyday life, communication usually involves human interactions in which information, thoughts, feelings and ideas are exchanged between two or more parties.

Communication can take several forms:

Verbal communication is based on the use of words and language when speaking or writing.

Nonverbal communication is based on the use of body language, facial expressions, posture and gestures with the help of which we express our emotions and intentions.

In addition, there is **written communication**, for example, in the form of letters or emails, as well as visual communication, for example, through figures, diagrams or images.

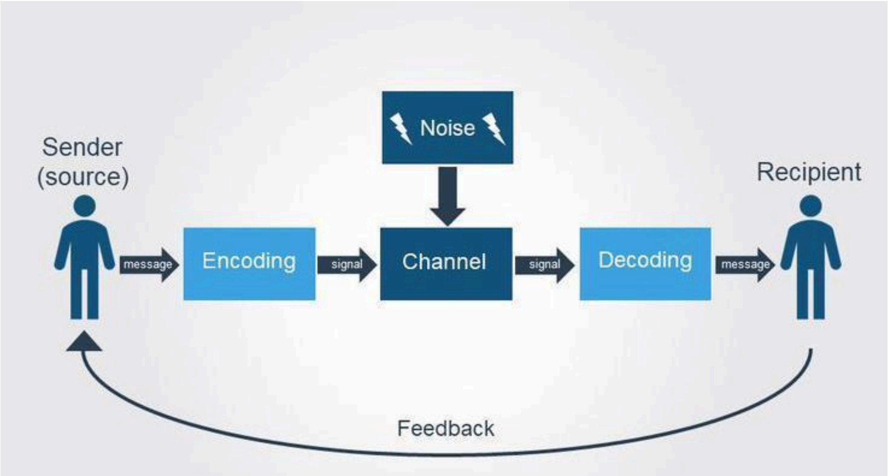
The term now has a much broader meaning than human interpretation. According to the definition of information theory, communication is any process in which information is transmitted, regardless of the form and code in which the information appears. In a broader sense, processes between inorganic and organic matter can be called communication as well as the transfer of information between machine systems.

1.2 Communication in information technology

In information technology, the concept of communication refers to the exchange of data and information between computers, devices, systems and applications. This includes, for example, the transmission of data over local area networks (LANs) or remote networks, but it can also include human-machine interaction. In this sense, the purpose of communication is the efficient, fast and secure transmission of data, information and instructions between different systems and users.

Transmitter/encoder	the source of information, the individual or group that creates, encodes and transmits the message if necessary.
Message	the information, thought, feeling, or idea that the source wants to convey.
Channel	the medium (medium) through which the message is transmitted, e.g. speech, writing, electronic media, etc.
Receiver/decoder	receives the message, decodes it as needed by an individual or group.
Loopback	The customer's response to the message, which is returned to the source if the communication is bidirectional.

Noise	any factor that impedes, distorts, or interrupts the transmission or reception of a message.



Components of the communication process
source: https://hu.pinterest.com/pin/482940760039226296/

Communication between IT systems can take different forms. Communication between computers is the process of transferring data (exchanging files, e-mail, and other digital content) over a local network or the Internet.

This includes communication between software and applications. For example, application programming interfaces (APIs) allow one software to communicate with another, request or transmit data, helping to integrate between applications and synchronize data.

This includes communication between users and computer systems. This is done through user interfaces (e.g. graphical user interfaces, command-line interfaces), where users provide information, give instructions and receive feedback from the system.

In the field of IT communication, reliability, security and efficiency are important. They use protocols, coding methods, and network architectures to ensure that information flows properly and can be interpreted by communicating systems.

2. Mobile communication

2.1 Basic concepts

Mobile communications refer to communication using mobile phones and other wireless devices. This technology allows people to communicate in real time with people living in remote locations or other devices.

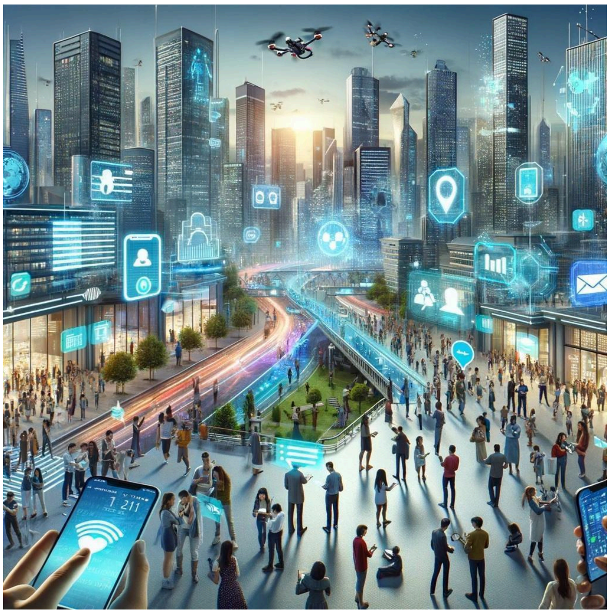
Source: https://www.brightlabelectronics.com/sensor-design

Mobile communication data transmission requires network infrastructure, mobile phone towers and base stations that ensure coverage and availability of communication services.

Mobile phone networks can use technologies such as GSM (Global System for Mobile Communications), CDMA (Code Division Multiple Access), 3G (Third Generation), 4G (Fourth Generation), LTE (Long-Term Evolution) and 5G (Fifth Generation). These technologies are gradually evolving and providing new opportunities for mobile communications.

The basic services of mobile communication are mobile calls, text messages (SMS), multimedia messaging (MMS), emails, social media applications, Internet browsing, and the latest applications such as video calling, live streaming, collocation and mobile payments.

The great advantage of these services is fast and efficient person-to-person communication, provided that there is mobile network coverage in the given geographical area. The mobile network allows us to stay in touch with family, friends, business partners. Newer generation mobile networks, such as 4G and 5G, bring additional benefits to mobile communications. They provide faster data speeds, lower latency, and higher capacity, enabling faster and reliable transfer of larger data and the evolution of new applications and services.



Source: Generated with DALL-E

Mobile communications have a significant impact on our daily lives and society. It changed the way people communicate, enabling fast and global contact. Mobile communications are equally important in the personal, business and social spheres, and further advances in technology will provide new opportunities in the future.

2.2 Applications

Applications (applications) used in mobile communication are widespread and allow us to perform various activities on mobile devices (smartphones or tablets). Here are some examples of the types of mobile apps you use most often:

1. **Communication applications:** to send text messages (for example, SMS, WhatsApp, Facebook Messenger), to make calls (for example, Skype, FaceTime, Viber).
2. Social media apps: to keep in touch, share opinions, photos, videos (e.g. Facebook, Instagram, Twitter, TikTok).
3. Email applications: used to set up an email account, send and receive emails (e.g. Gmail, Microsoft Outlook).
4. Music and video player apps: to play music, podcasts, movies, and series on your mobile device (e.g. Spotify, YouTube, Netflix).
5. Navigation applications: for route planning, receiving traffic information (e.g. Google Maps, Waze).
6. Health and fitness apps: to support health promotion, track nutrition, and access other health information (e.g. Fitbit, MyFitnessPal).
7. Banking and payment applications: for making bank transactions, paying with a mobile device, tracking finances (for example, PayPal, Revolut).

These are just a few examples of the diversity of mobile apps. Mobile apps are constantly evolving and offer new features and options for users to use their mobile devices more conveniently and efficiently in everyday life.

2.3 Mobile communication in agriculture

Mobile communications play a key role in modernising agriculture and increasing farmers' competitiveness. The introduction of new technologies and communication tools brings many benefits to farmers in the following areas:

Data collection and analysis: farmers can collect data on their soil, weather conditions and crop conditions in real time, which will inform them to make the right decisions about the necessary interventions.

Market information: mobile phones help farmers get up-to-date information, for example, on market price developments for different products.

Communication and advice: mobile communication makes it easy for farmers to connect with advisors, experts and other farmers to keep up with and share the latest developments and good practices.

Digital finance: Mobile banking and digital payment platforms facilitate financial transactions, the purchase of fertiliser or seed, and the management of revenues from crop sales.

Precision agriculture: thanks to precision agriculture technologies, drones and satellite imagery, farmers can accurately monitor and optimise the use of fertiliser, water and crop protection products.

Training and education: mobile communication allows farmers to access online training and learn about the latest agricultural practices and technologies via mobile devices.

3. Receiving, transforming, transmitting data transmission signals

3.1 Data and data volume

Data is a form of facts and concepts that is suitable for interpretation, processing and transmission by data processing tools. Data can be unstructured, such as a plain text document, or structured, such as stored in a database. Information is new knowledge created by processing data by machine or man.

Data volume is a measure that shows how much storage capacity is required to store data. Units of measurement for data volume include bits (the smallest unit of data that can take a value of 0 or 1) and bytes (usually 8 bits, which are used to store a character, such as a letter or digit). Other units of data volume are kilobytes (KB), megabytes (MB), gigabytes (GB), terabytes (TB), petabytes (PB), exabytes (EB), where each unit is usually 1024 times the previous one (although a factor of 1000 is often used to measure storage and throughput capacities for ease of understanding).

Based on the amount of data, we can determine the size of the required data storage device, data transfer rate and data processing capacity. For example, the amount of data required to store a digital image determines the load time on a web page, or the amount of data in a video can determine how long it takes to download or stream it at a given network speed.

3.2 Data transmission signals

Signals play a key role in all forms of communication and are an essential tool for transmitting data and information in information technology. Signals allow data to be physically transmitted through communication channels. Digital signals transmit information in discrete form (for example, a sequence of 0's and 1's), while analog signals can change continuously over time. Analog signals can take on infinitely many values within a given range and usually represent continuous changes in some physical quantity, such as temperature, pressure, sound waves, or light intensity. Analog signals change continuously, and discrete or digital signals change intermittently or cascadingly.

In the context of IT communication, the role of signals can be grouped according to several aspects.

Group signals by option set and range of interpretation:

- Analog signal: both its range of interpretation and its set of values are continuous (temperature changes over a given period),
- Discrete signal in the time domain: the signal has a discrete range of interpretation and a continuous set of values (e.g. hourly thermometer),
- Discrete signal in amplitude: its interpretation range is continuous, its set of values is discrete (e.g. adjustable output voltage of power supply),
- Digital signal: both its range of interpretation and its set of values (e.g., the second hand of a simple digital clock).

Some features, distinguishing features of analog and digital systems are:

- Digital systems use integers (such as binary) for input, processing, transmission, storage, or display.
- Analog systems use a continuous spectrum of values and non-numeric symbols such as letters or icons.
- In analog systems, small fluctuations and fluctuations also have meaning.

The concepts of analog and digital signal, with examples

- The analog signal: it can take any value, it is constantly changing, it gives realistic data that can be read at any time. For example: speedometer, conventional tensionmeters, conventional thermometer (mercury fiber), barometer, hydraulics.
- Digital signal: the discrete representation of a variable phenomenon or physical quantity, e.g. only by certain integer values. For example: digital thermometer, digital clock.

3.3 Signal processing, digitization of analog signals

Shannon's sampling law (or Shannon-Nyquist's sampling theorem as it is often called) is one of the fundamental principles of digital signal processing. The law determines the speed at which a continuous temporal signal must be sampled in order to perfectly restore the original signal from the samples without losing information in the process. The law states that for a signal with maximum bandwidth X, the sampling rate (sampling rate) must be at least twice the maximum frequency of the signal (i.e. 2X) in order to restore the original signal without distortion.

For example, if the highest frequency of an audio signal is 20 kHz, then according to the Shannon-Nyquist theorem, a sampling rate of at least 40 kHz is required to perfectly convert the signal into a digital form.

The sampling law is fundamental in digital audio, digital imaging, and many other areas where analog signals need to be converted to digital signals, as it helps prevent sampling error when the sampling rate is too low and high-frequency signal elements distort the restored signal.

Analog-to-digital (A/D) and digital-to-analog (D/A) conversion

Analog signals can be converted into digital signals (and vice versa) using A/D (analog-to-digital) and D/A (digital-to-analog) converters, enabling digital processing, storage and transmission of analog signals. Digital data transmission is often more efficient and less noise-sensitive than direct handling of analog signals. A/D conversion is the "quantization" of a continuous analog signal to discrete digital values, while D/A conversion is the conversion of digital signals to analog signals, allowing physical representation and perception.

Limitations of digitizing analog signals

- During digitization, analog signals are converted into signals that can be represented by digits, which can also be interpreted by a computer.
- The original data is sampled in steps and the continuous data set between the two steps is replaced by a value, which is obviously only an approximate value.
- Specifying a range of values is called quantization. Accuracy can be improved with denser sampling and smaller steps.
- Data loss occurs during digitization, so the original analog signal cannot be converted back from the digital signal.

Steps to digitize analog signals

- Sampling: sample the original continuous data set in increments and replace the variable value between the two steps with a single value.
- Quantization: specify the set of values from which the digital signal takes a specified value that approximates the value of the original signal.
- Coding: the sampled signal is assigned to the quantization value obtained by the encoding unit in a binary sequence.

3.4 Digitization of images and sounds

Digitize images

By digitizing images, photos, documents, images can be stored, edited and shared in digital format on any electronic device. By digitization, the analog image is converted to discrete digital format in two steps: sampling and quantization.

Sampling

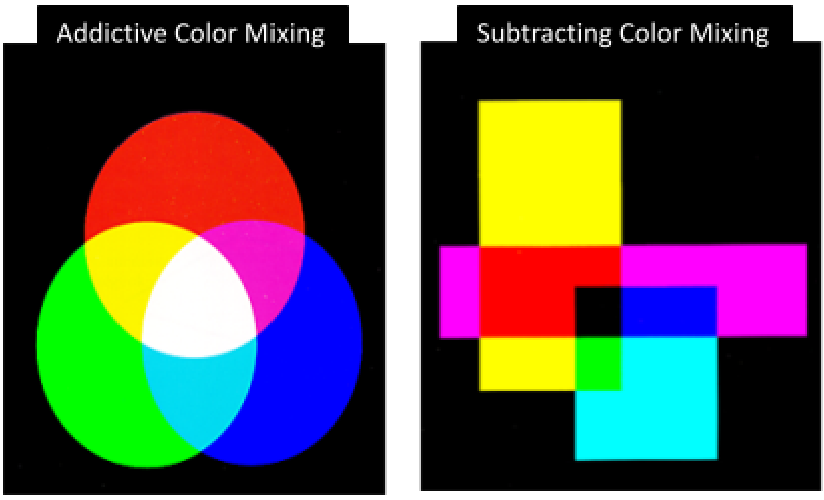
By sampling, the image is broken down into small squares called pixels (picture elements) using a grid. Each pixel represents one pixel in the digital image. The sampling rate, or pixel density, determines the resolution of a digital image: the more pixels an image has, the more detailed the digital version. High-resolution images better preserve the details of the original image, but obviously require more storage space.

Quantization

The next step is quantization: the light intensity values recorded per pixel are converted to discrete color depth values. Color depth determines how many different colors or shades can be displayed in a digital image. For example, in an image with 8-bit color depth, each pixel can display 256 (2^8) different colors or hues. Quantization determines the color accuracy and detail of a digital image. If 3 bytes (24 bits) are used for storage, more than 16 million (16,777,215) colors can appear in the digital image.

Color coordinate systems and formats

Digital images can be stored and managed in different color models and file formats. RGB (Red, Green, Blue), called additive color mixing, which combines red, green, and blue colors to create different colors, The RGB code contains the codes for red, green, and blue base colors separately.



CMYK (Cyan, Magenta, Yellow, Key/Black) subtraction color mixing is mainly used in image printing. Sunlight contains all the visible colors found on earth. When sunlight illuminates an object, the object absorbs (subtracts) a little of the light and reflects the remainder. Reflected light is the color we see. The fire engine is bright red because it absorbs all colors (blue and green) from the light spectrum except red.

File formats for storing digital images, such as JPEG, PNG, GIF, and TIFF, use various compression techniques and data management methods to optimize image quality and file size.

Compression

We often use compression techniques to store and transmit digital images. Compression can be lossy, like JPEG, where we lose the original data during compression to reduce file size, or lossless, like PNG, where the original quality of the image is preserved but less effective in terms of reducing size.

Audio digitization

Audio digitization converts physical, analog audio signals into signals that can be stored in digital form, enabling sound to be stored, edited, transmitted and copied on a computer. The first step in audio digitization is sampling, followed by quantization and coding, which convert continuous analog signals into discrete digital data.

Sampling

The first step in sound digitization is sampling: samples are taken from the analog signal at given intervals. The sampling rate (or sampling rate) determines how many times per second sampling is performed. The unit of sampling frequency is Hertz (Hz), where 1 Hz represents the reception of one sample per second. CD-quality audio, for example, records at a sample rate of 44.1 kHz, which means it takes 44,100 samples per second.

Quantization

Sampling is followed by quantization: sample amplitudes are rounded to discrete values. In this step, the continuous analog signal is converted into a finite number of digital signals that can be handled in digital systems. The number of quantization levels depends on the so-called "bit depth". The bit depth determines how many bits are used to store the sample amplitude. For example, a 16-bit audio system can distinguish 65,536 (2^16) different amplitude values. During quantization, a so-called quantization noise is generated, since continuous amplitude values are rounded to discrete values, but by increasing the bit depth, the quantization noise can be reduced accordingly.

Coding

For storage and transmission, after sampling and quantization, digital data must be encoded. Encoding compresses data to reduce the amount of data while maintaining sound quality. Compression can be lossy (for example, MP3, AAC), which omits certain information less perceptible to the human ear, or lossless (for example, FLAC, WAV), which preserves the original digital signal.

Digitization of motion pictures and videos

The digitization of analog moving images, films and videos takes place in steps similar to audio digitization: sampling is the first step, followed by quantization and compression. The result is the conversion of continuous analog signals into discrete digital data. Digitally stored movie can be stored on your computer, edited, and transferred to other devices.

Sampling

The first step in digitization is sampling: the frames of the film are recorded at given intervals. In the case of moving images, two main sampling methods are distinguished: temporal and spatial sampling. Temporal sampling determines the number of frames recorded per second (fps), and spatial sampling determines the resolution of the pixel matrix within a frame.

Quantization

After sampling, quantization follows: in the frames, the brightness of the pixels and color information are rounded to discrete values, that is, continuous analog signals are converted into a finite number of digital values. The quality of quantization is determined by the bit depth, which indicates how many bits per pixel the information per pixel is stored on. A higher bit depth results in better image quality, allowing you to distinguish shades of more colors and brightness.

Compression

Digitally stored video can take up a lot of storage space, so compression is very important. The goal of compression is to reduce the amount of data as much as possible without significantly affecting the quality of the movie. Types: lossy and lossless compression. Lossy compression (for example, MPEG, H.264) omits information that is less important for visual perception, while lossless compression (for example, PNG for images) preserves exactly the original data.

3.5 The importance of digitalisation in modern agriculture

Precision agriculture uses modern technologies and data analysis methods to optimize agricultural practices to increase productivity, reduce environmental impact and improve economic efficiency.

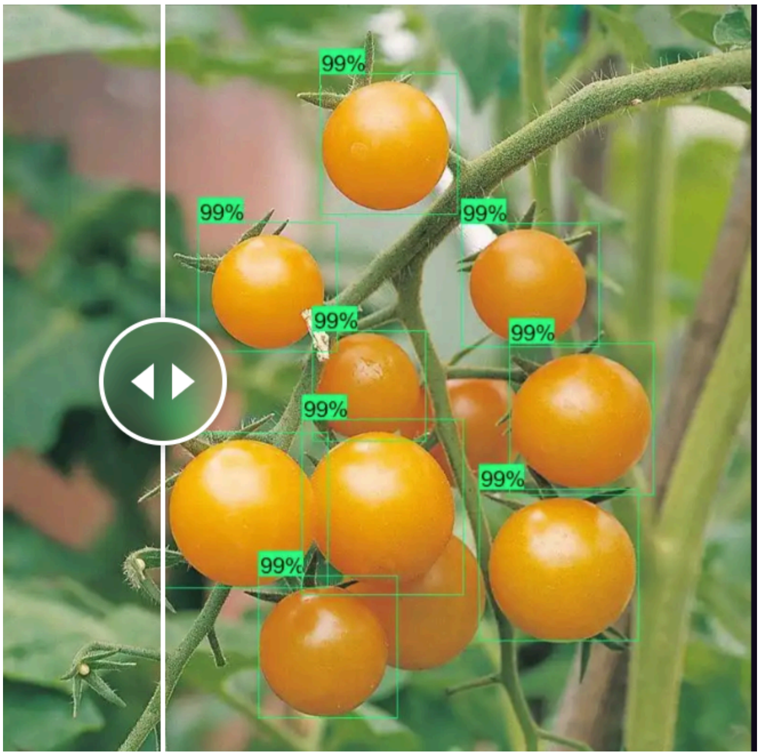
Digitalisation plays a key role in this process, as it allows for more accurate observation, analysis and management of agricultural processes. Let's look at some examples.

Audio digitization

- By analyzing audio recordings, we can observe and track the behavior of animals. By identifying sounds that give signs of stress or illness, early intervention is possible.
- Specific sounds indicating the presence of certain pests or diseases, such as insect buzzing or ultrasounds emitted by plants, can be identified using digital technologies, allowing farmers to take timely action.

Image digitization

- Using satellite imagery and aerial imagery taken by drones, farmers can monitor large areas to identify, for example, drought or infections. This allows for more accurate water management and targeted application of plant protection measures.
- With the help of digital images, farmers can detect plant diseases and pests early, enabling quick and targeted treatment, or they can estimate the expected tomato yield in a smart greenhouse using AI analysis.

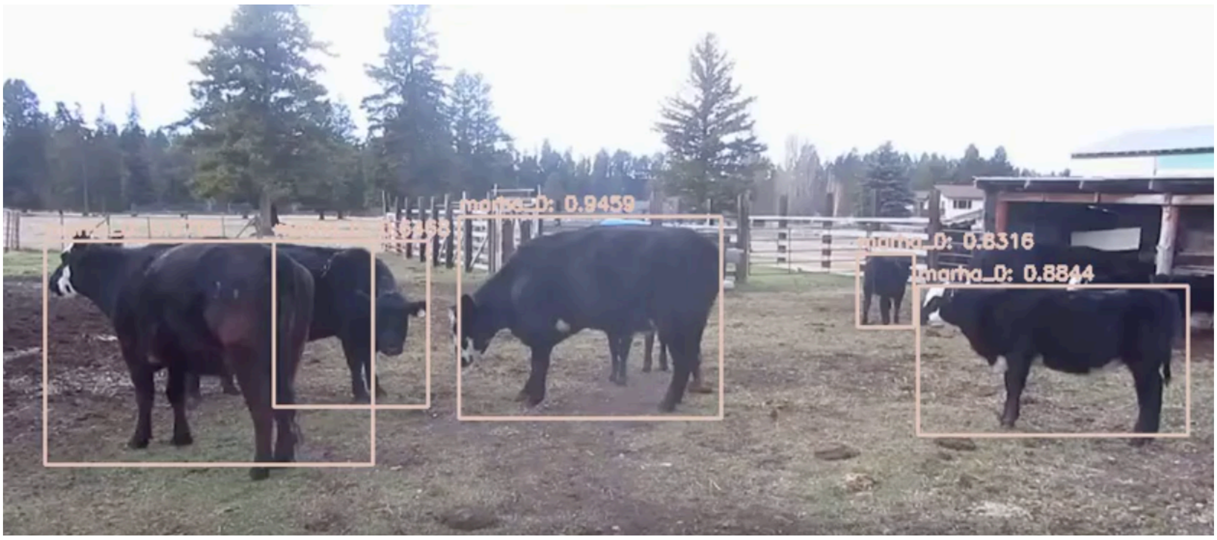


Source: https://www.prompt.hu/szoftver/ai/

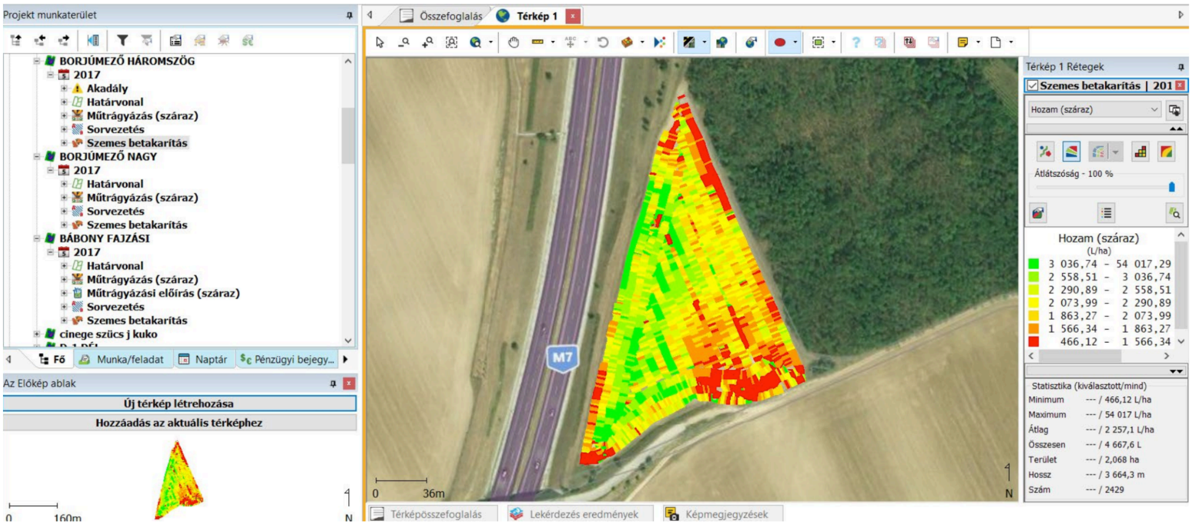
We can see AI solutions for further domestic developments for the above examples on the following website: https://www.prompt.hu/szoftver/ai/

Digitize videos

With video cameras and artificial intelligence (AI)-based analytics, farmers can monitor the condition of animals and crops in real time. Observing animal behavior can help identify welfare issues, optimize feeding strategies and improve the effectiveness of breeding programs.



Analysis of digital recordings allows you to improve the efficiency of agricultural workflows such as planting, spraying and harvesting.



Source: Dr Láng, Veres: Precision farming, 2018, https://mlc.itstudy.hu/hu/mlc-browser/precizios-gazdalkodas

Overall, the conversion of analog signals into digital signals, its digitization, is the technology that allows farmers to get a more accurate picture of production processes, helping decision-making processes, increasing productivity, reducing environmental impact and improving overall economic efficiency.

4. Concept and operation of sensors

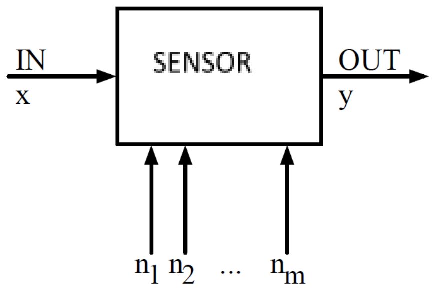
4.1 The concept of sensor

A sensor is a device that can detect physical or chemical quantities (such as temperature, light intensity, pressure, moisture, gas concentration, etc.) and convert them into electrical signals. Electrical signals can be analyzed, processed, visualized by various devices, and thus we can obtain information about the environment or perceived phenomena.

Sensors can be very simple devices, such as the temperature sensor above, or more complex systems, such as multispectral imaging sensors, which can collect data at different wavelengths of light. The development and application of sensors play a key role in modern technological innovation.

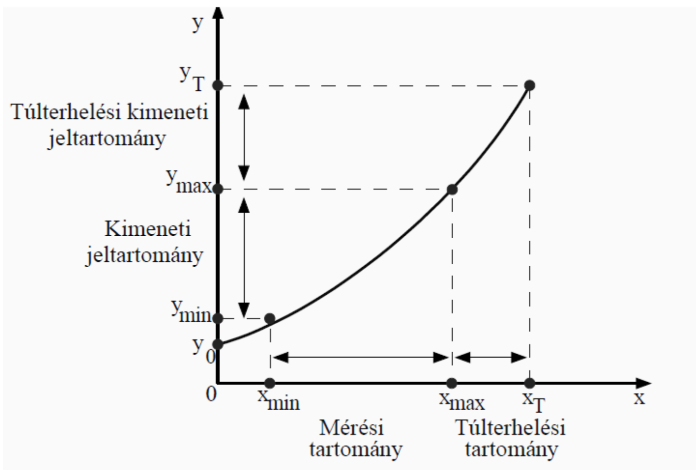
The conversion of the properties of various phenomena into electrical quantities has become so common that a sensor is any technical measuring device whose input is not an electrical quantity and whose output is an electrical quantity, and which satisfies the requirements of methodology: accuracy, repeatability, resolution, shelf life, immunity to environmental influences.

Sensors can be classified according to several criteria: according to their principle of operation, according to the nature and type of input quantities, and according to the nature of the outgoing electrical signals. The output signal (output – y) of each sensor used in the measurement process is a function of several input quantities. Of the input quantities, apart from the one to be measured (input – x), the rest are considered as interference signals (nk – noise), the effect of which we try to reduce during the measurement.



With the help of sensors, we are able to measure and detect physical or environmental characteristics such as temperature, pressure, light, sound or motion. Sensors can be used to monitor environmental conditions, collect data, or operate devices. Sensors convert features in their environment into electrical signals, which can then be transmitted and processed by other devices or systems. Sensors are widely used in industry, science, healthcare, automotive, smart devices and many other fields.

To determine the static characteristics of the sensors, we can determine the steady values of the output by recording the input quantity at a constant value in time. The relationship y(x) between output and input quantities can thus be obtained as a static characteristic.



Based on the static characteristic, quantities characteristic of an important sensor are determined. In order to limit the scope of the curriculum, we will mention only the most important ones:

Measuring range [xmin, xmax] in which the specifications specified for the sensor are met.

Output signal range [ymin, ymax], the interval in which the output signal values are located when x travels over the entire measuring range.

Overload range is the input signal [xmax, xT] value interval in which the sensor is still operational but no longer meets the required specifications. It is important that when returning from the overload range to the measuring range, the sensor operates according to the original static characteristics. If x > xT , then the sensor may become incapable of operation (xT − breaking limit).

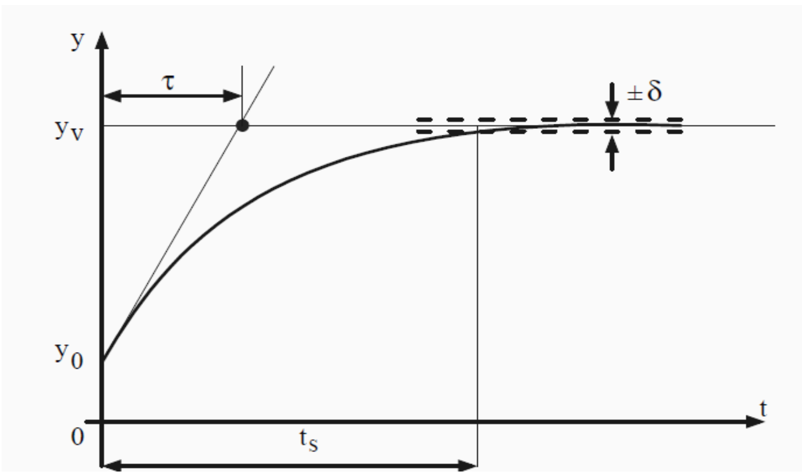
Sensibility is the differential quotient calculated at a given operating point M, which is the ratio of changes in output to input. Expresses the change in sensor output relative to unit change in input.

$$S_a = \frac{\Delta y}{\Delta x}\bigg|_M \quad \left[\frac{\dim\, y}{\dim\, x}\right]$$

Resolution means the change in input quantity that produces a perceptible (quantifiable) change in the output. If the sensor output is digital, the resolution is equal to the least important bit (digit). For example, if the display of a digital thermometer can display differences of 0.1 °C, the resolution of the sensor is r = 0.1 °C.

Dynamic time characteristics: if the input quantity x to be measured changes over time, the instantaneous value of the output quantity can be determined for the input quantity values at each time moment. The relationship between the instantaneous values of the input and output quantity is determined by the time-dependent differential equation of the sensor, commonly referred to as the dynamic characteristic of the sensor.

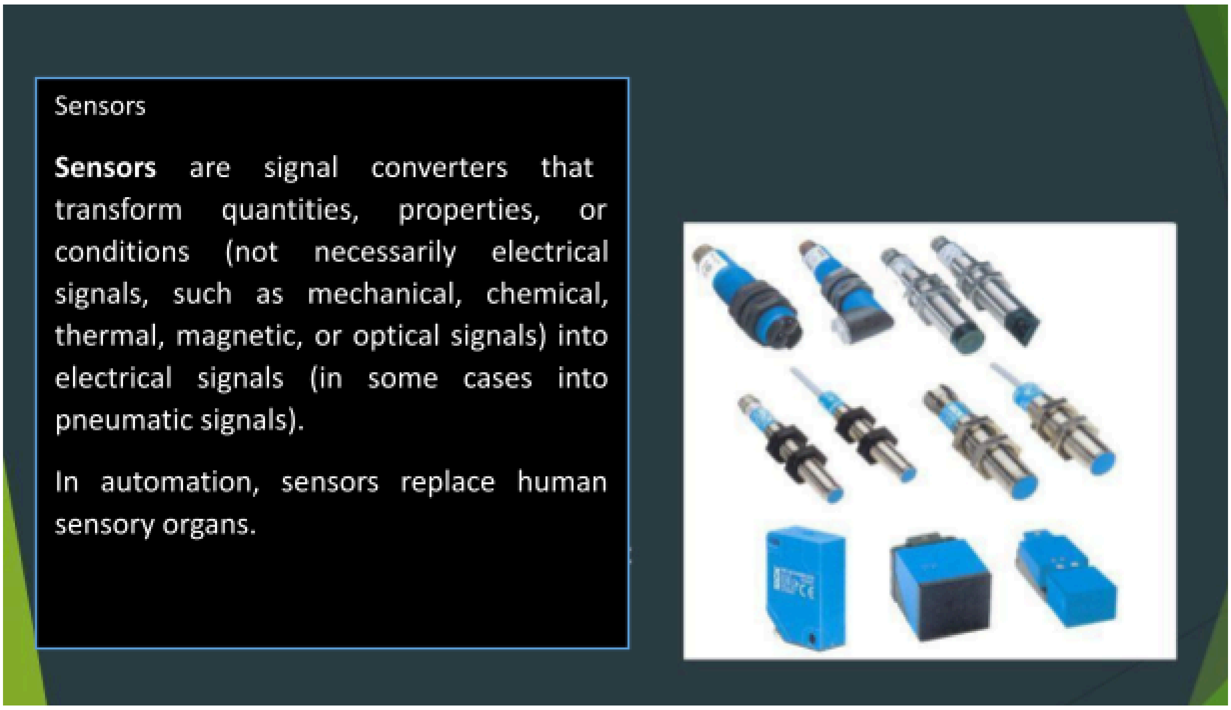
The dynamic time characteristics are determined by switching a stepwise jump input signal to the input. If the sensor can be described by a first-degree, linear, constant coefficient differential equation, then its dynamic characteristics are:



– **time constant −** ⍰ : at the moment of a sharp change in the input signal (t=0), the intersection of the tangent drawn to the curve on the line of the final (steady) value of the output signal YV.

− TS : the time between the sharp change in the input signal (t=0) and the moment when the output signal fits into the permissible deviation band around the final value of YV.

For example, the dynamic characteristics of a temperature sensor are typically used, as the thermal sensing element takes a certain amount of time to warm up to the ambient temperature. In generalterms, however, the dynamics of the sensor can be described by a higher degree differential equation.



The sensor element is the part of the sensor that detects the aforementioned physical factor. Since it is rarely used on its own, this element is accompanied by signal processing, transducer elements, housing, connector and fastening elements.

Sensors can detect one or more characteristics, and we can also talk about a multisensor system, when there are sensor elements capable of detecting multiple values within one sensor.

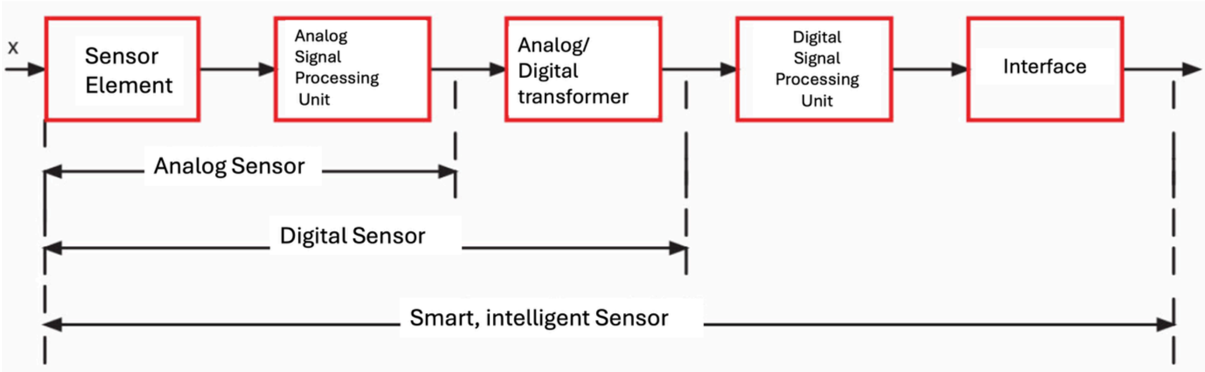


Diagram of the integration array of analog, digital and smart sensors:

A smart sensor is a micro-electronics integrated unit that includes at least one sensor, an analog signal processing unit, an analog-to-digital converter, a digital signal processing unit and a wired or wireless interface that can be easily connected to other systems.

A smart sensor is a smart sensor that has one or more functions such as self-testing, self-testing, validation, adaptation, etc.

4.2 Grouping sensors

Sensors can be grouped in several ways, depending on the characteristics by which we want to organize them. Here are some common groupings for sensors:

By physical characteristics:

- **Optical sensors:** e.g. light sensors, cameras.
- **Sound sensors:** e.g. microphones, sound sensors.
- **Motion sensors**: e.g. gyroscopes, accelerometers.
- Temperature and humidity sensors: e.g. temperature sensors, hygrometers.

By field of application:

- **Environmental sensors:** e.g. air pressure sensors, earthquake sensors.
- **Biometric sensors:** e.g. fingerprint readers, heart rate sensors.
- **Environmental sensors:** e.g. air pollution meters, radiation sensors.
- **Positional sensors:** e.g. GPS modules, compasses.

By communication interface:

- **Analog sensors:** sensors that output an analog signal.
- **Digital sensors:** sensors that emit a digital signal.

Based on the principle applied:

- **Photoelectric sensors:** e.g. photodiodes, phototransistors.
- **Chemical sensors:** e.g. gas detectors, pH sensors.
- **Biological sensors:** e.g. bioluminescent sensors, enzyme sensors.

It is important to note that the grouping of sensors is not clear and strictly defined, as many sensors can be divided into several categories depending on what aspects are taken into account.

4.3 Analog sensors

Analog signals are provided, for example, by flow sensors, displacement sensors or torque meters. Analog sensors are devices that generate analog signals. Analog signals represent continuous values according to the measured characteristics. Analog sensors detect physical signals from their environment, such as temperature, pressure, or luminance, and convert them into analog electrical signals. Analog signals are usually present in the form of voltage or current.

Analóg fényerősség mérő szenzor
Source: https://www.microcontroller.hu/termek/temt6000-fenyerosseg-mero-szenzor/

The output of analog sensors usually changes with the measured characteristic. For example, the output voltage of a temperature sensor depends on the measured temperature. Analog sensors are usually followed by an analog-to-digital converter (ADC), which converts an analog signal into a digital form for processing by digital systems or microcontrollers.

Analog luminance sensor
Source: https://www.microcontroller.hu/termek/temt6000-fenyerosseg-mero-szenzor/

Analog sensors are widely used in industry, electronics, automotive and other areas where precise measurement and control of ever-changing characteristics is important.

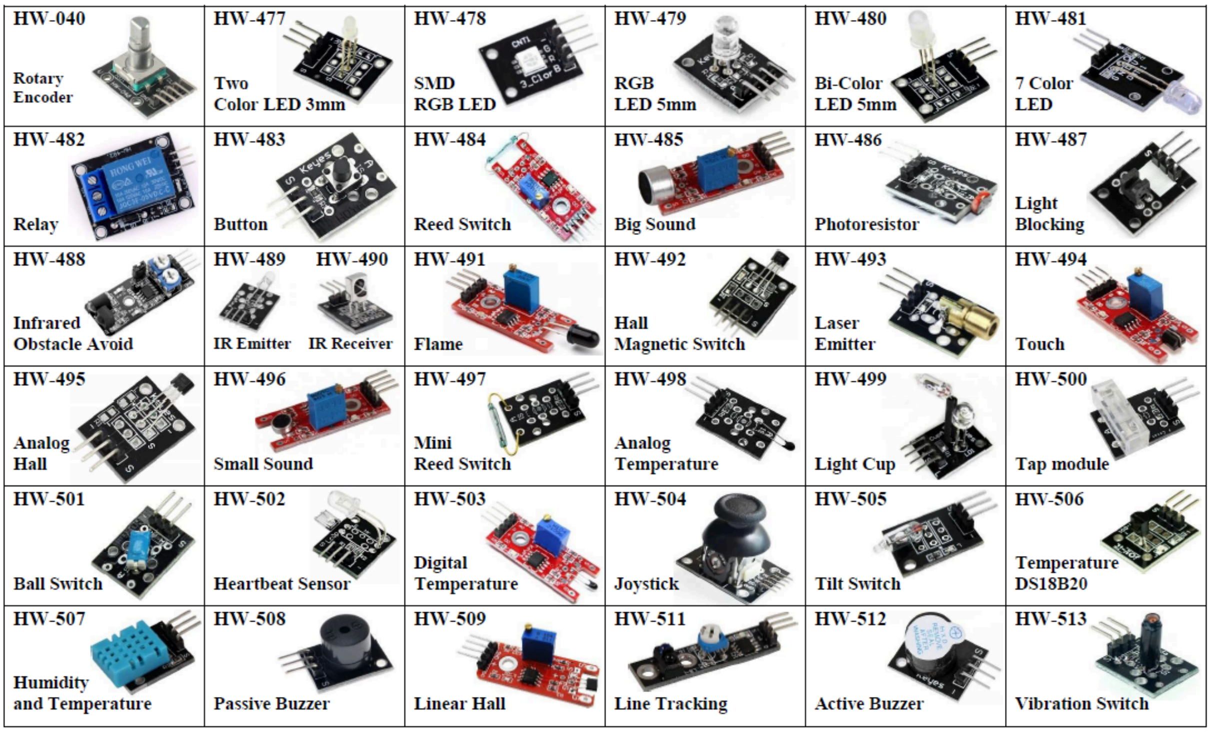
4.4 Digital sensors

Digital sensors are devices that generate or output a digital signal as a result of measurements, the output is displayed in binary form, usually with values of 0 and 1 or digital protocols.

Example of digital sensors:

1. **Digital temperature sensors:** these sensors can measure ambient temperature and return digital values. Digital communication protocols such as I2C or SPI are often used.
2. **Digital motion sensors:** these sensors detect movement in their surroundings and emit a digital signal when motion is detected. Passive infrared (PIR) technology is often used.
3. **Digital light sensors:** these sensors measure ambient light intensity and send digital signals based on perceived light conditions.
4. Digital distance sensors: these sensors measure distance relative to other objects. Distance is expressed in digital form, often in the form of pulses or digital codes. For example, laser distance sensors or ultrasonic sensors.
5. **Digital pressure sensors**: these sensors can measure pressure and output digital values. They can use digital communication protocols such as I2C or SPI.

The advantage of digital sensors is that output signals can be easily read and processed in digital systems. Data is more accurate and less susceptible to interference or noise. In addition, they often include a built-in analog-to-digital converter (ADC), which allows analog signals to be digitized, making it easier to connect sensors to microcontrollers or other digital systems. Some examples of different analog and digital sensors can be seen in the image below:



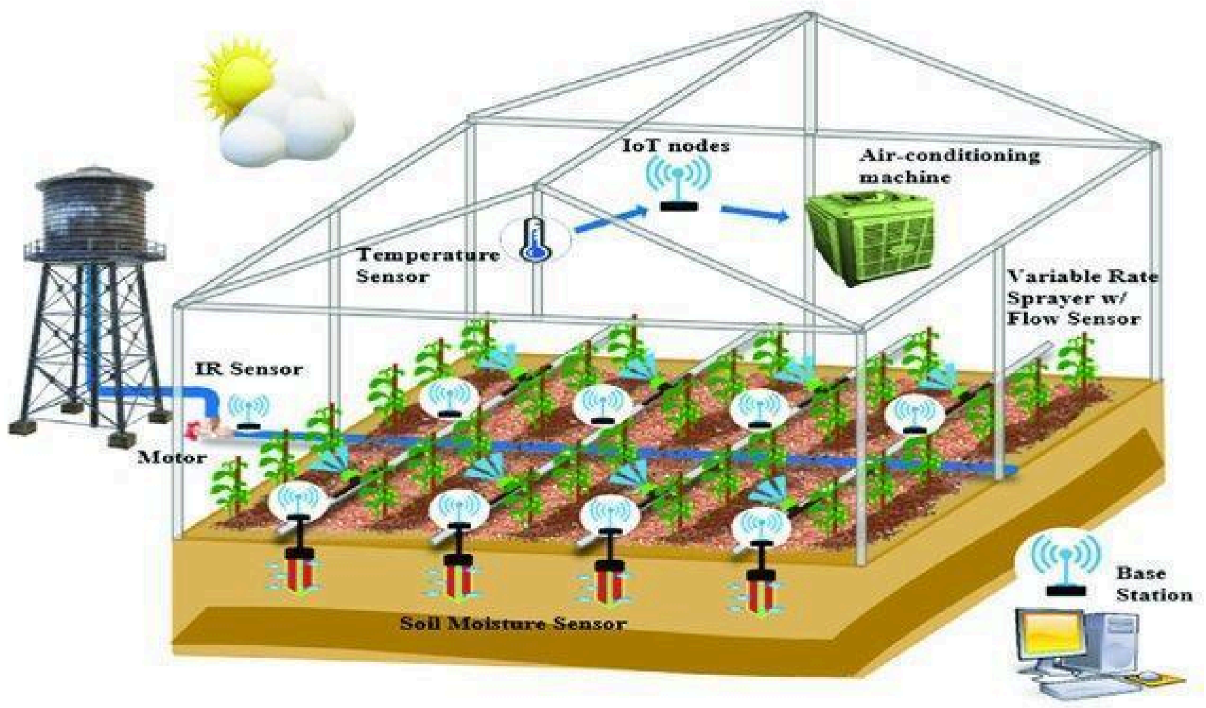
Analog and digital sensors
Source: https://cleste.ro/kit-37-senzori-arduino.html

5. Control systems

5.1 The concept of control systems

A control system is a set of devices, equipment or software designed to control and control the operation of a particular environment, process or machine in order to achieve the desired results or behavior. The control system monitors input signals from the environment (data coming from sensors) and generates output signals based on them, which affect the operation or status of the system.

Control systems collect data on the state of the environment, process the data, and then generate outputs to control and control the system to achieve optimal operation, efficiency and safety.



[Smart greenhouse ecosystem](https://www.researchgate.net/figure/An-example-of-smart-greenhouse-ecosystem_fig1_344728432)

https://www.researchgate.net/figure/An-example-of-smart-greenhouse-ecosystem_fig1_344728432

5.2 Classification of control systems

The two fundamentally different types of control systems are open-loop and closed-loop systems, which represent two basic approaches to automated control of systems. Both types have their own characteristics and scope of application, depending on how important feedback is in the operation of the system.

Open-loop (no feedback) control system

In an open-loop control system, the control device does not receive feedback on the output of the system. This means that the system takes into account only the input signals and performs actions or changes based on them, without checking whether the desired result has been achieved. Open-loop systems are simple, often cheaper, and are used when environmental changes and external disturbances have less impact on system operation or where accuracy and feedback are not critical.

Features of open-loop systems:

- Open-loop systems are generally much easier to use than closed-loop systems. No output data is required; they operate independently of the environment.
- Greater exposure to disturbances. They cannot detect errors, you cannot measure the output of your activities.
- Depending on the quality of programming, the chances of success are either very high or very low. If the system is robustly built, it is most likely to work well, otherwise it is more susceptible to failure.

Examples

- A simple electric heater that is turned on and off by a timer. Based on the settings of the timer, the heater turns on for a specific period of time, without taking into account the actual temperature in the room.
- An easy-to-understand example is an automatic washing machine, which performs washing cycles taking into account a certain period of time to maintain control of the system.

Closed-loop (feedback) control system

The closed-loop control system, also known as feedback control system, continuously monitors its output and sends feedback based on the received data, which affects the input of the system. Continuous feedback allows the system to adapt to environmental changes and unexpected disturbances, allowing it to maintain desired output state or performance more efficiently.

Example: the home heating system, which is equipped with a thermostat. The thermostat measures the temperature in the room, and when the temperature reaches the set value, the heating is turned off. If the temperature drops, the heating turns on again. Here, the feedback provided by the thermostat helps the system maintain the desired temperature.

How does the control system work?

A control system is a set of machines designed to manage other systems. The system usually consists of electronic circuits with pre-"burned-in" programs suitable for controlling the system.

5.3 The main components of control systems

Sensors

They collect measurable information about the environment or state of the system. These can be, for example, temperature, pressure, speed or position sensors.

Control unit

It processes data coming into the system from sensors, makes decisions and generates output signals to control the system. The control unit can be either a simple circuit or a complex computer system, depending on what tasks it is supposed to perform.

Actuators

Actuators are devices or equipment that respond to the output signals of the control unit and appropriately affect the operation of the system. These can be, for example, engines, valves, controllable electrical or mechanical equipment.

It is important to note that the design and implementation of control systems can be extremely diverse, and there are many different methods, technologies and standards for developing control systems. Depending on the specific application, control systems can be analog or digitally based and use different control strategies such as open loop, closed loop or modular

5.4 Basic functions of the control system

A control system is a set of machines that are used to manage other systems. The system usually consists of electronic circuits with pre-"burned-in" programs that are suitable for controlling the system.

Control systems are usually grouped according to different criteria, but there are a few functions that are usually found in all systems. Such are control, planning, backup plan

Control

Control takes priority over other functions of the system, it is the system class that gives the commands. The specific functions vary, but the aim is always to manage the activities in the best possible way.

Planning

Each control system has a pre-programmed algorithm or other design. The plan consists of instructions for the implementation of the functions set. It shall include data defining the objectives and requirements to be met.

Whether it is an open-loop or closed-loop system, there is always the possibility of branching, where the system must choose the path by which it has the highest probability of achieving the intended result.

Fallback plans

Each control system has a "strategy" to avoid failure. Nevertheless, it happens that it is not possible to prevent a malfunction, for such cases there is a backup plan, which, with appropriate intervention, corrects the error and allows the system to return to a previous state.

Input current signals

Input current signals serve as a kind of warning or indication. Based on the input signal, the system is informed that an external power source is available. The signal can be identified by all control systems, but only closed-loop systems are able to interpret the signal and respond accordingly.

Variable that can be manipulated

In the control system, the "manipulable variable" (also known as the controllable or intervening variable) is the variable that is directly controlled or adjusted to achieve the desired output. This variable is the input sent to the system, which is modified by the control system so that the output variable (or measurable response) approaches the desired reference value.

For example, in a temperature control system, where the goal is to control the temperature in the room to a predetermined value, the variable that can be manipulated could be the power of the heating element or the cooling intensity of the air conditioner. The control system adjusts this variable to achieve and maintain the desired temperature level despite changing environmental conditions.

A variable that can be manipulated is often contrasted with disturbance, which is an unwanted external change that the system must compensate for, but cannot directly control. The task of the control system is to compensate for these disturbances and maintain the system in the desired state by properly controlling the variables that can be manipulated.

In open-loop control systems, the setting of manipulable variables does not depend on the output variable, i.e. there is no feedback. In this system, variables that can be manipulated are set according to predefined rules or programs, taking into account possible environmental conditions or other pre-known factors. Since there is no feedback, open-loop control cannot compensate for unexpected changes or disturbances that may affect system output.

In closed-loop (or feedback) control systems, the setting of manipulable variables directly depends on the difference between the output variable and the desired setpoint. The system continuously monitors the output variable and uses the received information (feedback) to precisely adjust the variables that can be manipulated so that the output approaches or matches the desired value. This enables closed-loop systems to react dynamically to changes and disturbances, improving system stability and accuracy.

Basic requirements for the control system:

The basic requirements for control systems can be broad and varied, depending on the application or industry in which they are used. These requirements generally include reliability, accuracy, stability, fast response time, and adaptability. I will go into more detail about these main requirements below:

- **Reliability**: the control system must work continuously for a long time with minimal maintenance. Reliability is key in safety-critical applications such as flight control or medical solutions.
- **Accuracy and repeatability:** the system must be able to produce the desired output values accurately and repeatably, even under changing environmental and operational conditions.
- **Stability**: the system must be stable in its responses, i.e. the output must not oscillate around the desired value, even if external disturbances occur.
- **Fast response time**: the system needs to react quickly to input changes or reference value changes to respond effectively to rapidly changing processes.
- Robustness: the system must be able to operate efficiently and maintain performance even if unexpected disruptions occur.
- **Adaptability and flexibility:** modern control systems must be able to adapt and operate flexibly under changing conditions and requirements, including changes in environmental conditions or user needs.
- **Energy saving and efficiency:** In energy-intensive industries and applications, it is particularly important that control systems operate in an energy-efficient manner, reducing operating costs and reducing the ecological footprint.
- **User-friendly interface:** Control systems must have an intuitive, user-friendly interface that allows easy setup, monitoring and maintenance.

These requirements are essential guidelines to be taken into account during the design phase in order to develop and build efficient, safe and reliable control systems.

5.5 Control systems in agriculture

Control systems used in agriculture make a major contribution to more efficient and optimised farming. They are useful both in crop production and animal husbandry, in the management and regulation of greenhouses. Some examples of agricultural control systems include:

Irrigation systems

Irrigation systems automate irrigation processes in agricultural fields. They use sensors to monitor soil moisture, meteorological data and water demand of plants, and then regulate the irrigation system based on this. This allows you to use water more efficiently, optimally water the plants and minimize water wastage.

Precision agriculture systems

Precision agriculture systems help farmers manage and monitor agricultural activities with greater precision. With GPS-based technology, they can accurately track the position and movement of machines on farmland, optimizing operations such as sowing, fertilizing or spraying. Precision increases productivity, reduces costs and minimizes environmental impact.

Production management systems

Production management systems help grow crops in greenhouses or other controlled environments. They monitor and regulate crop environmental parameters, temperature, humidity, light intensity and CO_2 levels, enabling farmers to provide ideal conditions for plant growth and development and optimise energy production and use.

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CHAPTER 2

1. MOBILE COMMUNICATION IN GREENHOUSES

Author:

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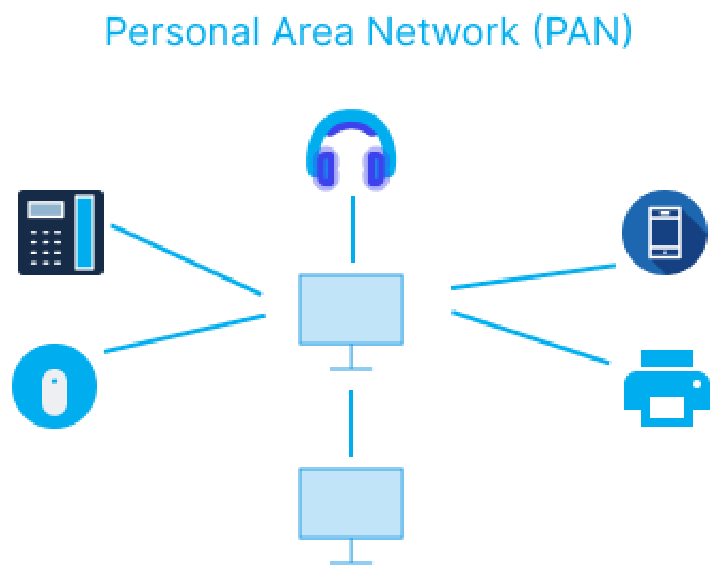
1. Network communication

The need to share information and resources between different computers has led to interconnected computer systems, known as networks, so that data can be transferred from one machine to another. In these networks, computer users can exchange messages with each other and share resources such as software packages, data storage facilities, printer access, etc. To run such applications, a software system is required that also provides a network-wide infrastructure (Brookshear & Brylow, 2017).

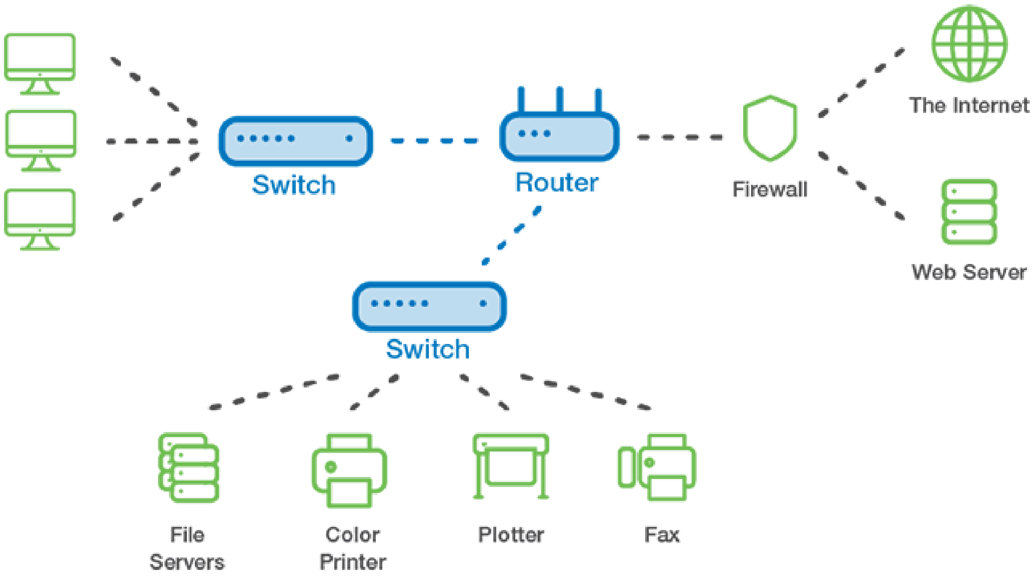
In the case of computer networks, we distinguish between:

- personal area networks (PAN), which are usually short-range systems, where devices involved in communication, such as digital TV, digital camera, printer, etc., are placed within a distance of less than a few metres:



Source: https://www.prepbytes.com/blog/computer-network/types-of-computer-networks/

- local area networks (LANs), which are the interconnection of computers, mobile devices, printers, etc. in a single building or group of buildings:



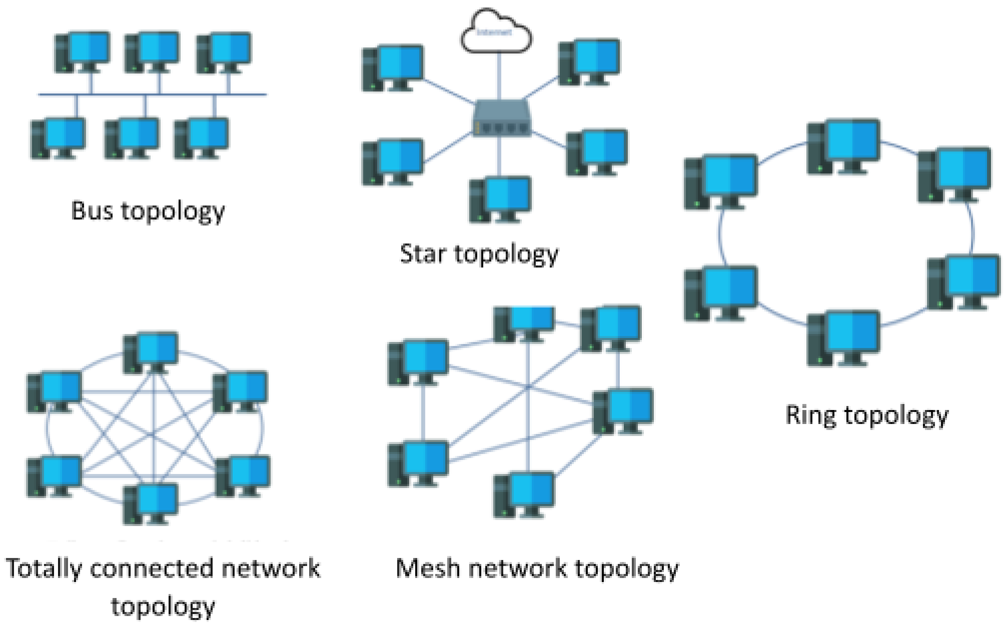
Source: https://www.tpx.com/learn/networking-solutions/what-is-a-local-area-network/

- metropolitan area networks (MAN), which are medium-sized networks, such as a network covering a local community,
- wide area networks (WANs), which connect machines that are far apart, for example in neighbouring cities or devices on the other side of the world.

Source: https://www.vecteezy.com/vector-art/5237398-wan-wide-area-network-concept-with-icon-concept-with-round-or-circle-shape

Another way to classify networks is based on whether the internal operation of the network is public or controlled. On this basis, we distinguish between **open** and **closed** networks. For example, the Internet is an open system. Communication over the Internet is governed by an open set of standards known as the Transmission Control Protocol/Internet Protocol (TCP/IP) protocol suite. Because it is an open system, these standards can be used freely by anyone without paying a fee or signing a licence agreement. In contrast, Novell Inc. develops and operates proprietary systems and earns revenue from the sale or lease of these systems. This is a closed system.

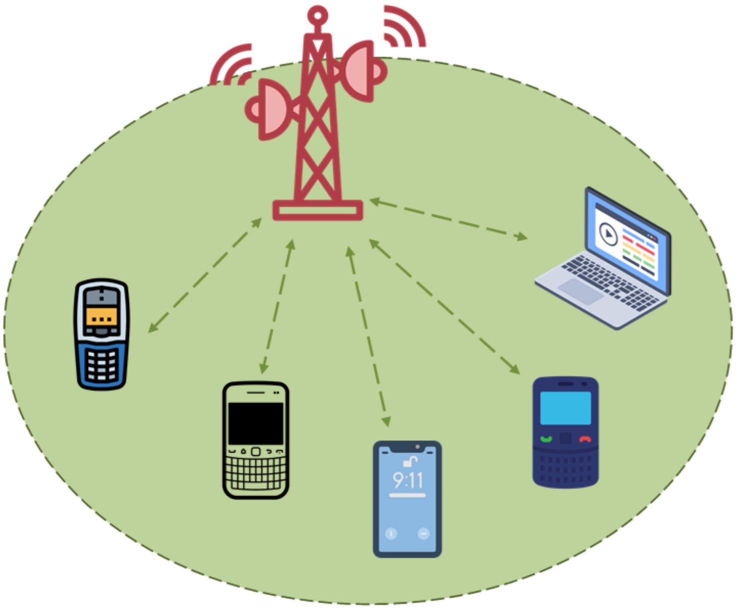
Another way of classifying networks is by the pattern in which machines are connected. The two most popular topologies are the bus, in which machines are all connected to a common communication channel, and the star, in which one machine is central because it is connected to all the other machines. Ring topologies, fully interconnected network topologies and mesh topologies are also used. Bus topology has been popular since the 1990s, when Ethernet networks were developed. Star topology has its roots in the 1970s and is used today to power wireless networks. In these networks, communication takes place via radio transmission and is coordinated by a central machine called an AP-access point. However, the difference between a bus network and a star network is not always obvious.



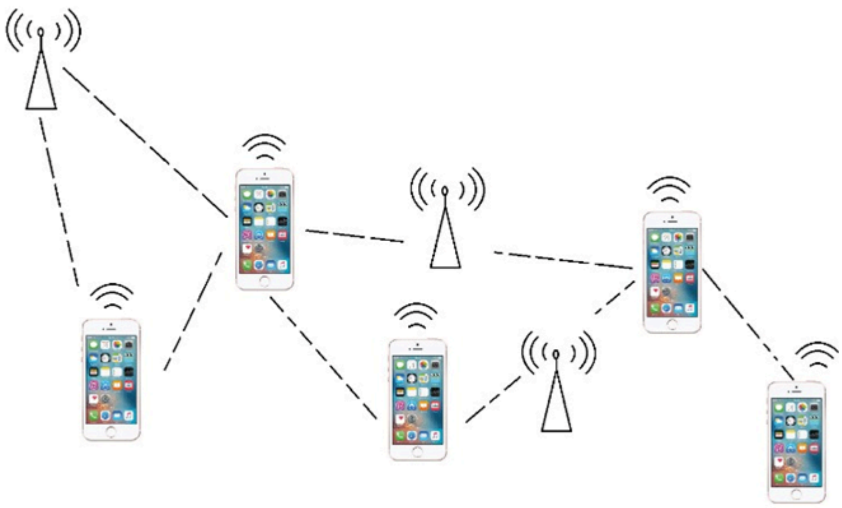
Mobile communication systems are usually divided into three categories.

These are:

- Systems based on a fixed communication infrastructure are the most commonly used systems, where an access point is used to connect to the network. This includes mobile systems such as 2G, 3G, etc. networks:



- Communication systems based on autonomous nodes are used for traffic management and routing. These systems often do not use a fixed communication infrastructure. Examples of such systems are ad hoc networks and wireless sensor networks:



- Hybrid networks combine the previous two categories.

In wireless ad hoc networks, data traffic is routed through nodes. Network devices are free to move around and the connections between devices change frequently, so the information needed to manage traffic in the nodes must be kept up to date.

Wireless sensor networks (WSNs) combine sensors with computing elements. They can integrate hundreds or even thousands of low power, low cost sensors. The sensors can be mobile or fixed, and their job is to monitor the environment. They often have one or more base stations. A base station may be connected to another network, to a high-performance data processing and storage centre, or serve as a connection point to human-managed units.

In order for a network to work reliably, it is important to establish the rules by which network activities can be carried out. Such rules are called **protocols** and developing them is an essential process, because without rules, for example, all computers may try to send messages at the same time, or one computer may not receive content from another computer. Protocols can be implemented at the hardware or software level, or a combination of both. During communication, the parties involved must agree on the protocol to be used. To be agreed, the protocol must conform to standard specifications.

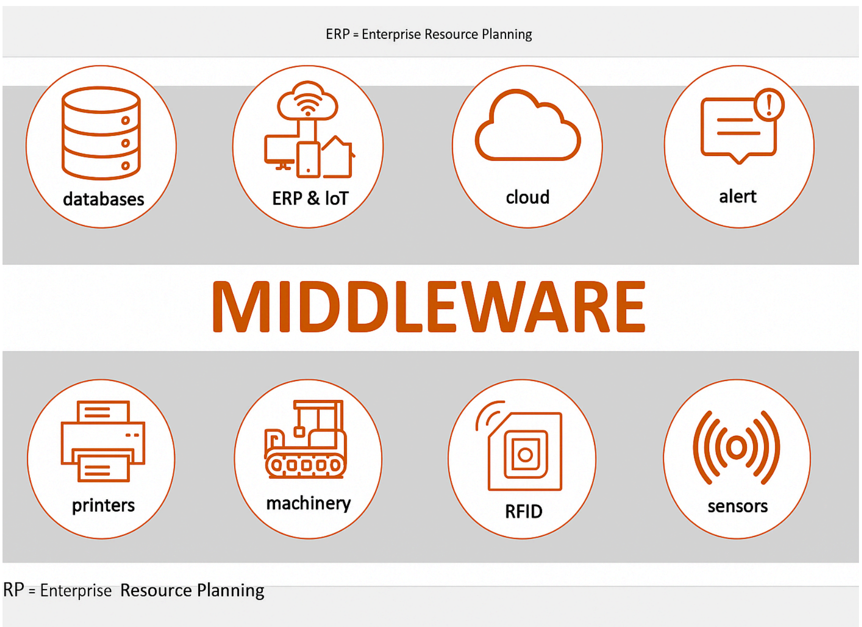
Internet communication protocols are published by the Internet Engineering Task Force (IETF). The Institute of Electrical and Electronics Engineers (IEEE) handles wired and wireless networks, and the International Organization for Standardization (ISO) handles other types.

Request-response (request-reply) is one of the most basic, efficient protocols by which computers communicate with each other. According to the protocol, an exchange of messages between two entities means that the requester sends a requesting message and the receiver, upon receipt, processes the request and sends back a message in response. This is similar to a telephone call, where the caller has to wait for the receiver to pick up and only then can the conversation start. In a client/server architecture, communication is therefore done according to the protocol. The protocol can be used in a **synchronous** mode, for example for web services over HTTP, which means that a connection is maintained until a response is received or the timeout period expires. The protocol can also be implemented in **asynchronous** mode, where the response is returned at an unknown later time.

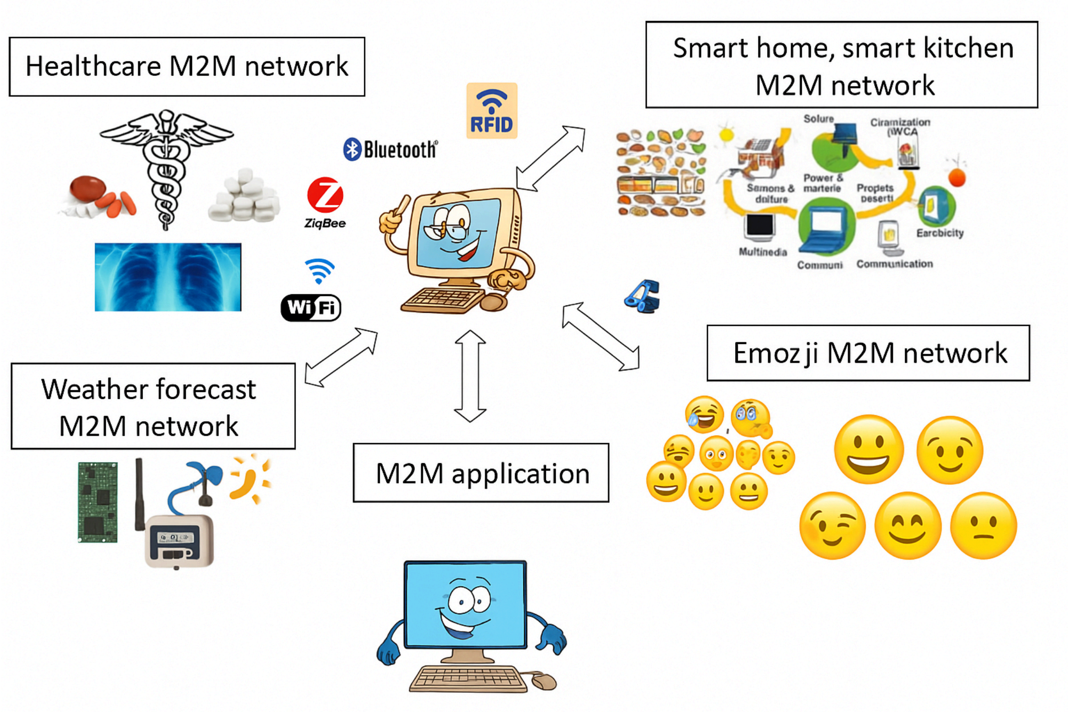
A **lightweight** protocol in a computer network carries a relatively small amount of data in addition to functional data.

Publish-subscribe is a communication protocol where message senders do not send messages directly to a specific recipient, but to so-called subscribers. Without knowing who the subscribers are, the senders group the published messages, and the subscribers, without knowing who published the message groups, indicate which message group they are interested in, i.e. they subscribe. Thus, subscribers will receive the messages to which they subscribe.

Middleware acts as an intermediary between computer applications, data and users. It makes it easier for software developers to intelligently connect applications, simplifying application development. It helps system operators to deploy applications:



Discovery of services and resources is a technology that enables devices or services to automatically connect to a computer network without manual intervention. It allows different types of applications and microservices to work together. There is client-side and server-side discovery.



M2M (machine to machine) is a set of communication techniques between two devices using a direct channel without human intervention. It can be used in both wired and wireless communication. M2M communication enables a sensor or measuring instrument to transmit the information it records (e.g. temperature, wind speed, humidity, etc.) to a device that stores, pre-processes and analyses this data using its own software.

2. Security of mobile systems

Security is defined by three factors: confidentiality, integrity, and availability (S. Bharati, et al., 2023):

Confidentiality means that only authorised devices, systems and persons have access to sensitive information. The oldest technique to protect data is to encrypt it. In computing, this means using top-secret information called a key to transform, encrypt, store and transmit data. When we need the original or transmitted data again, we use the key to recover it. However, the sharing of data encrypted during communication must be preceded by an exchange of information in which the parties agree on the top secret key to be used and authenticate each other. Both key agreement and authentication are very important parts of the communication.

Integrity means that data transmitted over the communication channel must reach its destination without modification. To achieve data integrity, hash functions or message authentication codes are most commonly used. Hash functions are mathematical functions that usually produce a smaller fixed-length string of data, such as 128, 160 or 256 bits, from a string of arbitrary length. This is also known as a trace of the data series. One of the most important properties of hash functions is that the trace cannot be used to recover the original data sequence. Both hash functions and message authentication codes have many applications. For example, when storing a password, the system does not store the password, but the hash value of the password. In practice, a frequently used and secure hash function is SHA-256, the first versions of which were designed by the National Security Agency (NSA) in 1993.

Availability means that data on a data storage server, a server device, must always be immediately available to legitimate users. Commonly used by attackers, denial of services (DoS) or distributed denial of service (DDoS) attacks are attacks that attempt to exhaust system resources. To ensure availability, the hardware and software that stores, manages and displays data must be properly maintained and the technical infrastructure must be constantly monitored.

The most common security problems encountered in mobile communications are (Boudriga, 2009):

- the communicating parties are not sure of each other's identity: when communicating parties who know each other can identify each other by email address, voice, but beyond that, the system usually lacks authentication, many will easily accept any identifier,
- it is easy for a third party to intercept your communications, because although the standards for communications provide some protection against targeted interception, they do not,
- the billing records kept by the service provider contain a lot of confidential information that can easily be leaked: identification numbers of the communicating parties, time and place of communication, etc.

Often, however, the security of mobile communications is affected by factors that are independent of the developers and operators of the system, because the services are often used by users who

- are not aware of basic safety issues,
- do not understand the basic security risks,
- do not have the right skills,
- do not have the means to protect themselves.

There are several ways to secure mobile systems. We distinguish between security at the network level, transport level and application level.

Security at the network layer is transparent to end users and applications. It offers general purpose security solutions with filtering options, for example, you can set to allow only selected traffic to be accessed. It is part of the operating system, so to modify it, the operating system must be modified.

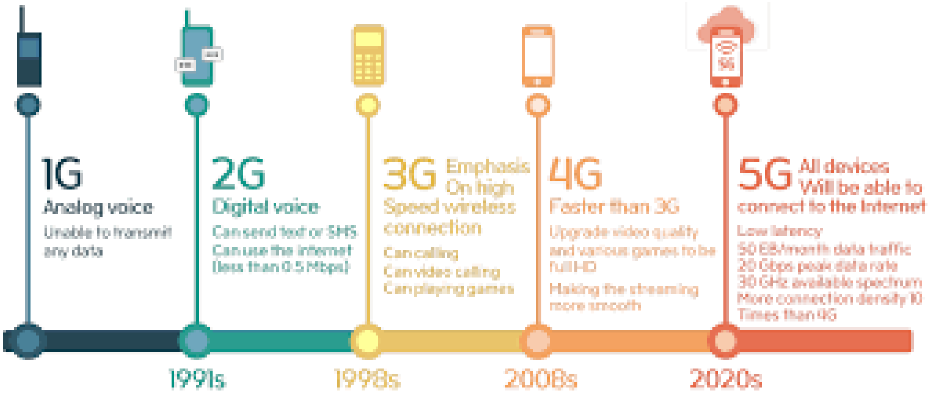
Security at the transport layer is primarily used to implement security for web transactions.

In application layer security, services are embedded in a specific application. The advantage is that the service can be tailored to the specific needs of the application.

Another security problem is that when messages are transmitted, they are not protected against unauthorised copying. Copyright protection can be ensured by embedding watermarks (special patterns). Watermarks can be used to prove ownership, identify the infringer, trace the distribution of the message/document or simply inform users of the rightfulness of the data.

3. Mobile network technologies: 2G, 3G, 4G, 5G and future developments

An important feature of wireless networks is the mobile service, which means that communication can be implemented anytime, anywhere, and users can even request roaming services autonomously (Boudriga, 2009). The development of mobile communication technology has led to increasing data transmission speeds, which nowadays, even for complex applications, often approach the speed of fixed networks:



Source: https://www.linkedin.com/pulse/1g-2g-3g-4g-5g-wireless-phone-technology-explained-meaning-samad

Since the first switchover from analogue 1G data transmission in 1981 to digital 2G transmission in 1992, new generations of mobiles have appeared every ten years or so. A new mobile generation represents a change in the fundamental nature of mobile service, where new technology is not always backwards compatible. A new generation means higher bit rates, new and wider frequency bands and more simultaneous data transmission capacity.

Mobile communications are based on the GSM (Global System for Mobile Communications) standard, developed by the European Telecommunications Standards Institute (ETSI) for cellular networks. In cellular networks, data to and from end points is received and transmitted over a wireless link. The network is distributed over a terrestrial area called cells and each cell is served by at least one, but usually three, transceiver base stations. A cell uses a different set of frequencies from neighbouring cells to avoid interference and ensure quality of service. Portable transceivers (mobile phones, laptops, etc.) communicate with each other and with fixed transceivers via base stations (www.tell.hu, 2023).

The first GSM network, 2G, which was used between 1992 and 2001, still offered very slow data rates (9.6-14.4 kb/s). It initially promised a very high theoretical bit rate (172 kb/s), but the maximum bit rate achieved in practice was only 45 kb/s. It allowed users to call each other on the phone, send SMS (Short Message Service) and MMS (Multimedia Messaging Service) messages to each other.

Low data traffic devices, such as payment terminals, cash registers, legacy phones, IoT devices, smart meters, eCall systems, vehicle trackers, are still widely using 2G technology. These systems have thus been able to avoid newer technologies with high usage costs. It is not even possible to eliminate 2G services altogether, as this would risk that devices with only 2G infrastructure would not be able to connect to the appropriate service providers, for example in an emergency the device owner would be unreachable or unable to contact the appropriate authorities.

UMTS (Universal Mobile Telecommunications System), the 3G network, whose widespread use dates from 2001 to 2008, achieved higher data rates, typically 384 kb/s, even though theoretically 2 Mb/s was announced. However, the actual performance of UMTS under real-world conditions with high network loads was variable. The 3G service provided Internet browsing, music listening, video and music downloading, streaming and navigation. Today, it is no longer economical to maintain 3G infrastructure, which is why devices that cannot connect to the next generation 4G and 5G networks are switching back to 2G.

4G technology has been available since 2008, while 5G has been in use since 2018. Both can handle much higher data traffic and are more secure.

4G technology offers mobile web access, gaming services, high-definition mobile TV, video conferencing, 3D TV, etc. The latest standards offer upload speeds of 150 Mbps and 50 Mbps compared to previous technologies.

The 5G standard has 3 levels, the weakest being Low Band, followed by the medium Mid Band and the strongest being High Band. The Low Band offers speeds 20-30% faster than 4G and uses the same 600-900 MHz frequency range as 4G. The Mid Band offers data speeds six times faster than 4G, from 100-900 Mbps. It is the most widely used service, and is the most commonly deployed in metropolitan areas. High Band can also increase the medium band level tenfold. It uses frequencies between 24 and 47 GHz and often reaches download speeds of up to Gbit/s, similar to fixed services. Due to its high deployment cost, it is only deployed in dense urban environments where crowds gather, and therefore not ubiquitous due to incomplete coverage.

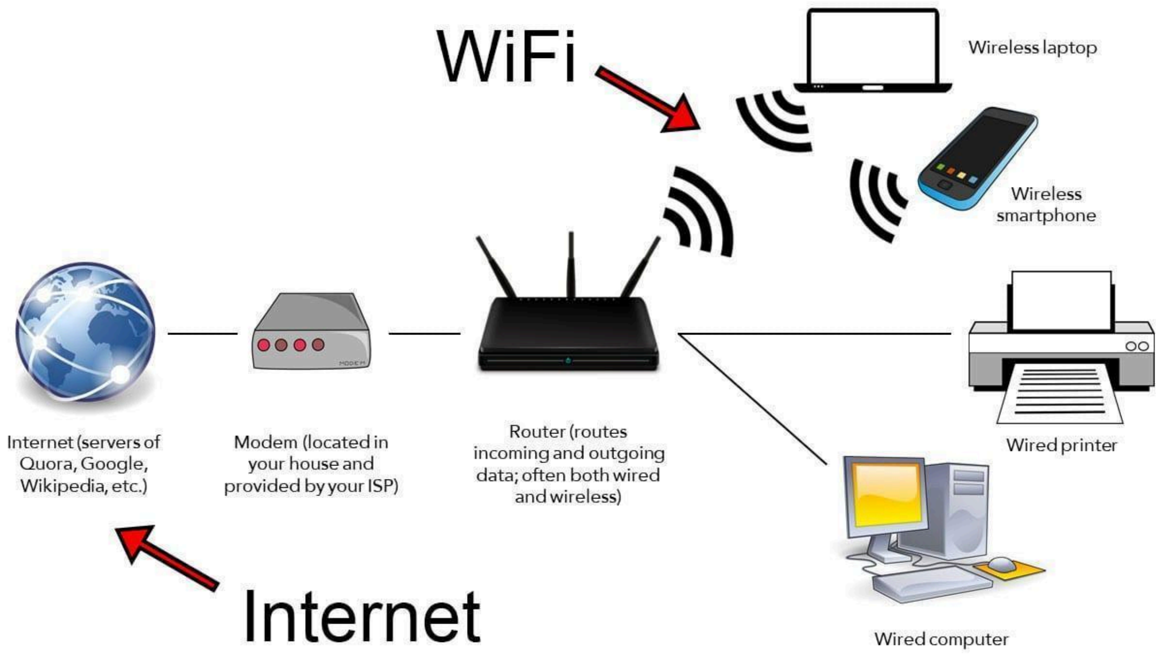
A new generation of mobile services usually requires an update of the software of your mobile device, a change of network settings or a device replacement.

Additional wireless communication systems are in use to provide wireless communication between devices in smaller areas. These include satellite-based systems, wireless local area networks (WLANs) and wireless personal area networks (WPANs). These networks provide high data transmission speeds.

4. Mobile connectivity

4.1 Wi-Fi

Wi-Fi (Wireless Fidelity) is a family of wireless networking protocols commonly used to connect different devices together or to connect devices to the Internet, allowing data to be exchanged between devices. It is one of the most widely used technologies used worldwide to connect devices to the Internet in homes, small office networks, public places such as hotels, libraries, airports, etc. Wi-Fi is designed to work seamlessly with wired Ethernet. Compatible devices can connect to each other, to wired devices and to the Internet via wireless points. Wi-Fi is a trademark of the Wi-Fi Alliance, which limits the use of the term "Wi-Fi Certified" to products that are compatible with each other:



source: https://www.hellotech.com/blog/what-is-the-difference-between-bluetooth-and-wifi

Different versions of Wi-Fi are defined by different IEEE 802.11 protocol standards and different radio technologies. The available radio band, maximum range and speed also depend on the version. Wi-Fi most commonly uses the 2.4 gigahertz (120 mm) UHF and 5 gigahertz (60 mm) SHF radio bands; these bands are divided into several channels. The channels can be shared between networks, but only one transmitter can transmit on a channel at a time within range.

Nowadays, more and more wireless technologies are being used in communication messaging. NFC and Bluetooth technologies are the biggest players in this field. Both technologies allow two devices to communicate within a short range, ensuring secure data transfer between devices.

4.2 Bluetooth

Bluetooth is a wireless technology that allows data exchange between fixed and mobile devices within short range. It is an open source standard. It is named after the Danish King Harald the Blue Tooth, who reigned in the ninth century.

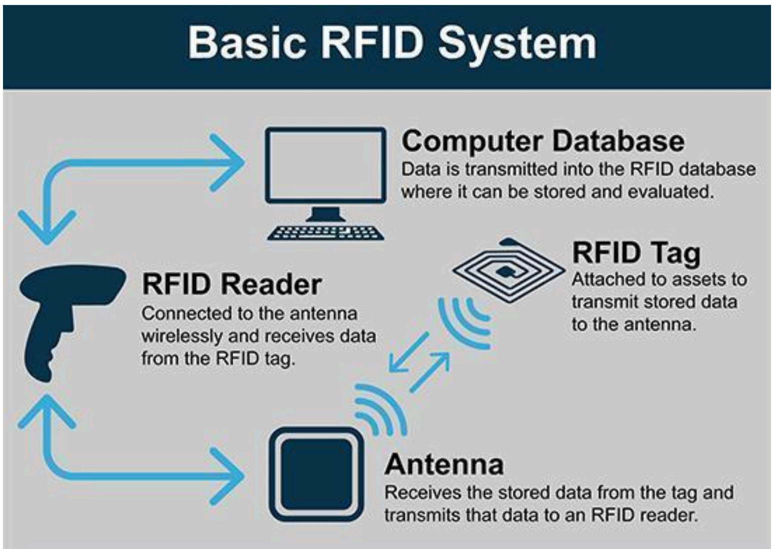
Bluetooth uses UHF radio waves, in Europe and the USA this means the range between 2.402 GHz and 2.480 GHz. It manages a total of 79 dedicated Bluetooth channels with a bandwidth of 1 MHz per channel. It splits the transmitted data into packets and transmits each packet on one of the designated Bluetooth channels.

Many systems use Bluetooth Low Energy (BLE) technology because the technology offers high energy efficiency and performance. Systems using BLE technology can run for months on a single-cell battery alone. Bluetooth-enabled smartphones have also become part of everyday life, and a mobile phone is always at hand so many devices can connect to your mobile phone via Bluetooth. No need to carry additional cards, remote controls or remember PIN codes.

4.3 NFC and RFID

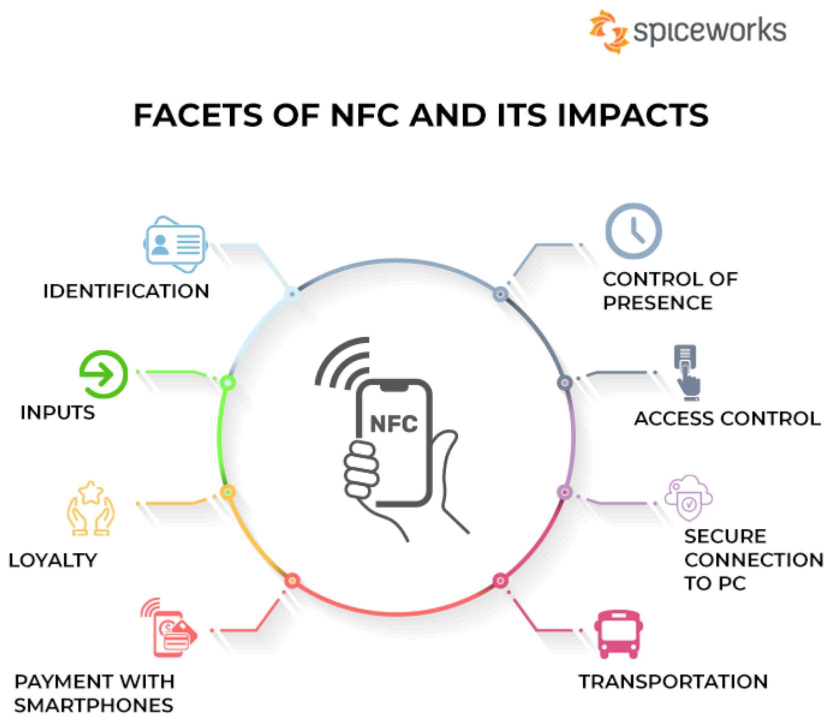
Near Field Communication (NFC) is a contactless short-range communication technology. NFC was launched by NXP Semiconductors and Sony as a further development of RFID (Radio Frecquency IDentification) technologies and smart card technologies. Radio Frequency Identification allows devices in close proximity to each other to identify and exchange data over radio waves.

An RFID system consists of three components: an RFID tag/transponder, an RFID reader/interrogator and an application.



Source: https://www.bradyid.com/intelligent-manufacturing/what-is-rfid

Operationally, the RFID reader "asks" the RFID tag by emitting a radio wave, and the RFID tag responds by sharing the data it stores with the RFID reader. It can read data from multiple RFID tags at the same time. The RFID reader transfers the data received to a database for storage. The application will process the data based on the data stored in the database. The RFID reader can read both stationary and moving RFID tags. RFID systems are used for asset and location tracking, theft prevention, access control, logistics, animal tracking, etc.



Source: https://www.spiceworks.com/tech/networking/articles/what-is-near-field-communication/

NFC technology is also built around three components. A tag, a reader and the software. But an NFC tag can also act as a reader, and vice versa, the NFC reader can be used as a tag. Therefore, unlike RFID systems, it is suitable for two-way communication, where a fast identification process and data transfer can be achieved between devices that are physically close to each other (1-10 cm). Data from one tag can be read at a time. Often used in contactless payment, smart greenhouses, intelligent transport, smart homes, industrial applications. Its popularity can be explained by its low cost, convenience, reliability and integration with smartphones. At the same time, it can be used to deploy management services due to the information storage capability of NFC tags. For example, NFC can be used to improve the management of production and sales processes in greenhouses. Connected to smartphones, even low-skilled farmers can effectively manage production and sales processes.

NFC has three modes: peer-to-peer, read/write and card emulation.

Peer-to-peer mode allows two NFC devices to communicate directly with each other. Communication is bidirectional and standard data structures can be exchanged. In read/write mode, an NFC device can access a passive NFC tag or interact with smart cards.

In card emulation mode, an NFC device emulates a contactless smart card, allowing NFC devices to work with legacy RFID readers.

Like any other electronic device, RFID and NFC devices must comply with various standards and regulations.

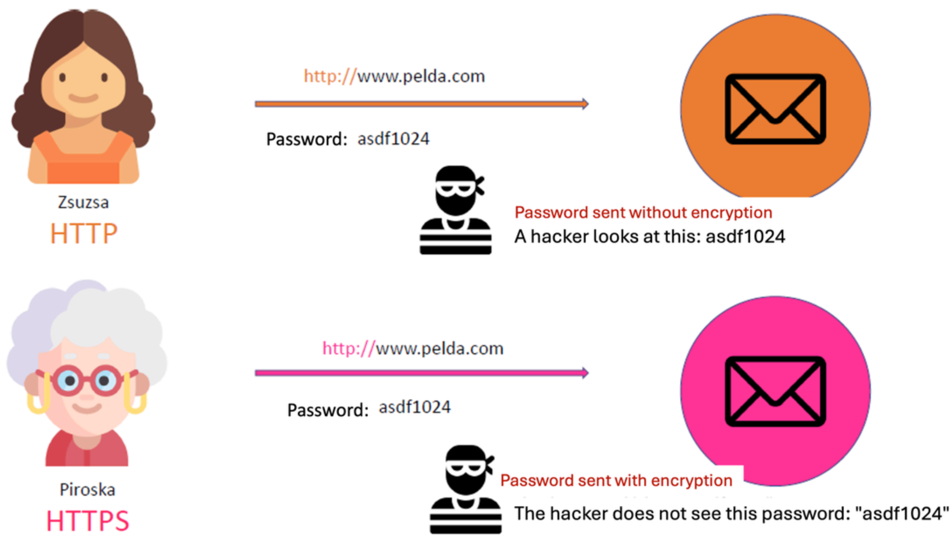
Alternatively, barcode, qr-code, wifi, bluetooth, etc. technologies are used.

5. Communication protocols in greenhouses

5.1 HTTP

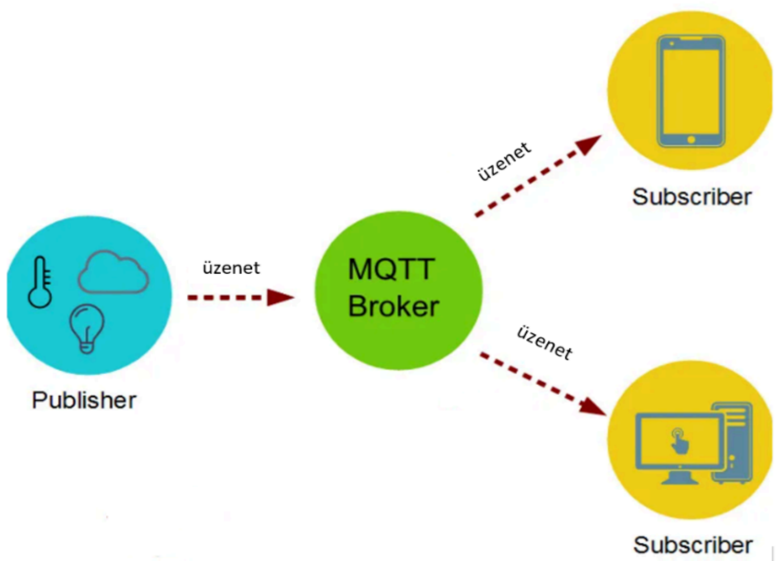
Hypertext Transfer Protocol (HTTP) describes the basics of web communication, the basis for all computer data exchange between a client and a server. For example, the client, a web browser, makes requests that are served by the server, the recipient. Requests can come from the client via text input, mouse clicks, screen taps. The protocol handles hypertext type documents, which means that references can be made in the documents through which the client's requests are fulfilled using various resources. It does not use encryption or authentication and is vulnerable to multiple attacks, but is fast due to the lack of security settings. It is generally used for information sharing. It is not expensive to maintain.

HTTPS is a secure version of HTTP, (httpwg.org, 2023), is not a standalone protocol, runs on top of HTTP and uses the TLS/SSL standard for security. It assures the user of the confidentiality and integrity of the communication and that the website being visited is authentic. However, secure communication can only be achieved if appropriate encryption packets have been selected and the authenticity of the server has been verified. Built into all modern web browsers, its use depends on the web server. It is protected against multiple attacks. Slower than HTTP due to the security settings used. It is mandatory for websites handling sensitive data (passwords, card details, etc.). It is expensive to maintain,



5.2 MQTT

Message Queue Telemetry Transport (MQTT) is a lightweight, open, free and easy to implement protocol for publish/subscribe communication between a client and a server. These characteristics allow it to be used in restricted environments such as M2M (Machine to Machine) communication or in IoT (Internet of Things) contexts where only a small amount of code sequences can be processed. It has been designed to work efficiently in low bandwidth, low battery usage and unstable connections. The messages are published by the sender (publish), but it is not necessary to know who has received or subscribed to the messages. Subscribers receive all messages via an MQTT broker.



5.3 CoAP

Constrained Application Protocol (CoAP) is a web transport protocol that can be used for restricted nodes and restricted networks. The nodes often have 8-bit microcontrollers, small amounts of ROM and RAM, while the network is often a low-power, wireless, personal network with frequent losses, packet errors, and a typical transfer rate of 10 kbps. The protocol is designed for machine-to-machine (M2M) applications, such as smart energy apps or building automation (datatracker.ietf, 2023).

Between application endpoints, CoAP provides a request-response type interaction protocol, supporting built-in discovery of services and resources, key web minds such as URIs and web media types. It is characterized by very low overhead and simplicity in constrained environments. It has been designed to be able to easily connect to HTTP, but also to meet specific needs such as unicast and multicast request forwarding, or asynchronous messaging.

5.4 AMQP

The Advanced Message Queuing Protocol (AMQP) is an open source standard for asynchronous messaging in wired networks. It is an Internet Protocol Application Layer protocol used by middleware. It features message orientation, message queuing, routing (including point-to-point and publish-subscribe), reliability and security. AMQP sends data as a byte stream and can therefore interoperate with any device that can generate and interpret this type of data, (amqp, 2023).

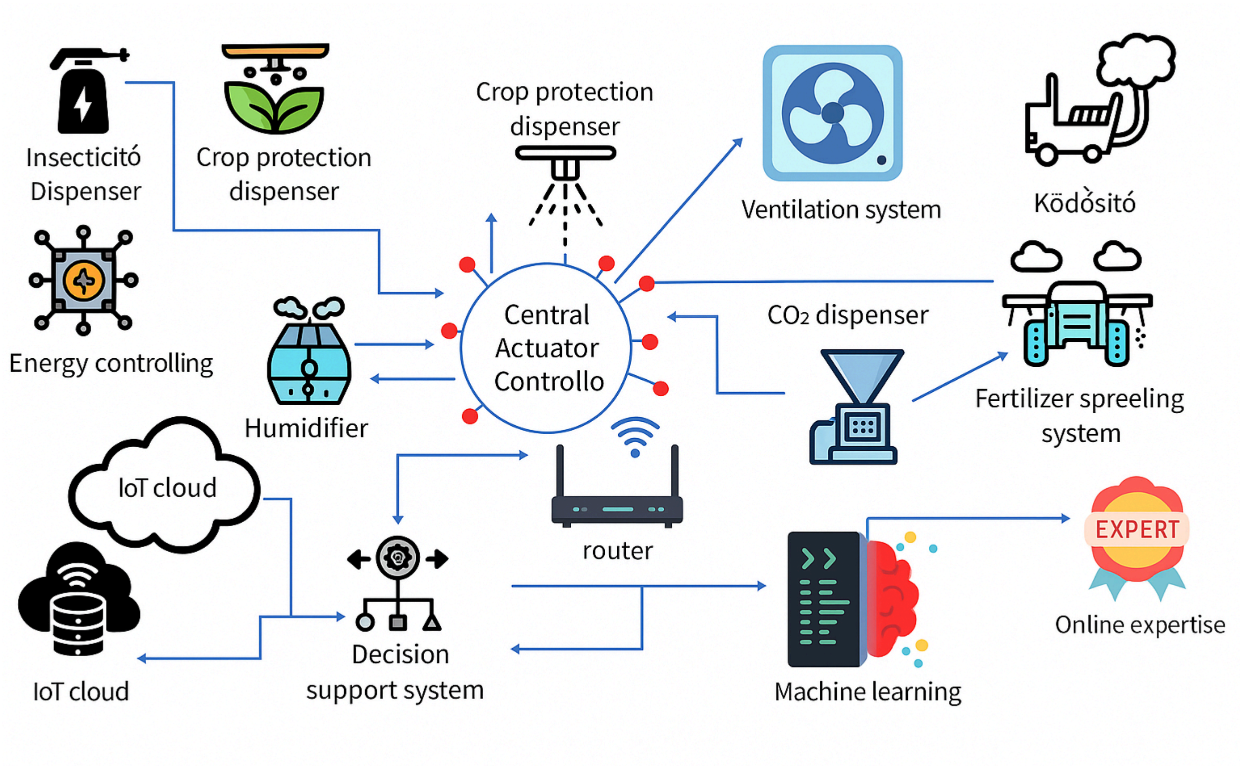
AMQP is designed to efficiently support a wide range of messaging applications and communication patterns. It provides continuous, message-driven communication, with three options for message delivery: at most once, at least once and exactly once. It also provides SASL and/or TLS based authentication and/or encryption. It assumes that a trusted transport layer protocol such as Transmission Control Protocol (TCP) is running in the background.

It is defined in the AMQP specification:

- the type system,
- the symmetric and asynchronous protocol for transferring messages from one process to another,
- the standard and extensible message format,
- a set of standard but extensible messaging options.

6. The IoT (Internet of Things)

The Internet of Things (IoT) is a network of physical objects accessible via the Internet. These objects are in constant contact with the external environment, with each other or with the user, using various technologies. The IoT is commonly seen as the third stage in the evolution of the Internet. In the 1990s, the Internet had around 1 billion users, mobile communications in the 2000s connected a further 2 billion users, and by 2022 the IoT was able to connect 35 billion 'things' via the Internet. These include smart watches, sensors in cars, greenhouses, etc... All because the reduction in the cost of sensors and processing power, the low cost of the hardware and software needed to connect devices, and the increase in bandwidths have made it possible to connect "things" in a simple and efficient way, (Banafa, 2023).



The IoT has features that make it significantly different from the regular Internet, such as sensing, efficiency, networked devices, specialised operations and ubiquity. These features could change the direction of technological developments, with significant implications for technology companies. For example, the shift from the former wired to mobile internet has shifted the focus from Intel to Qualcomm and from Dell to Apple.

Several technological changes have enabled the IoT to spread, including:

- cheap sensors: the price of sensors has fallen by an average of 60 cents from $1.30 over the past 10 years,
- cheap bandwidth: the cost of bandwidth has fallen nearly 40-fold in the last 10 years,
- low-cost processing: processing costs have fallen by almost 60 times in the last 10 years, allowing a device to process data generated and received in addition to connecting,
- smartphones: smartphones act as remote controls or hubs in connected homes, connected cars, greenhouses, or health and fitness devices,
- wireless coverage: the extensive Wi-Fi coverage means that wireless connectivity is available at a very low cost,
- big data: IoTs generate large amounts of unstructured data, which is crucial to analyse,
- IPv6: IPv6 is the latest Internet Protocol (IP) standard that supports 128-bit addresses, as opposed to IPv4 which could only handle 32-bit addresses and has been exhausted by connected devices worldwide. 128-bit addresses, however, translate into approximately 3.4 × 1038 addresses - enough to handle every IoT device imaginable.

One of the downsides of IoT is that it is difficult to draw the line on privacy and security issues. Smart devices handle a lot of personal data and information about the user, and misuse of this data can cause great harm. Another disadvantage is that most devices cannot communicate only with other devices from the same manufacturer. It is true that the AllJoyn Open Source Project, (openconnectivity, 2023) is trying to ensure that devices from different manufacturers can be connected, but IoT technology is still a long way from developing a unified system.

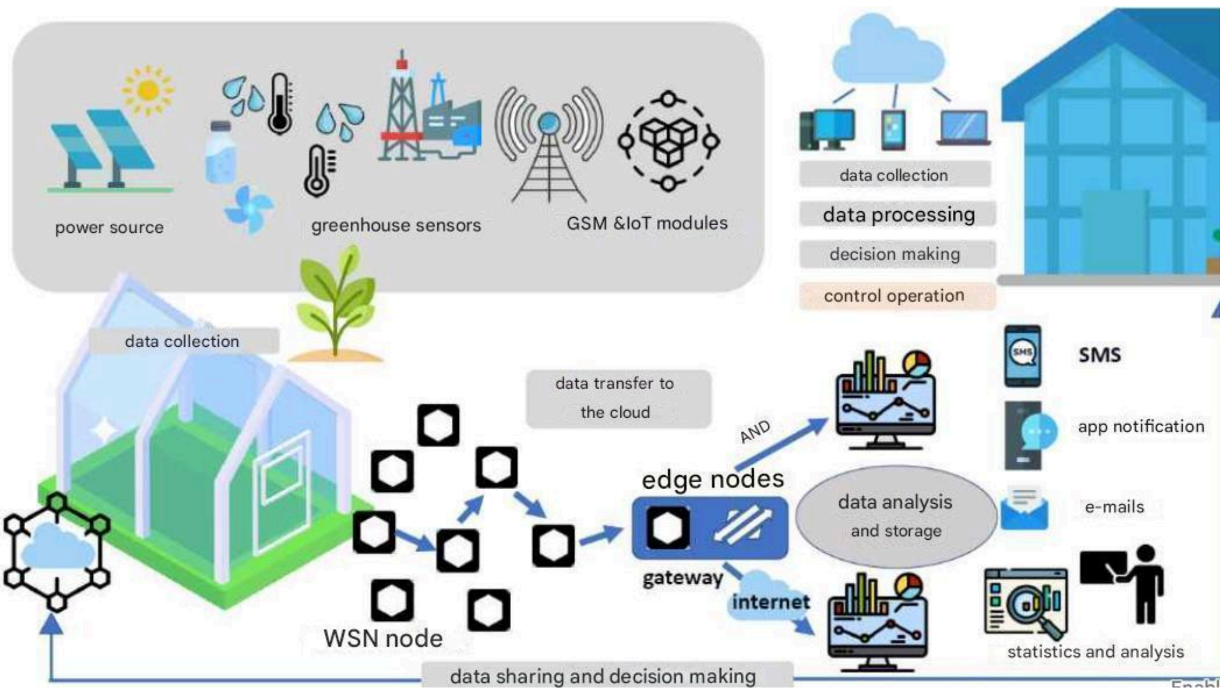
7. Greenhouses and mobile communications

The world population is likely to reach 9.7 billion by 2050, which will also lead to an exponential increase in food demand. This could lead to a number of problems such as water and air pollution, greenhouse gas emissions and global warming. These problems highlight the need to develop sustainable solutions for food production. The deployment of precision farming greenhouses could be a key to solving these problems.

The mobile control systems installed in greenhouses are fully capable of providing integrated control of temperature, humidity, irrigation, fertilisation, CO2, light and shade levels. Precise control of the cultivation operation allows farmers to achieve greater savings in energy, water, chemicals and crop protection products. Mobile control generally promotes greater operational consistency, scheduled production, higher product quality and environmental cleanliness, (Manohar & Igathinathane, 2007).

In a greenhouse, a single computer can control hundreds of devices (ventilators, heaters, fans, hot water mixing valves, irrigation valves, curtains, lights, etc.) and can process thousands of input parameters, such as indoor and outdoor temperature, humidity, wind direction, wind speed, CO2 level, etc. Mobile systems can receive signals from all the sensors installed and send commands to each device at the appropriate intervals. At the same time, a computer system can collect and record data from various external parties, which, once processed, allow the farmer to know all the factors affecting the quality and quantity of the product:

Systems can produce data visualisations (graphs, reports, summaries) of past and present environmental conditions, which present the evaluated data in a more transparent way.



Even with the proliferation of computerised systems, it should be remembered that the success of crop production depends first and foremost on the farmer's knowledge of crop management. These systems can help, first and foremost, by making greenhouse production more precise, and are only as effective as the software they run correctly and the digital competence of the farmer operating the system.

In addition to the advantages of computer systems, it is also worth considering the disadvantages:

- high initial investment costs,
- requires skilled system operators, both digital and mechanical,
- the number of maintenance, care and precautionary measures may be higher,
- for small-scale and seasonal production is not always economical.

In terms of computing technologies, the following can be applied to greenhouse operations: wireless sensor networks (WSN), Internet of Things (IoT), artificial intelligence (AI), space technologies, remote sensors, computational algorithms, blockchain technology, big data, and radio frequency identification (RFID). These technologies can be used to analyse, generate, receive, transmit and process data.

And microchips, sensors, positioning systems (GPS systems), computer software, communication systems, internet protocols, meteorological data are the tools that provide the data processing for crop production (Mottram, 2022).

The invention of transistor switches, and later silicon etching techniques and the advent of **microchips, enabled the** emergence of today's electronic and digital devices, and their dramatic reduction in size and production costs has led to their widespread use in various sectors of agriculture, such as precision greenhouse cultivation.

The emergence of various sensors and **detectors** provided the detection and monitoring of data such as speed detection, airflow, humidity, animal and plant disease characteristics, etc.

Global Positioning Systems (GPS systems) were originally developed by the US military in the 1970s. These and more recent global navigation satellite systems have made it possible to determine positional data within a few metres, which can be used for vehicles in the field, but also for locating plants in open or confined areas.

Computer software are applications that can analyse digital images, multimedia content, build models, explain relationships, etc. They can be used to recognise plants, detect pests, identify physiological stages, etc. Data were first digitised in the 1950s, but soon afterwards software was developed that allowed structured, systematic processing of large amounts of data. All current databases store huge amounts of searchable and analysable data.

Communication possibilities have changed dramatically with the advent of the Internet and then mobile devices. Every digital object (text, video, image, sound), e-mail and web page travels over the Internet as a series of packets, each of which can be precisely identified by the Internet Protocol standard, knowing where it comes from and where it is being transmitted. The World Wide Web provides a Uniform Resource Locator (URL) anywhere on the Internet so that these digital objects can be easily linked and transmitted.

In developed countries, modern **meteorology** can provide detailed weather forecasts down to 1 km resolution and predict the weather up to 7 days in advance. This has a major impact on the planning and execution of operations in greenhouses, significantly reducing the risks from weather-related hazards.

A greenhouse farmer's network of contacts has a big impact on the business success of the greenhouse. Direct, fast and regular communication with different people is facilitated by the Internet and mobile communications, but you need to know how to use them. In addition to customer contact, advertising services, customer management and information services may also need to be included in business policy. In the case of suppliers, GPS technology can be used to make delivery logistics easier. In dealing with different agencies, the appropriate use of software can ensure two-way data provision and availability of specifications. With the right services from financial institutions, mobile payments, dues payments and internet banking can be made easy. Advocacy organisations can provide quick access to information, up-to-date information and advice.

Mobile applications include applications for production management, process control, product tracking and quality assurance.

A farmer running a greenhouse has to take several data into account when deciding on operations on the farm. This is usually raw data from sensors on tools and machines:

- crop and GPS data: data correlated with GIS information from drones,
- market and pricing data from third-party cloud servers to help you build a picture of potential crop value and demand,
- Internet weather forecast data (temperature, wind speed, wind direction, precipitation, humidity, air pressure, etc.),
- data from sensors that measure local environmental conditions (current weather data, soil condition data, crop data, image and video data indicating plant condition/disease,
- Data on the water supply in the area via the Internet,
- Price information on agricultural products via the Internet in national and international contexts.

8. Mobile communication applications in greenhouses

There are now a number of sensors and tools on the market to support farmers to build smart greenhouses on their own, even on their own. Current digital technology can be used to monitor soil quality, for example, and the systems also offer solutions to help farmers avoid soil degradation, (S. Bharati, et al., 2023). IoT technology enables soil management, with a focus on soil water retention, texture and absorption rate. They can help avoid excessive fertilizer use, reduce compaction, salinization, acidification, pollution and erosion. For example, serious soil analysis can be carried out with the Labin-a-Box soil analysis toolkit from AgroCares (AgroCares, 2023). Any farmer can use the Labin-a-Box to analyse 100 samples a day without having to visit a laboratory with the samples taken.

In 2009, the Soil Moisture and Ocean Salinity (SMOS) satellite was launched, which provides maps of global soil moisture every day or two (earth.esa.int, 2023). It uses remote sensors to collect soil moisture data on a regular basis, which helps to analyse droughts in different areas.

In 2014, Spanish researchers used the SMOS L2 system to assess the Soil Water Depletion Index (SWDI). They also used the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor to scan different soil properties to quantify the risk of soil degradation in sub-Saharan Africa. Additional sensors and vision-based technology were also used to determine the distance and depth required for effective seeding.

IoT-based smart devices such as wireless sensors, drones and robots can accurately detect crop pests, allowing farmers to drastically reduce pesticide use. Contemporary IoT-based pest management offers real-time monitoring, disease forecasting and modelling, making it more effective than traditional pest control. State-of-the-art pest and disease detection techniques depend on the image processing technology of the system. Raw images are collected in the agricultural field using remote sensing satellites or field sensors. The images collected usually cover large areas and can be processed with good efficiency at low cost. There are also field sensors that can collect samples of crop conditions and the presence of pests at all stages of the crop cycle. IoT-based systems can collect, count and describe pest species and then analyse them in detail using a cloud service. Such an IoT-based pest monitoring system can minimise overall costs while helping to restore the natural climate.

IoT-based fertilisation technologies accurately measure fertiliser demand with minimal labour. For example, the Normalized Differential Vegetation Index (NDVI), based entirely on the reflectance of visible and near-infrared light from vegetation, uses satellite imagery to assess crop condition, measure healthy yields, and measure vegetation. It also helps to assess soil nutrient levels. These measurements can significantly increase the efficiency of fertilizer use while avoiding environmental side effects. Geo-mapping, GPS accuracy, autonomous vehicles and variable rate technology (VRT) are contributing to IoT-based smart fertilization.

IoT-based technologies can also be used effectively for yield monitoring. Suitable sensors can be installed on any harvesting computer and the data can be processed, for example, via the FarmTRX mobile application (farmtrx, 2023). The application can be used to generate high-quality yield maps that can be exported by the farmer to other farm management tools for further analysis. Satellite imagery is also used to monitor yields on large farms. For example, in Myanmar, Sentinel-1 interferometric images have been used to determine yields of rice crops; colour (RGB) depth photographs have been used to track fruit stages in mango fields; optical sensors have been used to measure shrinkage of papaya during drying.

Crop water stress index (CWSI) based irrigation management is another application of IoT-based strategies. Irrigation is based on predictions, which can lead to significant improvements in crop yields. CWSI calculation requires monitoring both crop yield and air temperature at different times. In a wireless sensor-based monitoring system, all field sensors are connected and the measured data are transmitted to a processing system, where the data are analysed using appropriate software. Satellite images and meteorological data are also incorporated into CWSI models to determine water demand. Exclusive irrigation index values are generated for each site. CropMetrics' variable rate irrigation (VRI) method determines the amount of water needed based on soil and topography conditions (cropx, 2023).

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2. GREENHOUSE AUTOMATION, SENSORS, ROBOTICS

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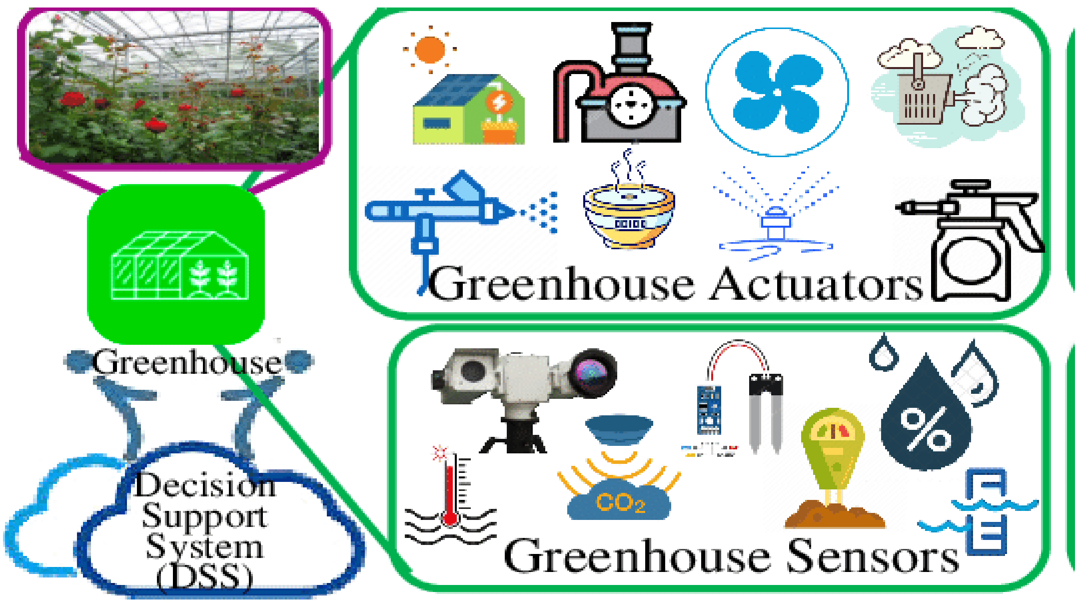
1. Introduction

The combination of automated sensors, robotics and artificial intelligence is revolutionising crop production. Properly designed and integrated systems will enable better monitoring of crops, early detection of diseases and pests, and optimal growth and production. Steps towards sustainable agriculture, facilitated by automation and robotics, will contribute to maintaining food security and protecting the environment.

2. Automated monitoring and care of plants

In the field of agricultural production, automation, sensors and robotics are playing an increasingly important role in increasing efficiency and achieving sustainable production. Automated monitoring and care allows continuous monitoring of plant health and optimal growing conditions. In this paper, we describe the use of automated sensors for monitoring and diagnosing plant health, early detection of plant diseases and pests, and the role of robotic care systems and artificial intelligence for optimal plant growth and cultivation. Figure 2.1 illustrates the units used in an automated greenhouse:



Source : https://www.researchgate.net/figure/IoT-Enabled-Greenhouse_fig1_348989431
Figure 2.1 Main units used in an automated greenhouse

2.1 Using automated sensors to monitor and diagnose plant health

Automated sensors are a key tool in modern agriculture, helping farmers to monitor and care for crops more accurately. The following is an overview of the most important sensors:

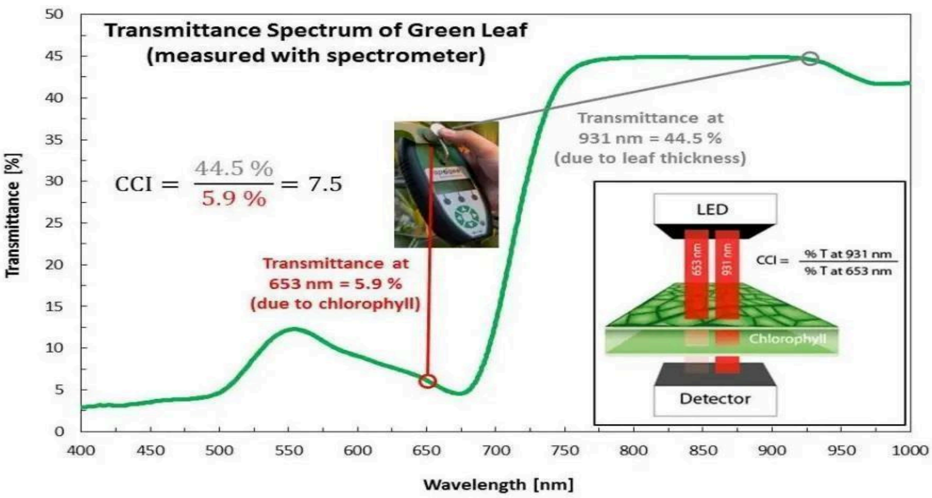
- **soil moisture sensors** can continuously measure soil moisture content**, ensuring that irrigation schedules are optimised, preventing over- or under-irrigation, promoting sustainable farming and ultimately increasing agricultural productivity**, minimising water wastage. Among the older, simpler technologies we can mention *tensiometric*, *resistive* and *capacitive* soil moisture meters. **These have the advantage of their relative simplicity of construction and low cost, but are now being pushed out of modern smart metering systems because of their measurement speed, limited applications and low accuracy. The most accurate and reliable soil moisture sensing known** today is based on the principle of **time-domain reflectometry** (TDR), which can be used to measure moisture content indirectly based on the correlation with the electrical and dielectric properties of the soil. The principle of this measurement is to inject a very fast rise time (about 200 ps) electrical pulse into a probe guided in the soil. The propagation speed of the pulse is closely related to the moisture content of the soil. An example of a time-domain reflectometry-based instrument is the John Morris Group's TDR 350.
- **temperature and humidity sensors** measure environmental conditions and help create the ideal microclimate for plants. This data is particularly important in greenhouse environments, where temperature and humidity control is vital to the success of the crop. Classical air temperature and relative humidity sensors have now been replaced by integrated smart sensors that convert and process noise-sensitive analogue signals locally and communicate with central measuring systems in the form of a digital signal. A very good example is the SHT4X, one of the many smart sensors from the Swiss company Sensirion. One of the strengths of this device is that 128 sensors can be connected to a pair of sensors via the I2C communication bus and protocol, enabling the principle of multipoint measurement in a simple and cost-effective network.
- **photosynthetic active radiation** (PAR) sensors measure light intensity, which is critical for photosynthesis and nutrient production in plants.

Accurate measurement of photosynthetic active radiation helps to achieve optimal plant growth and yield. The sensor can be used to measure Photosynthetic Photon Flux Density (PPFD) over plant canopies in outdoor environments, greenhouses, growth chambers, and in reflected or under canopy (translucent) environments. Instruments from the US company Apogee Instruments are considered industry standard, including the PPFD Quantum SQ-500 sensor family.

Source : https://www.amazon.ca/Apogee-Instruments-MQ-500-Full-Spectrum-Quantum/dp/B09KWQJ8XP?th=1

- **the chlorophyll concentration sensor gives the** concentration in the leaf in absolute units - µmol/m2. It can be used to assess nutrient status, to estimate plant stress and to optimise harvesting. Despite providing very important plant life information, its relatively high price means that it is not yet widely used. The Apogee MC-100 chlorophyll concentration meter and the measurement method and principle are shown in the figures below:

Source : https://www.apogeeinstruments.com/mc-100-chlorophyll-concentration-meter/



Source : https://manuals.plus/apogee/mc-100-chlorophyll-concentration-meter-manual#axzz8QqVt1E8l

2.2 Early detection of plant diseases and pests using automated computer vision systems

With dwindling natural resources, one of the biggest problems in agriculture is that yields are struggling to keep up with the world's population growth. The main challenge is to increase productivity regardless of adverse environmental factors. Modern precision agriculture uses the latest technological advances to improve productivity.

The automated disease detection system provides the farmer with an immediate and accurate diagnosis of plant disease, speeding up the diagnostic process. Automating the disease detection system is critical to speeding up crop diagnosis and intervention.

Nowadays, in agriculture, image processing has become an essential application and one of the fastest growing subjects of study in the field. A wide range of industries, including agriculture, have found image processing to be a useful tool for data analysis. Data is collected using cameras, aircraft or satellites and computer image processing algorithms are used to process and analyse the images. An automated leaf disease detection system for precision farming uses image acquisition, image processing, image segmentation, feature extraction and machine learning techniques.

Many of the problems facing agriculture have been greatly simplified thanks to recent developments in image capture and data processing technologies. Images can be used to detect diseased leaves, stems and crops, thereby quantifying the area affected by disease.

Source : https://phenospex.com/products/plant-phenotyping/planteye-f500-multispectral-3d-laser-scanner/

Figure below illustrates the complex recording system of a smart greenhouse:

Source : https://phenospex.com/products/plant-phenotyping/planteye-f500-multispectral-3d-laser-scanner/

Smart greenhouse complex recording system

The University of Minnesota pilot scheme can be seen HERE.

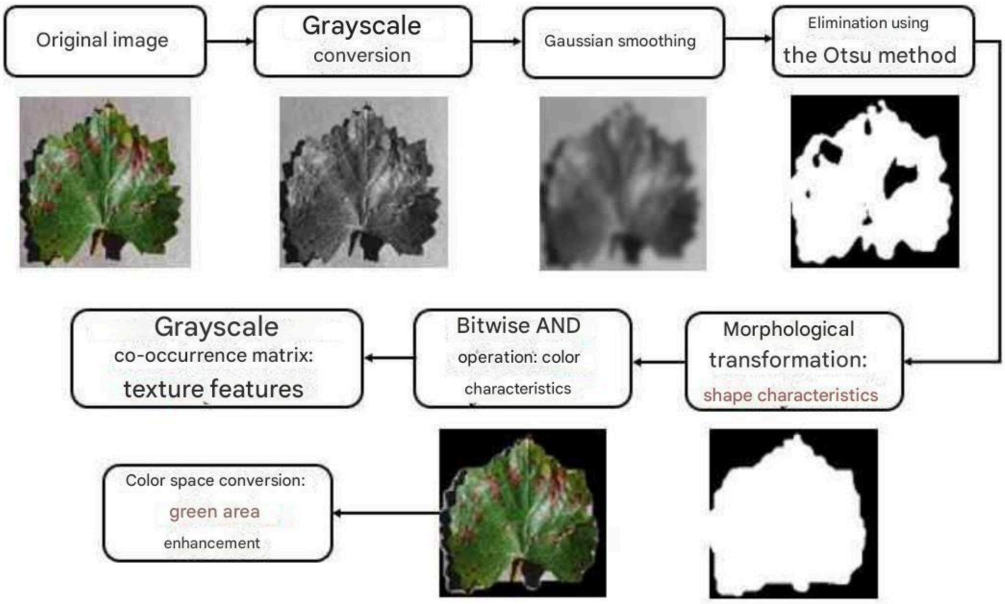
Data pre-processing is an important part of any computer vision system. To achieve accurate results, any background noise must be filtered out before extracting features. To do this, the colour image is first converted to greyscale and then a Gaussian filter is used to smooth the image. The Otsu thresholding algorithm is then applied to the binary version of the image. A morphological transformation is then applied to the binarized image to close small holes in the foreground.

After the foreground is detected, the bitwise AND operation is performed on the binary image and the original color image to obtain an RGB image of the segmented leaf. After segmenting the image, the system extracts the shape, texture and color from the image. The outlines are used to calculate the area of the leaf and the circumference of the leaf. Contours are the lines connecting all points along the edges of objects of the same colour or intensity. We also estimate the mean and variance of each channel in the RGB image. To calculate the amount of green colour in an image, the image is converted into an HSV colour space and then extract the texture and color features from the grayscale co-occurrence matrix (GLCM) of the image.

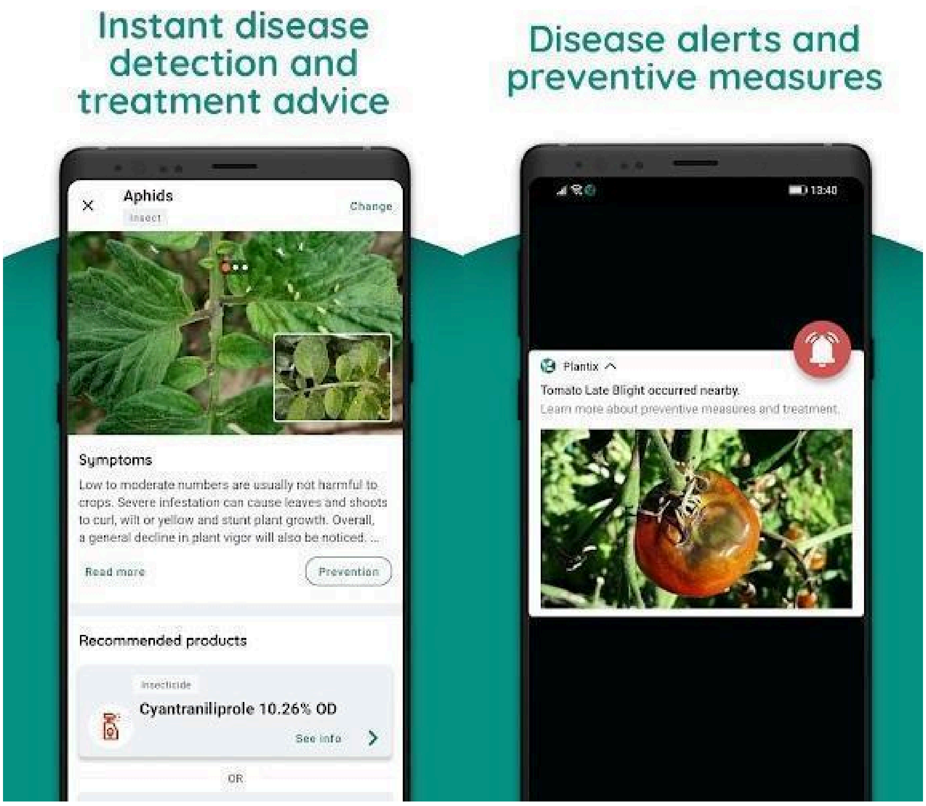
Once all the features have been extracted from all the images in the dataset, another important step in machine learning is feature selection.

The characteristics are selected based on the correlation between the variables and the target variables. For example, in the case of apple disease prediction, the correlation between the green part of the leaf characteristic and the green part of the leaf is very high, i.e. the two variables are interdependent. After selecting the most salient features, the data are now analysed into machine learning classifiers to find patterns in the data. Among several classification algorithms, for example, the random forest classifier can be used in combination with decision trees to achieve higher accuracy. After running the complete set of operations, high accuracy diagnostics can be obtained for continuously expanding plant types.

Based on current reported results, computer vision-based systems can detect and indicate, for example, apple diseases with 93% accuracy and potato diseases with 98% accuracy. A possible practical implementation can be seen in the movie HERE.



One notable example is Plantix, a smartphone application based on the Android operating system, which detects plant diseases and pathogens based on a photo taken and uploaded with the user's own camera and provides recommendations for intervention. It should be noted that, due to the limitations of the database used and the lack of specialised knowledge of the development team, this application can be considered as amateur level. A demonstration film of the application is available HERE.



Source : https://cafebazaar.ir/app/com.peat.GartenBank.preview?l=en

At the same time, world-renowned companies in the industry are also developing similar applications for professionals, aimed at making a profit.

2.3 Robotic care systems and artificial intelligence for optimal plant growth and cultivation

Source : https://mezogazdasag.ma/mesterseges-intelligencia-a-mezogazdasagban/

Robotic care systems and artificial intelligence (AI) are revolutionising crop production. Smart robotic care systems are able to autonomously perform various tasks on plants.

For example, robots can precisely prune plants according to their growth stage and needs. This allows plants to grow and fruit optimally. The use of artificial intelligence helps robots to learn, so they become more accurate at performing tasks over time.

The concept of precision agriculture is based on combining technology and data to optimise agricultural production and minimise environmental impacts. Artificial intelligence in this context enables deeper analysis of data and support for farming decisions.

Artificial intelligence can help farmers get real-time information on soil conditions and crop health:

- Sensors and IoT (Internet of Things): smart sensors measure soil moisture, pH and other key parameters. IoT devices allow this data to be transmitted to central systems.
- Drones and satellite imagery: these devices take pictures of the land, allowing early detection of plant diseases, nutrient deficiencies or pests.
- AI models for data analysis: the collected data is analysed by AI algorithms to identify patterns, make predictions and optimise management.

Precision agriculture is being radically transformed by artificial intelligence. AI will enable farmers to farm their land in a more sustainable, efficient and environmentally friendly way. This development will not only reduce production costs, but also minimise environmental impacts and improve global food security.

In recent years, artificial intelligence (AI) has exploded in agriculture, allowing the sector to reach new heights. However, like all technologies, AI has its challenges that the agricultural sector faces. The potential challenges and added value of AI in agriculture include:

- Added values: productivity gains, reduction of inputs, minimisation of environmental impact, etc.

- The challenges of AI systems are: high upfront costs, accurate data collection and processing, data security and protection, lack of skilled professionals and last but not least ethical and security concerns.

While AI offers huge opportunities for agriculture, it is important that farmers, decision-makers and industry professionals are aware of these challenges. With a proactive approach and proper training, the industry can reap the benefits of AI while managing potential risks and concerns.

In one of the lectures of the Hungarian Science Festival 2023, organised by the Hungarian Academy of Sciences, you can follow a series of interesting presentations on *Sustainable agriculture: precision farming, large-scale digitalisation, artificial intelligence.*

3. Greenhouse robots and self-driving vehicles

Automation and robotics are playing an increasingly important role in crop production, especially in greenhouses or greenhouses. Greenhouse robots and self-driving vehicles offer solutions to labour shortages and reduce labour costs, while also significantly increasing the efficiency and productivity of crop production. In this paper, we will elaborate on the use of robotic systems in greenhouses, the use of self-driving vehicles and drones for watering, spraying and tending plants, and the benefits of robotics in crop production.

3.1 Using robotic systems in greenhouses to reduce labour shortages and labour costs

In crop production, labour shortages can be a critical problem, especially for manual tasks such as harvesting, spraying or fertilising. Robotic systems offer an effective solution to this problem. Robotic machines can perform these tasks autonomously, significantly reducing dependence on human labour.

Greenhouse robots ensure quality work with their precision and reliability. Automated harvesting robots, for example, enable precise and timely harvesting of crops, optimising yields. This not only reduces labour costs, but also improves the quality and quantity of the harvest. Not insignificantly, the intertwining of robotics and regenerative agriculture enables the promotion of organic farming. With the help of robots, chemical use and environmental impact can be minimised, while yields and soil quality can be increased.

3.2 Use of self-driving vehicles and drones in plant care

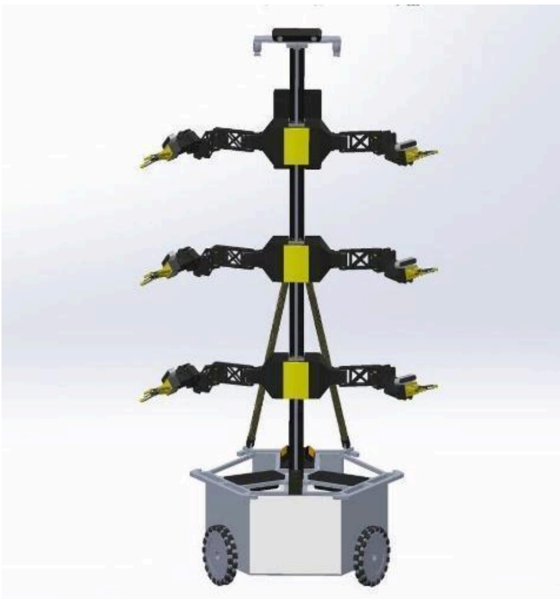
Self-driving vehicles and drones are extremely versatile in crop production. Self-driving tractors and robots can follow crop beds along a designated path, while drones can monitor and care for crops from the air.

The use of self-driving vehicles and drones in watering and spraying crops allows precise and efficient work. Automated systems minimize the use of chemicals or water thanks to precise GPS control, reducing environmental impact and costs.

Aerial surveillance by drones allows fast and efficient inspection of plants in large areas that are difficult to reach manually. Drones can monitor whole plants or even their leaves with a camera, helping to detect disease or pests early, before they become widespread.

Robotic pollination of plants

The lack of natural pollinators worldwide threatens global food production. According to the US Department of Agriculture's Forest Service, about 80% of flowering plants are fertilised by animals, meaning that without pollinators, many plants cannot reproduce, bear fruit or mature seeds. Researchers at West Virginia University are developing robotic pollinators to address this pressing problem. ű



Source [: https://www.biokontroll.hu/wp-content/uploads/2022/08/Biokultura_2022-2-3_oldalparban.pdf?x18764](https://www.biokontroll.hu/wp-content/uploads/2022/08/Biokultura_2022-2-3_oldalparban.pdf?x18764)

A six-armed robot called StickBug, which resembles a batshit and can pollinate a variety of plants, has been created by a team led by *Yu Gu,* an associate professor in the Department of Mechanical and Aerospace Engineering at West Virginia University. The development was supported by a $750,000 grant from the US Department of Agriculture. StickBug first surveys and maps the environment and then maps plants in great detail. It then knows exactly where the flowers are and which ones need pollination, and uses this information to create a work plan. It then approaches the plants one by one and uses the moving arms to pollinate them.

The actual pollination efficiency of StickBug will be evaluated in greenhouses at West Virginia University, where blackberries and tomatoes are grown. These species were chosen because they are both very popular in the US and have significant economic value. According to Yu Gu, tomatoes are probably one of the most important crops grown, but nowadays they need help to pollinate. Moreover, tomatoes can be grown all year round, so the robot can be tested continuously. The ultimate goal is to put these developments into practice and develop a platform for robots that can be widely used in agriculture. Find out more about how the robot works [here.]()

3.3 Robotic inspection and spraying of plants

Spraying chemicals is also a common practice in greenhouse plant protection. This operation is essential, but it can cause some problems, such as human and environmental damage from pesticide overdosing. Recently, researchers have focused on precision agriculture to make it smarter. They use sensors to detect the leaves of plants and spray them only when necessary. In this way, the dosage of chemicals can be kept under tight control.

Nowadays, advanced applicability trials are being conducted with automated spraying robots using artificial intelligence-based image processing systems. These robots can detect weeds in the soil or signs of infestation on plants and spray herbicides or pesticides with minimal human supervision. Consequently, the robotisation of these operations can reduce costs and increase environmental and human safety.

Among the many manufacturers, the Chinese company XAG, working on the challenges of Agriculture 4.0, has some notable robots for automatic spraying, rolling and flying. The R150 unmanned guided vehicle (UGV) is designed for next-generation farming with unmanned systems. With powerful scalability and multiple modes of operation, it is the first mass-produced agricultural robot platform of its kind. From precision crop protection to field scouting to agricultural material handling, it offers ground autonomous solutions. You can see the robot in action in Hungary spraying an indoor cabbage crop **here**. The manufacturer's website is available **here.**

4. Interaction and cooperation of intelligent systems

The interaction and cooperation of intelligent systems in agricultural production is a key factor in achieving efficient, sustainable and effective crop production. The interconnection of automated systems, sensors and robots allows for the joint collection and analysis of data, providing important information about the condition of crops and the growing environment. In this paper, the benefits of intelligent systems collaboration in crop production are presented.

Connecting sensors, robots and automated systems to collect and analyse data together

The interconnection of automated systems, sensors and robots allows the integration of information from different data sources. Sensors continuously collect data on plant and growing environment parameters, such as soil moisture, temperature, humidity, light intensity, etc. Automated systems and robots perform tasks such as irrigation, spraying or harvesting.

Integrated data collection and analysis allows farmers or agronomists to get a comprehensive picture of the health of crops and the growing environment. By analysing the data, smart systems can instantly identify problems or anomalies and send alerts so that appropriate action can be taken in a timely manner.

Intelligent decision-making and adaptive control in complex crop production environments

The integration and analysis of data supports intelligent decision making and adaptive management in the crop production environment. Automated systems can learn from data and adapt to changing conditions, enabling optimised operations.

For example, automated irrigation systems make intelligent decisions by analysing soil moisture sensor data. When soil moisture levels drop to critical levels, the intelligent system automatically triggers the irrigation system to ensure optimal water supply to the plants. This minimises the waste caused by over-irrigation and the harmful effects of excessively dry soil.

Cooperation between automated systems and robotics for efficient workflow and resource utilisation

Automated systems and robotics work together effectively to help optimise workflows and available resources. Robots that communicate and collaborate with each other can distribute tasks and work together efficiently throughout the growing process.

For example, a self-driving irrigation system and a self-propelled spraying robot can work together to optimise irrigation and spraying according to the needs of the plants. Sensors continuously monitor soil moisture and plant conditions, and the robots use the data to decide on the optimal operations. This minimises the waste of resources and increases the efficiency of cultivation.

5. Greenhouse drones and drone-based technologies

Drones and drone-based technologies are also becoming more widespread and useful in agriculture, especially in crop production. Drones in greenhouses offer particular advantages in supporting cultivation processes, monitoring crop condition and quality, and facilitating precision farming. In this paper, we will elaborate on how drones and drone-based technologies are helping to promote efficient and advanced crop production.

The use of drones in greenhouses to support growing processes

Greenhouse drones are great tools to support crop production processes. Self-guided drones can precisely follow designated paths between plant beds and perform various tasks automatically. For example, spraying drones can spray crops efficiently, minimizing chemical use and human labor.

Drones allow for a higher level of monitoring and surveillance of plants. Camera-equipped drones allow farmers and agronomists to easily monitor crop growth, development and potential problems such as the presence of diseases or pests.

Using drones to monitor crop health and quality

The drones' cameras and sensors allow continuous monitoring of crop condition and quality. Drones equipped with multispectral cameras are able to capture images of crops in different spectral bands. This makes it possible to assess the stress levels, nutrient supply, water requirements and the presence of diseases.

With the help of drones, farmers can detect stressed crops and potential problems in time to take immediate action to restore them. In addition, drones can predict crop quality, which can help produce better products and achieve better market prices.

Drone-based data collection and image processing for precision farming

Drone-based data collection and image processing enables precision farming in agriculture. Data collected by drones is analysed by image processing algorithms and provides detailed information to farmers.

Accurate soil moisture, nutrient supply and plant health data help farmers make better decisions. Precision farming can minimise chemical and water use, reducing environmental impact and costs. And more accurate nutrient and water supply increases productivity and crop quality.

5.1 Human-robot interaction and ethical issues

The rise of automation and robotisation in agriculture opens up the possibility of human labour and robots working together in crop production. However, technological advances and the use of artificial intelligence also raise some ethical questions. In this essay, we present the benefits and challenges of human-robot interaction in agriculture, as well as ethical considerations related to the use of robotics and artificial intelligence.

Human workers and robots working together in greenhouses

Human-robot cooperation in greenhouses offers many advantages. Robots and automated systems can perform difficult and monotonous tasks, reducing the burden on human labour. Freeing human labour from such tasks allows people to focus on their expertise and higher-level tasks such as decision-making or technical supervision.

Human-robot cooperation also increases efficiency. Humans and robots work in complementary ways to optimise crop production processes, improving productivity and crop quality.

Ethical considerations in the application of robotics and artificial intelligence in agriculture

The use of automation and robotics in agriculture raises ethical questions. One important consideration is the situation of the labour market and workers. The replacement of human labour by robots and automated systems may lead to unemployment among agricultural workers and thus to social inequality.

In addition, ethical issues include data protection and privacy in the use of AI. Sensors and data collection systems continuously monitor the condition of plants and the growing environment, but this data can also contain personal and sensitive information. It is important to consider data protection measures to ensure that the data of growers and farm businesses is protected.

The role of human labour and skills in the automation and robotisation of crop production

Human labour and skills remain critical to the automation and robotisation of crop production. Human expertise is essential for the optimal functioning of automated systems and robots. Skills enable robots and systems to be set up and monitored efficiently and to intervene when necessary to solve problems.

Human labour and expertise are also critical in addressing ethical issues. Humans must be prepared to deal with the use of robotics and artificial intelligence in agriculture with appropriate ethical considerations. It is important that farmers, agronomists and agricultural workers are aware of the benefits and challenges of automation and robotisation and use them responsibly.

6. Ecosystem services and sustainability

The rise of automation and robotisation in crop production is affecting ecosystem services and biodiversity. It is important to recognise the sustainability challenges and opportunities facing agriculture. In this paper, we present the impact of automated crop production on ecosystem services and biodiversity and focus on the balance between economic efficiency and environmental sustainability in greenhouses.

Impact of crop automation on ecosystem services and biodiversity

Automated crop production can affect ecosystem services and biodiversity. The precision operation of automated systems and robots enables more accurate and less resource-intensive cultivation, such as optimal irrigation and spraying. This can reduce soil erosion and environmental stress, with positive impacts on ecosystem services.

However, automation can sometimes lead to a loss of biodiversity. One-sided cultivation methods and large-scale production practices can reduce ecosystem diversity if appropriate sustainability measures are not applied.

Sustainability challenges and opportunities in automated crop production

Automated crop production poses a number of sustainability challenges. The more efficient use of resources (water, energy, chemicals) makes it possible to reduce environmental pressures. However, the introduction of robotics and automation can be costly and this can make it difficult for smaller farms to access the technology.

Sustainability options include the use of intelligent decision-making and adaptive control to optimise operations based on environmental conditions and crop needs. To promote sustainability, automated crop production must balance economic efficiency with environmental sustainability.

Balancing economic efficiency and environmental sustainability in greenhouses

Automation and robotisation in greenhouses can promote both economic efficiency and environmental sustainability. Automated systems can reduce labour costs and increase productivity, improving economic outcomes. Precision operations allow for more efficient use of resources, thus reducing environmental pressures.

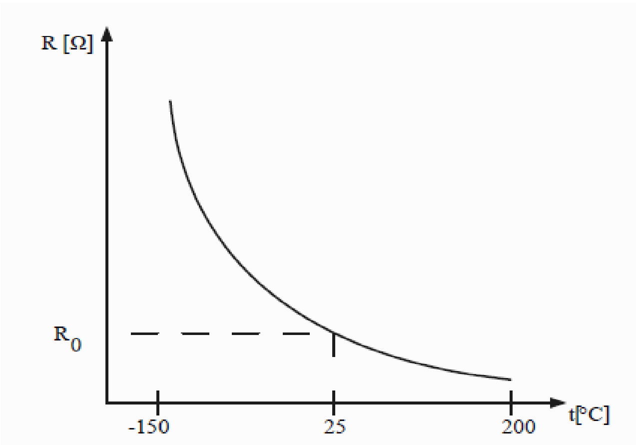
But finding the balance is a challenge. Maximising economic efficiency does not always go hand in hand with environmental sustainability. For example, excessive use of chemicals can damage soil quality and ecosystems, in addition to the economic benefits. This is why smart and responsible automation and robotisation that takes into account both economic and environmental aspects is important.

7. Sensors used in greenhouses, agriculture

Given that the sensors used in agriculture can be diverse in their design, we provide some insight into the principle of operation of these sensors for a better understanding, but also some examples that can be used in professional or even hobby level horticulture, the examples are not exhaustive in this respect.

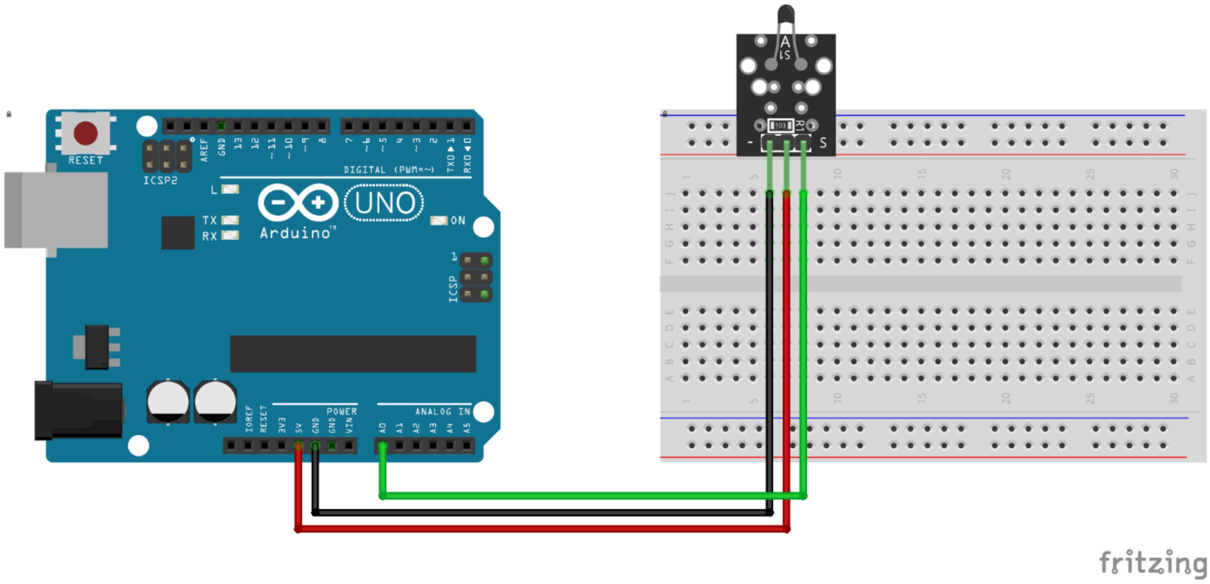
7.1 Analogue temperature sensor

Let's look at a concrete, simpler example of a temperature measurement, which is traced from sensing through signal processing to the display of the information. In our example, the sensing element is an NTC type thermistor. The best approximation of the thermistor's temperature dependence is given by the Steinhart-Hart equation. The input of the sensor is the temperature and the output is the value of the electrical resistance.



This sensing element (thermistor) is connected to a voltage divider circuit of another with resistor.

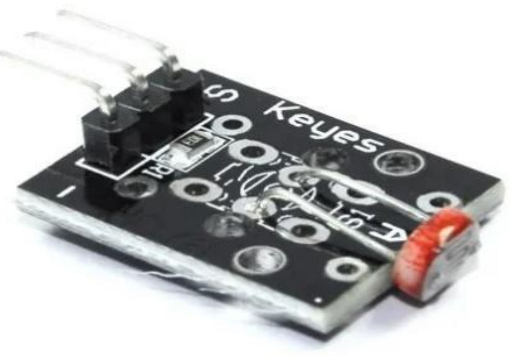
The voltage divider circuit is powered by +5V, with an analog voltage output connected to an analog input of the Arduino UNO.

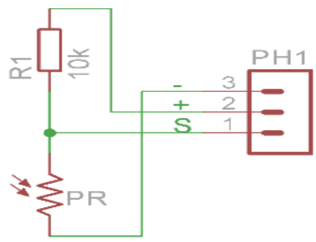


The analogue-to-digital conversion is done in the Arduino UNO, which runs a program. The task of the program is to perform the analog-to-digital conversion in a cyclic manner. The result of the conversion is a numeric value that is passed through a digital signal processing process. During the signal processing, mathematical calculations, taking into account the value of the resistor used in the voltage divider and the static characteristics of the sensor, allow the temperature value in Celsius or Kelvin to be calculated accurately. The result is transmitted via the USB port to a computer, which displays the displayed information.

Photoresistor

It is used to detect illumination, the resistance decreases as the illumination increases, but it is also sensitive to the wavelength of light. The figure below shows a photo-resistive sensor and its circuit diagram.





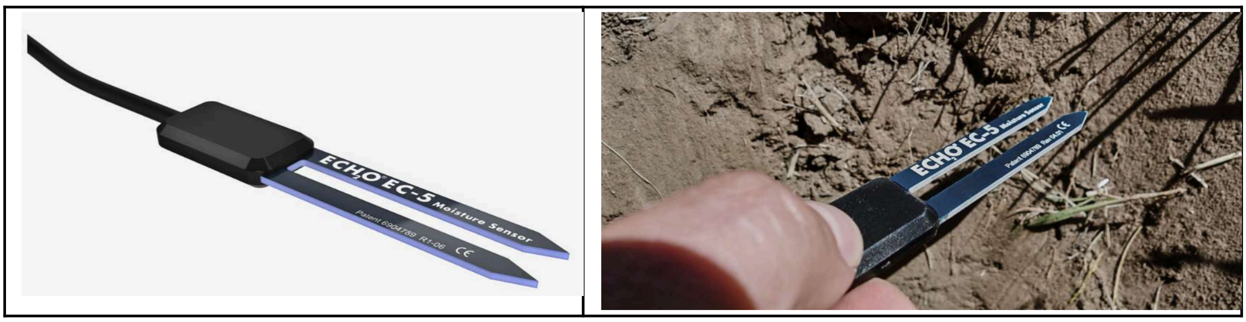
Likewise, **photodiodes**, **phototransistors** and sensors are used on these elements to detect light.

7.2 Soil moisture sensor

Moisture meters are used in agriculture, in the cultivation of plants and flowers, where soil moisture is measured and the amount of water applied is controlled depending on the measured values, using automatic irrigation systems. In the case of resistive humidity sensors, the resistance decreases and the conductivity increases as the humidity increases.

In the case of capacitive humidity sensors, the dielectric between the two armatures changes in response to humidity, e.g. when measuring soil moisture, the dielectric may be wet soil.

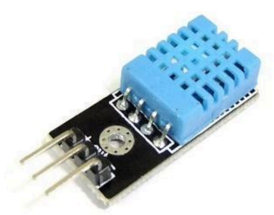
Source : https://ardushop.ro/ro/home/44-modul-senzor-umiditate-sol-higrometru.html



Source : https://www.metergroup.com/en/meter-environment/products/ech20-ec-5-soil-moisture-sensor

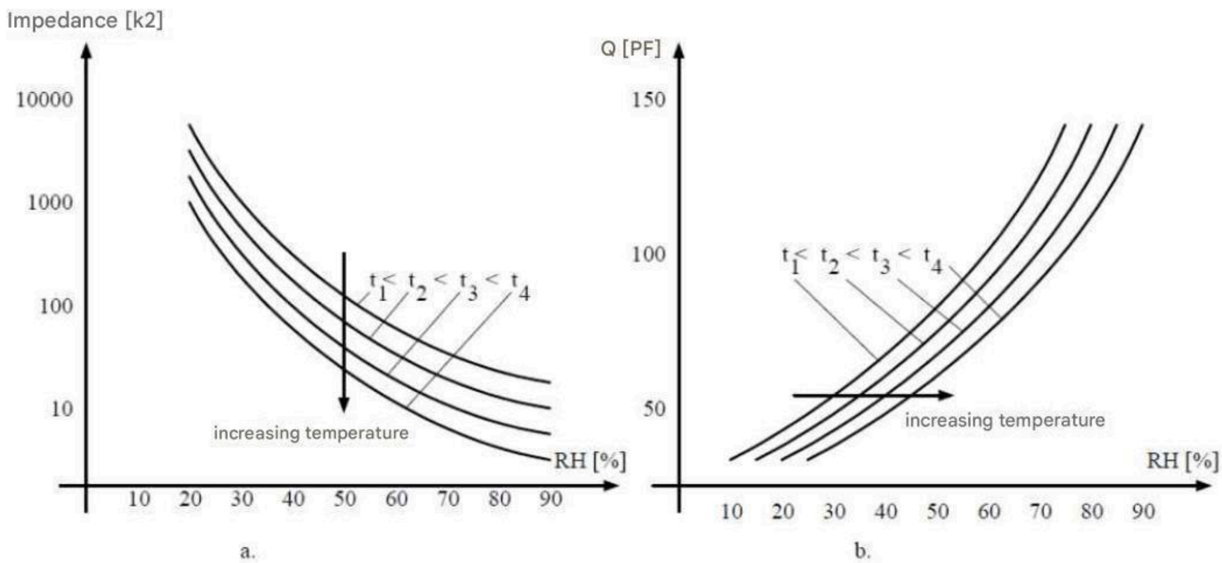
7.3 Temperature and humidity/humidity sensor

Water is almost ubiquitous and comes in many forms: drops, vapour, grit, snow, mist. Vapour in air or any other gas is usually called moisture. Absolute Humidity - gives the mass of water in a unit volume of gas.



Source : https://ardushop.ro/ro/electronica/619-modul-senzor-temperatura-i-umiditate-digital-dht11.html

The figure shows the typical static characteristics of moisture meters based on resistance (impedance) and capacitance changes.



Both characteristics are temperature-dependent, and it is no coincidence that most humidity sensors in integrated circuits also include temperature sensors.

7.4 Raindrop sensor

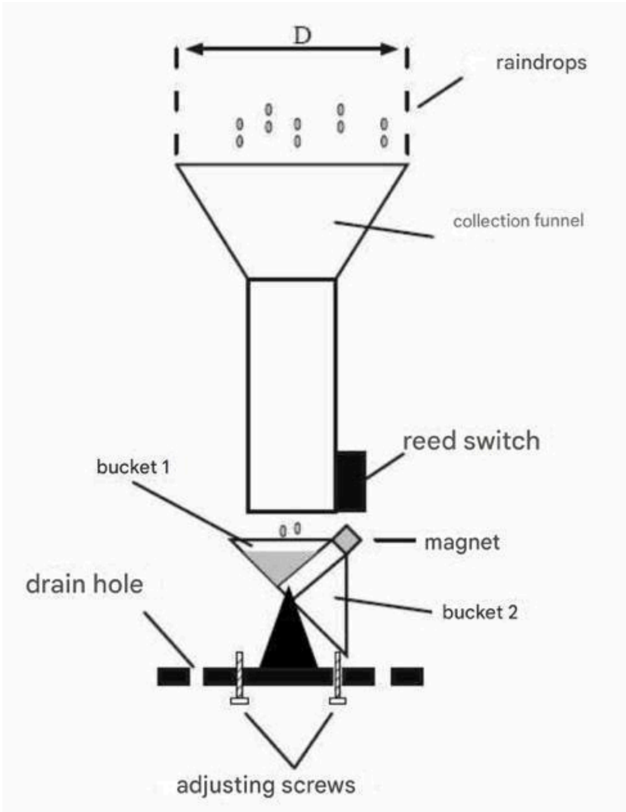
Raindrop sensors mostly detect the presence of rain, but provide little information on the amount of rainfall. The design of such a raindrop sensor is shown in the figure below.

Source : https://ardushop.ro/ro/home/130-senzor-picaturi-de-ploaie.html
User Guide: https://www.youtube.com/watch?v=uDdiMMdVb90

7.5 Precipitation sensor

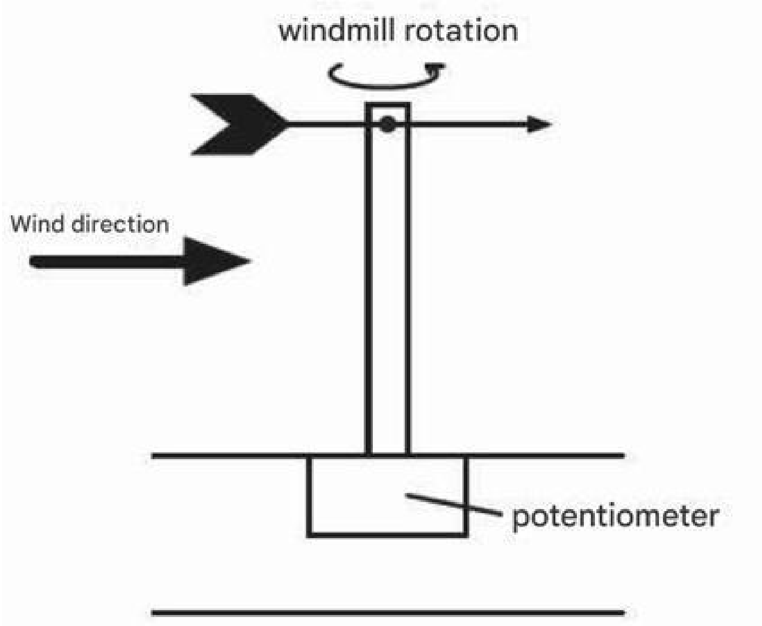
Precipitation measurement is mainly important from a meteorological, agricultural point of view, and the weather in a given geographical area plays a decisive role in its formation. It may be liquid (rain), solid (snow, sleet, hail) or mixed (hail). **Precipitation is** measured in mm, which is the number of litres of precipitation per 1 m2 of area (1 *l of precipitation* falling on 1 m^2 = *1*dm^3 of area *h* = 1 mm of precipitation height). The intensity of precipitation is given by the amount of precipitation falling during a unit of time.

The tipping bucket method is very common and is shown in the figure below. The tipping bucket consists of a collection funnel with a diameter D, which allows the collection of raindrops over a large surface area. Minél nagyobb az átmérő, annál hatékonyabban gyűjti össze a szórványosan eső esőcseppeket. csapadékot is pontosabban tudjuk érzékelni, ugyanakkor az összegyűjtött csapadék mennyisége is növekszik, ezáltal a tölcsér alján elhelyezett vödrök is hamarabb megtelnek, növelve az érzékelés felbontását, mely a gyűjtő vödrök méretétől is függ. Buckets 1 and 2 (left and right) will fill and empty sequentially as the rain fills them as a consequence of gravity. While one is being filled, the other is being emptied (and vice versa). The adjusting screws allow you to control the amount of emptying and the angle of tilt to ensure that the buckets are emptied. At the top of the tipping mechanism is a permanent magnet, while at the bottom of the hopper is a fixed Reed switch. When the permanent magnet comes close to the reed switch, the latter's contacts close (bucket 1 fills), and when bucket 2 fills, the reed switch is removed from the immediate field of the permanent magnet and the contacts disengage. These state changes can be easily counted by a program running on an embedded system using a simple signal conditioning electronic circuit and from there, taking into account the volume of the bucket and the time elapsed while counting the empty buckets, the intensity of the precipitation can be obtained by mathematical calculations.


D
raindrops
collection funnel
reed switch
bucket 1
magnet
drain hole
bucket 2
adjusting screws

7.6 Measurement of wind direction

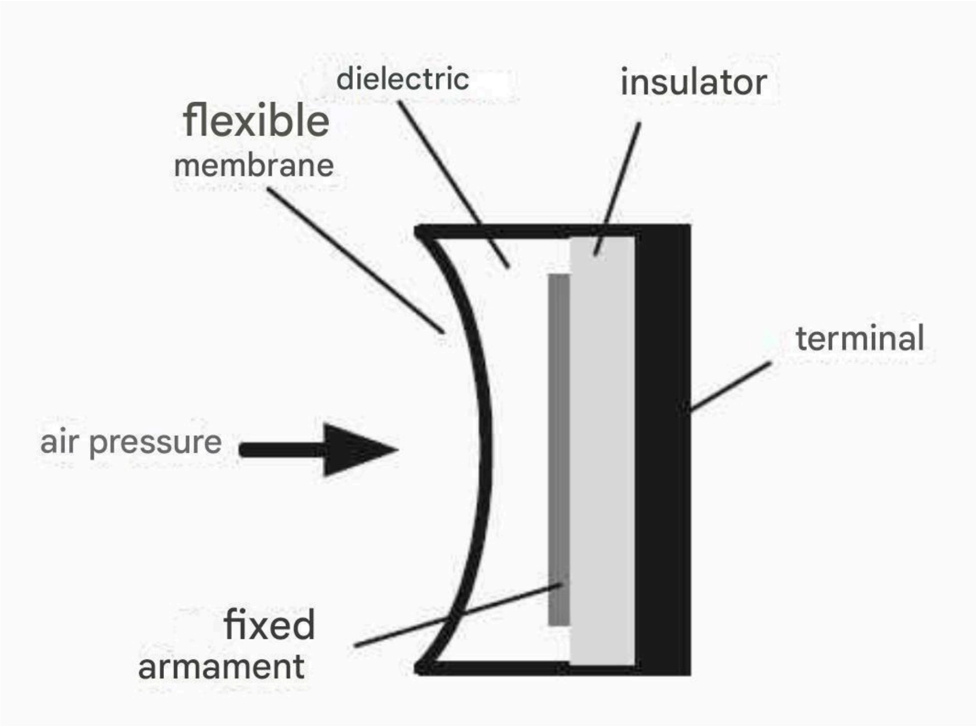
A wind box is typically used to measure wind direction. Officially, this is usually placed at a height of 10 m. A wind vane is a device placed on the ground perpendicular to a pole. This arrangement allows the wind to cause the wind vane to always turn in the current wind direction around the axis defined by the pole. It thus indicates the current wind direction in two dimensions.



In a simple embodiment, a rotary potentiometer is used, where the cursor moves parallel to the axis of the wind vane. As a result, the position of the potentiometer cursor changes as the environmental parameters are measured, i.e. as the wind direction changes. Thus, the measured resistance value changes between one end point and the position determined by the cursor. The change in the resistance value causes an electrical voltage/current change in the electronic circuitry which, after analogue-to-digital conversion of the information, can be used to accurately determine the wind direction value in the digital system during signal processing.

7.7 Measuring barometric pressure

The weight of the air molecules around us per unit area is called air pressure. Air pressure measuring devices are also called barometers. Air pressure varies with altitude. One of the most common methods of measurement is the capacitive method, whereby the capacitance of a capacitor, which is measured, changes in response to the air pressure. In general, the two armatures of a capacitor are a fixed and a flexible membrane, with a capacitance formed by the action of a dielectric between them. Under the effect of air pressure, the armament created by the flexible membrane moves closer or further away from the fixed armament, thereby changing the capacitance of the capacitor.

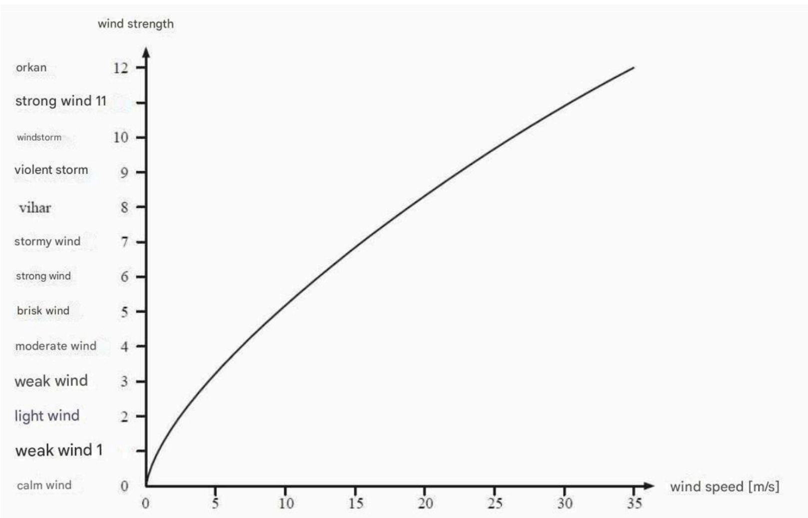


Another sensor often used to measure air pressure is the piezoresistor.

7.8 Wind speed measurement

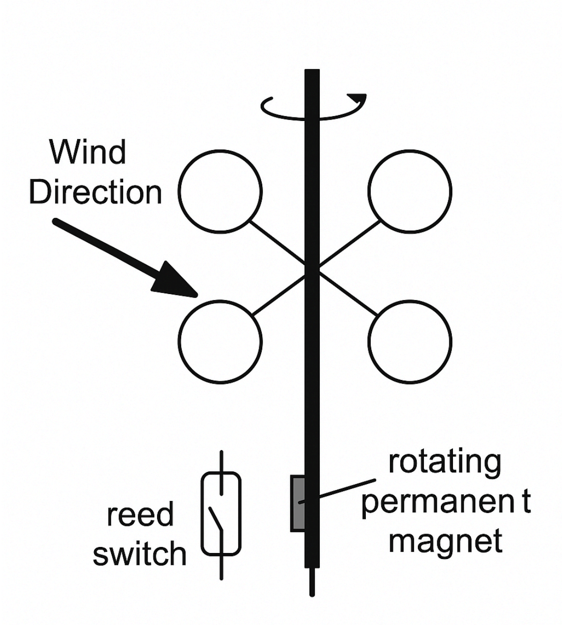
The wind flow velocity is caused by the movement of air from high to low pressure, usually due to changes in temperature. The greater this pressure difference between two points in the atmosphere (pressure gradient), the greater the wind speed (from the higher pressure point to the lower pressure point) will be to compensate for this difference.

Measuring wind strength on the Beaufort scale:



Several wind measurement systems are used to measure wind speed. One approach is the propeller solution, in which a propeller is placed on the nose of the wind vane and the rotation speed of this propeller increases with the wind speed. This rotation speed is measured by different methods.

Another, and perhaps the most common, method is to use a spoon wind gauge. In this case, a 3 or 4 spoon device is placed on the axis of the wind vane. The spoons rotate depending on the wind speed, and this rotation speed is measured.



In both cases, the wind speed is related to the rotation speed, which is measured by some optical or magnetic method.

There are also solutions that do not include rotating parts that are subject to mechanical wear. These include hot wire anemometers or methods using the propagation speed of sound waves. In the latter case, ultrasound is excited in a range inaudible to the human ear, which allows not only the speed of the wind but also its direction to be determined. Three ultrasound transceivers are placed 120 degrees apart in a virtual circle and transmit signals to each other in turn. Given that the ultrasound speed and the wind speed are vectorially additive, by measuring the propagation time of the sound waves and knowing the exact distance between the transceivers, the wind direction and wind speed can be calculated mathematically.

There are so-called meteo stations, which integrate most of the listed environmental parameters into a single system, or can measure several parameters.

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3. MICROPROPAGATION TECHNIQUES IN THE LABORATORY

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1. Pest-free plant production and micropropagation

1.1 The importance of micropropagation in pathogen-free crop production

Disease-free crop production is one of the most important challenges for the agricultural economy, as plant pathogens such as fungi, viruses and bacteria can cause serious damage to plant health and production. In traditional propagation methods, pathogens can often be transferred with the plant material, exposing plants to diseases. In addition, plants propagated under inappropriate conditions are more susceptible to the spread of pathogens and diseases.

Micropropagation is an innovative technique that allows pathogen-free plant propagation. This method relies, among other things, on the propagation of microscopic parts of plant tissue and the totipotency of cells under laboratory conditions. The procedure usually involves taking pieces of plant tissue from the healthy part of the parent plant, mainly from shoot tips, such as buds. These tissue fragments are grown in a sterile environment on nutrient-enriched media where new plants are formed.

The advantage of micropropagation is that the propagated plants can be completely free of pathogens that may be present in the parent plants. As a result, pathogen-free plants are healthy, vigorous and, under the right conditions, can have better yields. In addition, micropropagation allows plants to be propagated very quickly and efficiently, regardless of the weather, and can therefore result in economical and sustainable crop production.

Source: ChatGPT 4.0 DALL-E

1.2 Laboratory conditions and hygiene requirements for pathogen-free propagation

Laboratory conditions and careful hygiene protocols are essential for successful micropropagation. The laboratory operates in a sterile environment that minimises the presence of pathogens and other contaminants. Laboratory staff wear special clothing, including gloves and masks, to prevent contamination and contamination by pathogens.

The culture media on which the plant tissues are propagated are strictly sterilised and enriched with nutrients and synthetic hormones to ensure the proper development of the plants. Tools such as scissors, scalpels and glassware are completely disinfected to avoid the spread of pathogens among the propagated plants.

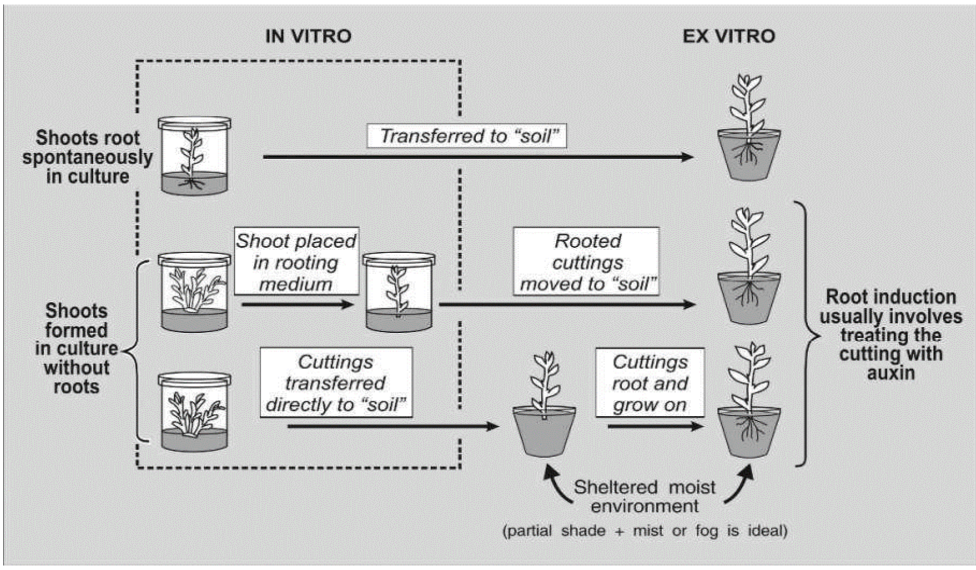
Continuous monitoring and maintenance of the laboratory environment is essential for pathogen-free propagation. Air conditioning and ventilation systems ensure that the correct temperature and humidity are maintained. Regular disinfection and cleaning ensure that the laboratory is kept clean and sterile.

1.3 Identification of pathogens and preventive treatments during micropropagation

Although micropropagation takes place in a laboratory environment, it is important that plant parts are selected from mother plants that are free from pathogens and diseases. Preliminary plant health testing and screening for pathogens is an important step in ensuring successful micropropagation. If the plants show symptoms of pathogens, appropriate preventive measures should be taken, such as removal of infected parts or quarantine of the plants.

During micropropagation, plants are regularly checked for plant health In the event of any infection being detected, the affected plants are immediately isolated and treated to prevent the spread of infection.

Overall, micropropagation is one of the most important tools for pathogen-free plant propagation, allowing plants to be propagated free of pathogens and pests, and quickly and productively. Strict adherence to laboratory conditions and preventive measures against pathogens are key to ensuring a successful micropropagation process. Pathogen-free plant propagation can lead to sustainable and efficient agricultural practices, contributing to the development of global food supply and agricultural production.



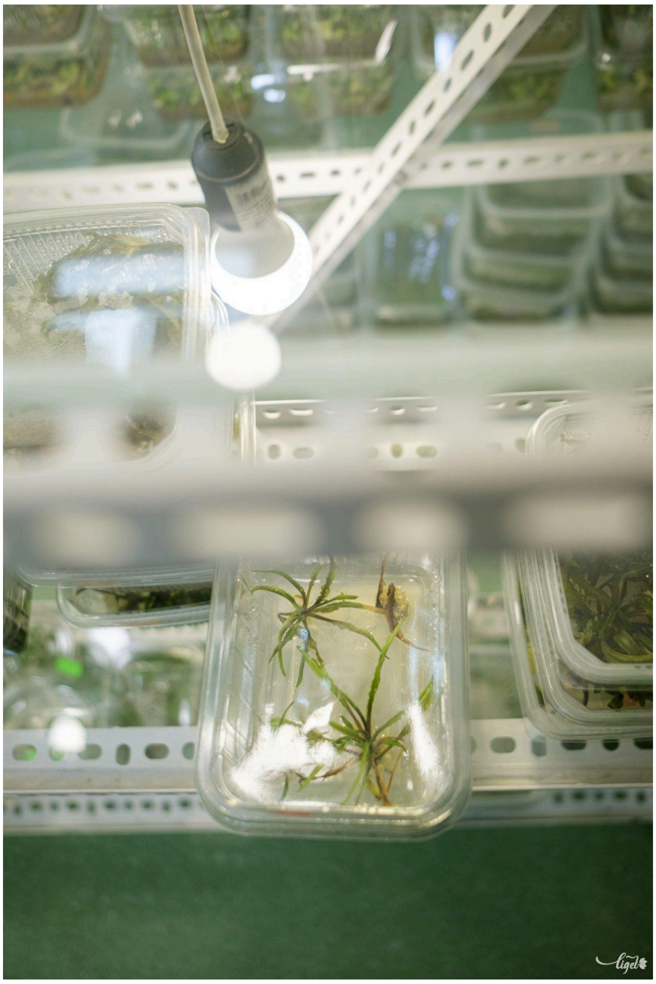
Source. George et al. 2007.

2.1 Preparation of tissues and other explants for in vitro propagation

In vitro propagation methods have brought major breakthroughs in agriculture and plant biotechnology, allowing plants to be propagated efficiently and rapidly in the laboratory. *In vitro* propagation is based on tissue culture techniques, where tiny tissue particles of plants, called explants, are placed in nutrient-rich media and given optimal growth conditions. Explants can be, for example, buds, leaf fragments or other tissue parts.

When testing plant parts and tissues, the selection and preparation of suitable explants for in vitro propagation is a key step. The explants are separated and prepared under sterile conditions to minimise the presence of pathogens and contaminants and to prevent the possibility of contamination. The explants are then sterilized, usually in sodium hypochlorite solution and/or ethanol, to ensure that they are completely free of pathogens.

The explants are carefully checked and the most suitable ones are selected for the propagation process. This allows only the healthiest and strongest explants to be used for in vitro propagation and guarantees the successful development of healthy plants in later stages.



Source : https://liget.ro/eletmod/egy-hely-ahol-mindig-nyar-van#&gid=1&pid=5

2.2 Comparison of different in vitro reproduction techniques

Among the various techniques of *in vitro* propagation, there are a number of options that may be suitable for propagating different plant species and their varieties. Some of them are:

Propagation from shoots	This method is suitable for propagating healthy shoots. The explants are sterilized and then grown on sterile media. This technique is particularly effective for plants that produce vigorous shoots.
Propagation from the stem	In this method, the stem part of the plant is used as an explant. This is used in the production of stem cuttings. The explant is placed on a medium where the plant part develops roots and shoots. This method is particularly useful for propagating trees and shrubs that are difficult to propagate conventionally.
Propagation by division	In this case, the mother plant is divided into several parts and the resulting smaller plant parts are placed separately on the soil. This method is effective for the rapid multiplication of plants and is particularly suitable for plants that are difficult or rare to propagate naturally.

3. Micropropagation and species conservation

3.1 In vitro propagation of rare and endangered plant species

In vitro propagation methods are particularly useful for the propagation of rare and endangered plant species that have limited access to protect their natural habitats or are difficult or dangerous to propagate conventionally.

Source : https://kert.tv/novenyek-szaporitasa-gyokereztetes/

Traditional propagation methods often require significant amounts of plant material, which can be problematic for endangered species. However, with *in vitro* propagation, even a single plant can be sufficient to initiate propagation, and propagation in culture media can achieve rapid and efficient multiplication.

Further research and development offers an opportunity to develop and optimize in vitro propagation procedures to promote the sustainable and efficient development of the agricultural economy.

3.2 Micropropagation and the preservation of genetic diversity of species

Traditional breeding methods are often insufficient to conserve endangered plant species because of a lack of available parent plants or because they take a long time to propagate. Micropropagation allows a significant number of offspring to be produced from a small number of parent plants, thereby increasing genetic diversity and contributing to species conservation.

During micropropagation, explants are cultured under sterile conditions, thereby minimizing the risk of environmental contamination and ensuring the genetic purity of the species. Consequently, micropropagation can be an ideal method for conserving endangered species, which can only be cultivated under special conditions.

- **Genetic databases and bioinformatics:** Monitoring and analysing the genetic diversity of species is critically important. Informatics enables the creation and maintenance of genetic databases, which assist in preserving and tracking genetic variation.
- **Sequencing technologies:** Modern DNA sequencing technologies allow for the construction of detailed genetic profiles, which support the conservation of genetic diversity and the optimisation of micropropagation processes.

3.3 Phenotypic diversity and adaptation in micropropagation

By selecting and processing different explants during micropropagation, new plants with varied characteristics can be produced, such as differences in leaf size, shape, or colour.

This phenotypic diversity is important for enhancing the adaptability and survival prospects of the species or cultivar. Plants with diverse phenotypes can adapt to different environmental conditions and stress factors, thereby making the plant population produced through micropropagation more resilient to changing conditions.

Data collection and analysis: Gathering and analysing phenotypic data helps to understand the impact of various environmental factors on plant development. This information can be important for developing and conserving adaptive traits.
Predictive modelling: Using informatics tools, predictive models can be created to forecast how different environmental changes may affect the plant's phenotype. This can assist in designing propagation strategies that enable plants to better adapt to changing conditions.

3.4 The contribution of micropropagation to sustainable crop protection and agriculture

Micropropagation has an important role to play in promoting sustainable crop protection and sustainable agricultural practices. Micropropagation allows for healthy and pathogen-free selection of plants, thus minimising the spread of pests and diseases in the propagated crop population.

Pathogen-free micropropagation allows the production of infection-free or resistant crops that require less pesticide application. This reduces the negative environmental and health impacts of chemicals and promotes sustainable agriculture.

In addition, micropropagation offers the possibility of producing hybrids and combining improved plant traits. This can increase the productivity and resistance of the crops grown and reduce the environmental stresses involved in their cultivation.

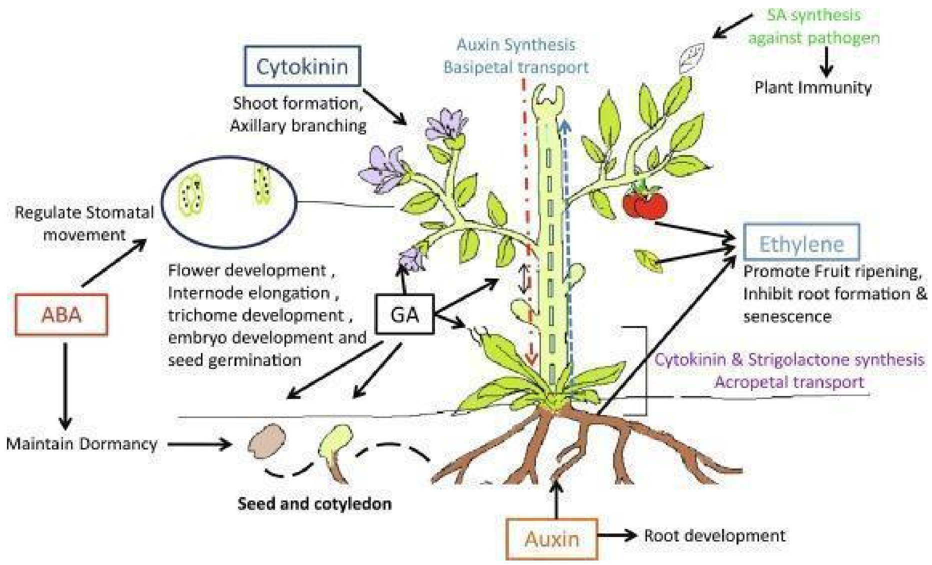
Overall, micropropagation has great potential for species conservation, contributing to the conservation of endangered plant species and increasing genetic diversity. In addition, it offers the potential to increase phenotypic diversity and improve plant adaptation, which is key to promoting sustainable plant conservation and agriculture.

4. Improving the efficiency and accuracy of micropropagation

4.1 Hormonal balance and regulation in the reproductive process:

Hormonal balance and regulation is a key factor in increasing the efficiency of micropropagation. Plant hormones such as auxin and cytokinin play an important role in plant reproduction and growth. Adjusting the optimal hormonal balance enables the efficient growth and differentiation of explants and promotes the development of healthy shoots and roots on plants.

Hormonal regulation requires the use of appropriate concentrations and ratios under *in vitro* conditions to maximise plant growth and reproduction. Hormonal regulation allows tissue differentiation and the development of the appropriate plant organs needed for successful reproduction.

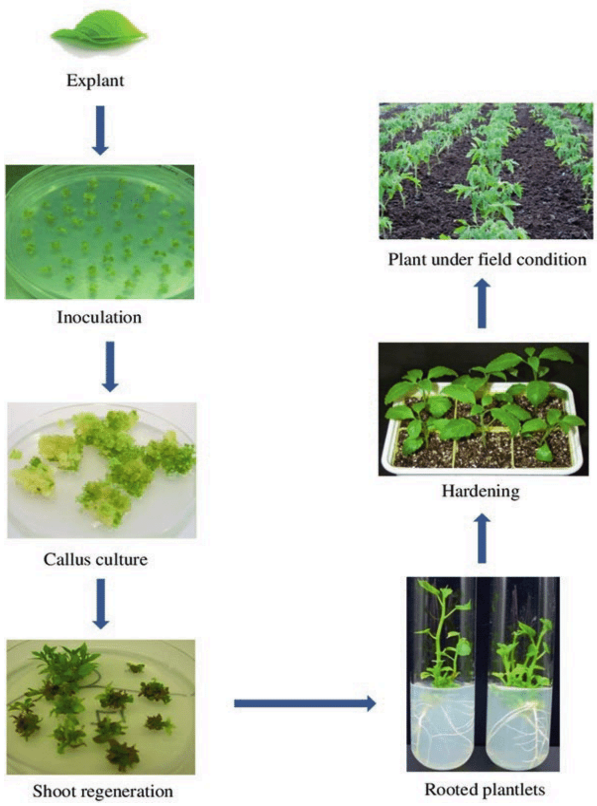


Source : https://www.sciencedirect.com/science/article/abs/pii/B9780323907958000023

Data collection:	**Data** collection technologies can be used to obtain detailed information on the hormonal responses of plants during the reproductive process.
Modelling:	The data collected will be used to build models to help understand the role of hormones in plant development.
Regulatory algorithms:	Developing algorithms to help maintain an optimal hormonal balance to promote healthy plant tissue development.

4.2 Optimising nutrients and media for efficiency:

Providing plants with the right nutrients enables healthy growth and development. Soil enriched with the right nutrients promotes rapid and efficient explant growth and the development of roots and shoots.



Source :
https://www.vedantu.com/question-answer/what-is-micropropagation-class-12-biology-cbse-5f9066d6d519b61dfd600b05

The pH and composition of the soil also affect plant reproduction and development. Optimal pH and nutrient ratios help minimise the possibility of contamination and improve explant survival rates.

Nutrient management: accurate monitoring and control of the composition of nutrients and media is important for optimal plant tissue growth.

Application of artificial intelligence: artificial intelligence-based systems can be used to optimise the composition of media, pH, temperature and other environmental factors.

4.3 Challenges and solutions for genetic stability and clonal breeding:

In clonal propagation, explants are genetically identical to the parent plants, resulting in excellent genetic stability. However, one of the challenges of clonal breeding is the lack of genetic variability, which in the long run can lead to vulnerability of the populations and difficulties in adapting to new environmental conditions.

To improve genetic stability and adaptability, genetic diversity should be introduced into the breeding stock. This can be achieved by introducing new plant material into the breeding process, which can be derived from different parent plants. In addition, genetic variability can be generated in the propagated plant stock through mutation techniques and control of the maturation phase.

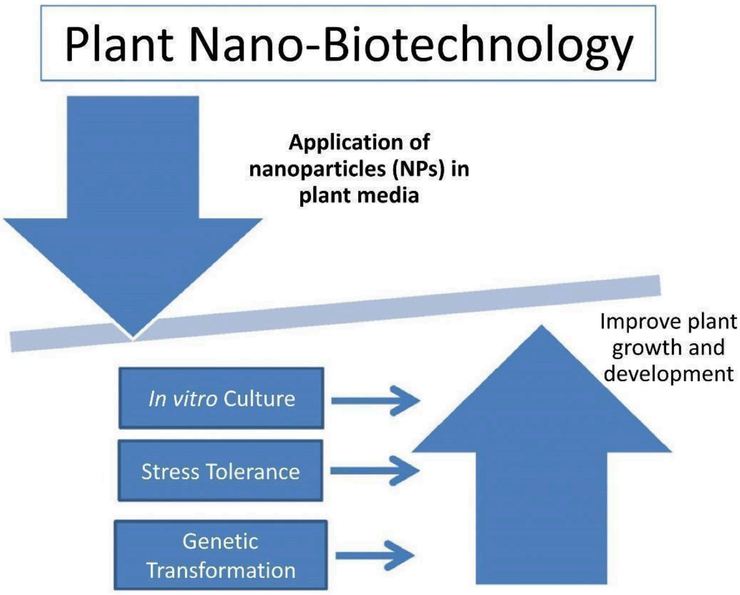
Genetic analysis: genetic sequencing technologies can be used to monitor the genetic stability of plant tissues.

Databases and bioinformatics tools: storing and analysing genetic data with bioinformatics tools can help detect early signs of genetic instability.

Predictive modelling: analysing the relationship between genetic data and plant development can help predict and address challenges in the cloning process.

Overall, to increase the efficiency and accuracy of micropropagation, a number of aspects need to be considered, including regulating hormonal balance, optimising medium and nutrients, and addressing the challenges of genetic stability and clonal propagation. Further research and development offers the potential to further improve *in vitro* propagation techniques and promote sustainable crop production practices in the agricultural economy.

5. Nanotechnology and micropropagation



Nanotechnology is employed in different aspects of plant biotechnology to foster food security, and produce genetically modified plants that are resistant to environmental and stress conditions.

Source : https://www.eurekaselect.com/article/118920

The use of nanotechnology in micropropagation could represent a major advance and the IT aspects can be integrated into the development of this field as follows:

5.1 Application of nanoparticles in micropropagation:

Because of their small size and high surface area, nanoparticles interact very efficiently with other materials, such as plant cells. In micropropagation, the use of nanoparticles allows plant explants to grow and multiply more efficiently. For example, nanoparticles are able to penetrate plant cells and deliver nutrients, hormones and other necessary substances to the cells in a targeted manner, which can accelerate growth processes and improve reproduction rates.

Data collection and analysis: data collection techniques can be used to monitor the effects of nanoparticles on plant cells. These data help to understand the interactions of nanoparticles with cells and their effects.
Modelling: the data can be used to develop models that help predict the behaviour of nanoparticles under different conditions, allowing the optimisation of the propagation process.

5.2 The benefits of containers and nutrients in plant cell culture:

The nanoscale containers provide a large surface area for cells, which helps to improve nutrient uptake and optimise growth processes.

In addition, they can also target nano-sized nutrients to cells, thereby enhancing cell growth and differentiation.

Precision dosing: nanotechnology can be used to precisely control the delivery of nutrients and hormones, improving the growth conditions of plant cells.

Simulations and analytics: IT tools can be used to model and analyse the effects of nanocontainers and nutrients, allowing the development of more effective formulations and treatment protocols.

5.3 Impact of nanotechnology on reproductive efficiency and phenotype:

The integration of nanotechnology into the micropropagation process can provide significant benefits through precision dosing, more efficient propagation processes and improved phenotypes. Informatics tools such as data analysis, modelling, simulations and predictive analytics are key to exploiting these benefits.

Nanotechnology is an advanced scientific field that deals with the manipulation of materials and structures at the nanoscale. In recent years, nanotechnology has also been used in agriculture, in particular in plant biotechnology, and thus has also found applications in the field of micropropagation. The benefits of nanotechnology and its innovative solutions can lead to more efficient and sustainable micropropagation processes.

However, it is important to note that the application of nanotechnology is still a relatively new and under-researched area, and further research is needed to determine the extent to which it affects the micropropagation process and the phenotype of the resulting plants.

Data mining and machine learning: machine learning and data mining techniques can help to extract relevant information from large data sets, thus identifying the most important effects of nanotechnology on reproductive efficiency and plant phenotype.

Predictive analytics: predicting the effects of nanotechnology interventions can help fine-tune breeding strategies and achieve desired phenotypes.

6. Automated micropropagation systems

Automated micropropagation systems are innovative solutions that enable the efficient and precise propagation of plants in large quantities, minimising the need for human resources and time. Automated systems represent a significant advance in micropropagation and offer many advantages over traditional manual propagation methods.

The following automated systems are the most commonly used in the micropropagation process:

6.1 Light rooms

Source : https://www.darjeelinggardens.com/tissue-culture.html

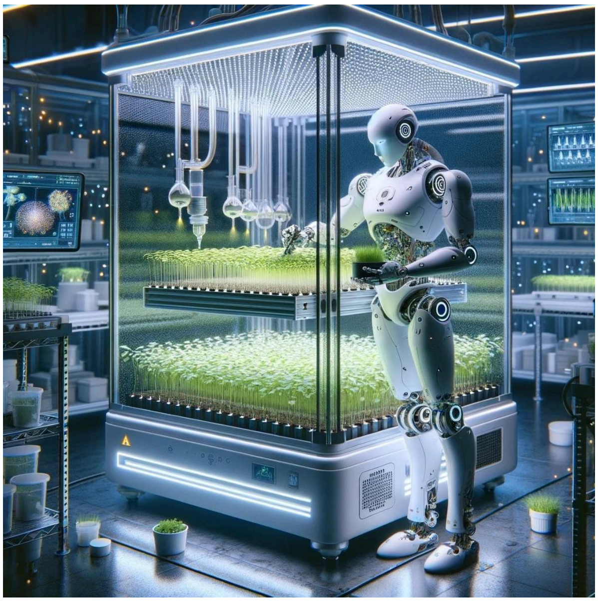
The light rooms used in the process of micropropagation can be thought of as a special greenhouse, with all the technologies that we will learn about in the other 6 topics in Module 2.

Here is some basic information about the light rooms used in micropropagation:

- **Function and purpose:** The purpose of light rooms is to provide optimal growing conditions for crops. This includes the right light intensity, light composition, temperature, humidity and other environmental factors that promote healthy plant growth and development.
- **Control and Supervision:** in artificially lit light rooms, automated systems ensure the control of light intensity, wavelength and spectrum, which are essential for healthy plant growth.
- **Light sources:** different types of light sources are used in the light rooms, such as fluorescent lamps, LED lamps or special plant growth lamps. These light sources provide different wavelengths of light that affect the photosynthesis and growth of plant cells.
- **Temperature control:** temperature control is also important in light rooms, as plant growth and development is highly dependent on the ambient temperature. Temperature control devices in the rooms allow researchers to precisely set and maintain the desired temperature.
- **Humidity and ventilation:** Maintaining adequate humidity and ensuring adequate ventilation are also vital for healthy crop growth. Humidity controls and ventilation systems in light rooms help to optimise these factors.
- **Controllability and control:** when designing light rooms, special attention is paid to ensuring that environmental factors such as light, temperature and humidity can be accurately and easily controlled. This allows workers to tightly control and regulate the growing environment of crops. Sensors can be used to continuously measure temperature, humidity, carbon dioxide levels and light intensity, providing real-time data on the plant environment.

Light rooms are therefore essential in micropropagation to ensure healthy and controlled growth of plants. These rooms allow researchers to precisely control the environmental conditions required for plant cultures, thus facilitating efficient and successful propagation.

6.2 Combining robotic systems and micropropagation



Source: ChatGPT 4.0 DALL-E

In automated micropropagation, the use of robotic systems allows the rapid and accurate handling of explants, planting and automation of the whole process. Robotic systems are capable of high speed and accuracy and can process multiple explants at the same time, allowing for higher volume micropropagation.

The precision and consistency of robotic systems contribute greatly to the reliability and success of the breeding process. Robotic systems are able to plant explants at a consistent distance and depth in the culture medium, minimising the risk of damage and contamination.

6.3 The role of artificial intelligence in automated micropropagation

Artificial intelligence (AI) is increasingly being introduced into automated micropropagation systems, further improving efficiency and accuracy. AI allows systems to learn and adapt autonomously to different conditions and changing circumstances.

AI algorithms are able to detect and react appropriately to the condition of plants and intervene in time if any problems or abnormalities occur during the reproduction process. This proactive approach increases success rates and minimises risks.

Optimisation algorithms. AI and machine learning algorithms can help determine optimal growing conditions and automatically adjust light room parameters.
Predictive maintenance: AI analytics can help predict the maintenance needs of your lighting room system, reducing downtime and increasing system efficiency.

6.4 Scalability and mass propagation options

Automated micropropagation systems are excellent for scalability and mass propagation. Because robotic systems are faster and more efficient process plants more efficiently, they allow for larger planting sizes and mass propagation.

With the potential for scalability and mass propagation, automated systems can contribute to increasing agricultural production and producing the large quantities of crops needed to maintain varieties. Thus, automated micropropagation systems can contribute to sustainable and efficient agricultural production.

Overall, automated micropropagation systems are revolutionising plant biotechnology and agriculture, enabling faster, more efficient and more reliable plant propagation. The combination of automated systems with robotics and artificial intelligence will enable a significant increase in crop production efficiency and productivity, contributing to sustainable and high quality agricultural production.

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4. GREENHOUSE GROWING

Author:

- Pék Zoltán - Magyar Agrár- és Élettudományi Egyetem

1. Greenhouse growing, vegetable propagation

The spread of greenhouse cultivation of vegetable crops, or vegetable sprouting in technical terms, on a factory scale began in Hungary in the 1950s. Initially, this meant exclusively soil cultivation, which was gradually replaced by soil-less (hydroponic) cultivation in high-tech facilities from the 1990s onwards. From the technological point of view, the more environmental factors can be controlled in a growing system, the more advanced it is considered to be, the more precisely it can be controlled, while achieving higher yields and better quality. These growing objectives are best achieved today in vegetable production, in large air-space, climate-controlled greenhouses with biological control and soil-less cultivation (1). It is estimated that less than 0.3% of the world's total agricultural area is covered by some type of growing equipment.

Not only vegetable growing, but almost all branches of horticulture are subject to the high demand for manual labor, which today presents an almost insurmountable task for practicing gardeners. The development of robots in the field of precision farming that can be used for agro- and phytotechnical work also offers a solution to this problem.

Crop production facilities can be divided into 3 broad categories.

1.1 Low technology (small airspace installations)

They are less automated and highly dependent on their environment, usually using a single cover, typically plastic, with passive ventilation (top and side ventilation), without heating, and grown almost exclusively on the ground. For this type of structure, it is very important to know the differences between day and night temperatures due to the lack of heating and inefficient ventilation. They do not provide the microclimate necessary for the year-round cultivation of heat-demanding crops and can therefore be used for temporary cover (foil tunnels) or for growing during frost-free periods.

Equipment belonging to this subheading: foil tunnel, foil bed, Soroksár '70 type foil tent without side ventilation, wandering pollane (Figure 1)

Fig. 1 Foil tunnel, foil bed, Soroksár '70 type foil tent, sledge foil

1.2 Medium technological level (heated and unheated equipment)

Typicall,y plastic-covered units, which are already equipped with climate control (emergency heating, heating, side and/or roof ventilation), programmable irrigation with or without soil (hydroponics). Productivity and quality are generally higher than the previous technology and temperature control is usually very simple. It cannot yet compensate for extreme external temperatures and is therefore not suitable for continuous year-round production. The installation of side vents can be retrofitted, so that existing lower quality equipment can be upgraded. The side vents can also be installed afterwards, so the existing lower-quality equipment can be modernized. Equipment belonging to this subheading: foil tent with side ventilation, block foil houses Figure 2.

Figure 2 Foil tent and foil block with side ventilation

High technological standards (heated high air volume equipment)

Typically large airspace installations (average ceiling height > 3 m), with a single layer of glass (4-6 mm thick), for plastic, several layers (0,04-0,3 mm thick). To optimise the use of space, rolling tables are often used in the production of ornamental plants and propagating material. These special tables are usually equipped with a tidal irrigation system (see 4.5).

Raising Phalaenopsis on a roll-top table and pots with tidal irrigation

Facilities with fully automated climate control (highly independent from the outside weather), computer-controlled irrigation, CO_2 fertilisation, almost exclusively micro-irrigation. For this purpose, they have sensor-controlled irrigation and ventilation systems, shade nets for light (and climate) control, usually soil-less cultivation (except for organic cultivation). The greenhouse reacts instantly to changes in the external environment by means of external climate sensors. With these systems, the grower can optimise plant growth, maximise yield and crop quality.


Large airy plastic-covered greenhouse and glasshouse

1.4 Vertical farm

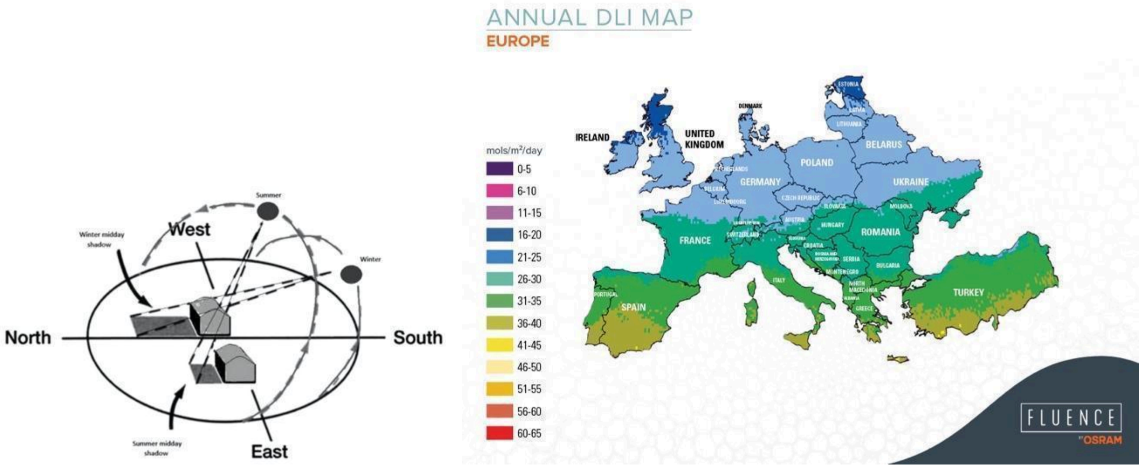
One of the fastest growing and most intensively researched topics in greenhouse production today, and one of the most important, is the topic of vegetable crops grown in fully enclosed and automated production facilities, the so-called Vertical Farm (Plant Factory). This would not have been possible without the development of LED lighting, whose energy efficiency allows its economic application in production and food production in places where it was not possible until now due to lack of light (barren areas, Arctic, space vehicles).


Vertical farms from Aerofarms (New York, USA) and VegetaFarm (Haneda, Japan)

Not only in vegetable production, but in almost all sectors of horticulture, the demand for manual labour is high, which nowadays presents practising horticulturists with an almost insurmountable challenge. One solution to this problem is the development of robots for agro- and phytotechnical work in the field of precision farming.

2 Basics of climate control for production equipment

The climate control of a production facility can be designed in relation to the geographical location (latitude) and microclimate of the implementation. The former determines the maximum/minimum angle of incidence of the sun's rays and, through this, the maximum and minimum day length (summer/winter solstice) and the theoretical expected daily solar radiation energy (Daily Light Integral, DLI).



The angle of incidence of the sun at the summer and winter solstices and Europe's DLI skyline

The latter is also strongly influenced by the microclimate of the area, which, in addition to the basic climate classification, is influenced by the local topography and other surface features. Growing facilities in the temperate zone are designed so that the rows of crops grown in them, generally oriented east-west (2).

High-tech equipment, which can therefore be implemented at the highest cost, must also be equipped with external meteorological sensors to protect the crop and equipment against extreme climatic events (wind, precipitation).

The climate control, which is highly dependent on the technological level of the plant, is based on data measured and transmitted by sensors, which are usually used by a control software to develop the optimal climatic and edaphic conditions for the specific technological version of the vegetable crop.

(For more information, see chapter 2).

3. Grower control in practice: the Priva Operator

To create optimal growing conditions, it is essential that all systems work together seamlessly, coordinated by the intelligent controller. This operations centre is the basis of the control system, to which several systems are connected. The more intelligent the controller, the better the processes achieve an optimal balance.

Temperature, humidity, CO_2 concentration, nutrient and water supply are optimised according to the amount of light irradiated, adapted to the needs of the crop. The control system continuously monitors the greenhouse growing conditions, such as ventilation, heating, shading, CO2 levels, fans, humidity, lighting, boilers, irrigation, nutrient solution and drainage water reuse, 24 hours a day, using data from sensors. All commercially available control systems have the necessary control options, as well as a graphical interface that can be accessed via a mobile client.

Graphical user interfaces for the Priva Operator greenhouse control system

4.Grower control in practice: Gremon Systems

All the major greenhouse control systems available in Hungary have sensor-controlled climate control and modules for optimal water and nutrient supply to plants.

Unlike the previous one, Trutina is a Hungarian solution developed by Gremon Systems, which can be used even for soil cultivation. In addition to the basic services, it also provides real-time monitoring of plant biomass (with an accuracy of 1 gram), based on the use of specially developed plant scales. The scales can be retrofitted in the crop and the number of sensors can be extended. It continuously monitors the biomass evolution and automatically warns when the tray weight decreases. By continuously monitoring irrigation water/fertilizer solution, it optimizes irrigation strategies to save water and fertilizer. Thanks to the client software, you can also monitor the process on your smartphone. Its alert system automatically sends a message when irradiation, temperature, nutrient EC, drainage water, bowl weight, root medium parameters reach undesirable values.

Gremon Systems, Trutina Greenhouse Control Software graphical user interface and sensors for measuring plants

Tungsram Agritech's Power Grow system can be used exclusively to control the company's proprietary vertical farm, which is unique in that it is completely closed. It is based on fully artificial lighting, using proprietary LED lamps to set specific lighting recipes. The lamps emit light not only in the photosynthetically active spectrum (PAR) but also in the ultraviolet range, which can be used to produce similar effects as in the open air under natural lighting conditions. The full potential of varying the ratios of the different wavelengths has not yet been scientifically investigated, so it is not surprising that several universities and research institutes are using their systems to study the effects of light on plants.

5. Soilless growing systems

The cultivation of a plant species on a given soil over several years is called monoculture. The monoculture of vegetable crops results in steadily decreasing yield averages year after year, even with species rotation. The main reason for this is the damaging effects of pests, pathogens and weeds that accumulate in the soil, which are avoided by soilless growing systems in greenhouses (9). Such systems must replace the abiotic functions of the soil to ensure that the roots of the plants receive adequate water, oxygen and nutrients (macro-, meso- and micro-nutrients). In previous production systems, there was a conflict between the supply of these needs, with an excess or deficiency of one causing an imbalance of the other or both.

In soilless cultivation, the nutrients needed for plant growth are applied in the form of nutrient solution, which is analogous to the nutrient supply capacity of soil, since the mineral nutrients are present in the aqueous phase of the soil as dissolved ions. Since the solid supporting medium (substrate) of plant roots usually contains little or only minimal amounts of nutrients, nutrient solution is mandatory for plant development.

A number of soilless cultivation systems have been developed, the most important of which are not exhaustive:

- Drip irrigation (Drip irrigation)
- Nutrient film technique (NFT)
- Deep flow technique (DFT)
- Tápköd culture (Aeroponics)
- Low tide system (Ebb/Flow)

Systems that apply nutrient solution directly to the roots of plants are called hydroponics (hydroponics), while systems that apply nutrient solution to the root medium are called agroponics (10).

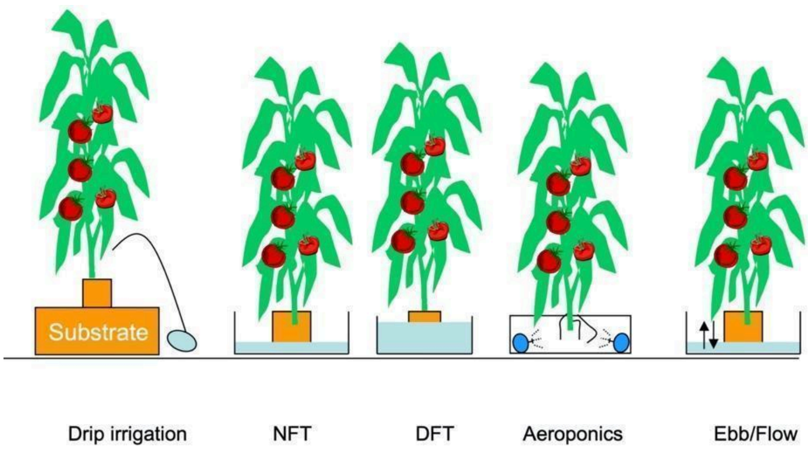
So-called agrosponge systems using a substrate are not really suitable for growing high density crops (e.g. leafy vegetables), so they are used more for growing vegetables grown for their yield (tomatoes, peppers, cucumbers). For growing leafy vegetables without soil, mainly NFT and DFT hydroponic systems are used, but aeroponics is also used. In totally enclosed growing systems using only artificial lighting, as in the case of vertical farms, hydroponic systems are generally used (11).

The Nutrient Film Technique (NFT) system is based on a 1-2% sloping channel with a thin layer of nutrient film continuously flowing at the bottom. This is where the roots of the plants take up the water and nutrients they need. The advantage of this system is that much less nutrient solution is present, which is an advantage in vertical growers because of the lower weight. The oxygen supply to the roots is also more favourable, which increases the flow rate by increasing the slope angle, thus improving the oxygen level in the nutrient solution (12). The disadvantage is that the temperature of the smaller amount of nutrient solution is more variable, but this is not a problem in growing systems with strict air temperature control (13).

Deep Flow Technique (DFT) was historically the first hydroponic soil-less cultivation system. Created in the 1920s, the tank culture was based on a 15 cm layer of nutrient solution in concrete basins. The plants were planted in a so-called seedbed on a metal mesh, which also served as a light barrier for the nutrient solution. The disadvantage was that it was not aerated, but it became the starting point for many solutions using a shallower layer of nutrient solution.

Aeroponics is a soil-less cultivation method requiring high investment and operating costs and a very precise technical background. It was developed in the 1970s and is also suitable for factory-scale cultivation. The basic principle is that the roots of the plants are suspended in a completely enclosed space, where the nutrient solution is injected in very fine atomization, in doses of a few seconds every 2-3 minutes. From the nutrient mist that forms around the roots, the roots, suspended in the air, are able to take up the nutrients continuously, with an excellent oxygen supply. The disadvantage is that even a short power failure is enough to dry out the roots and kill the crop (14).

In Ebb/Flow systems, the growing area is flooded with nutrient solution for a period of time to allow the plants and growing medium to absorb sufficient nutrient solution, and then the remaining nutrient solution is drained off. It is also used by home gardeners, mainly for seedlings, potted herbs and ornamentals on growing tables.



The main soilless systems used in greenhouses

6. Soilless cultivation water and nutrient supply (closed system)

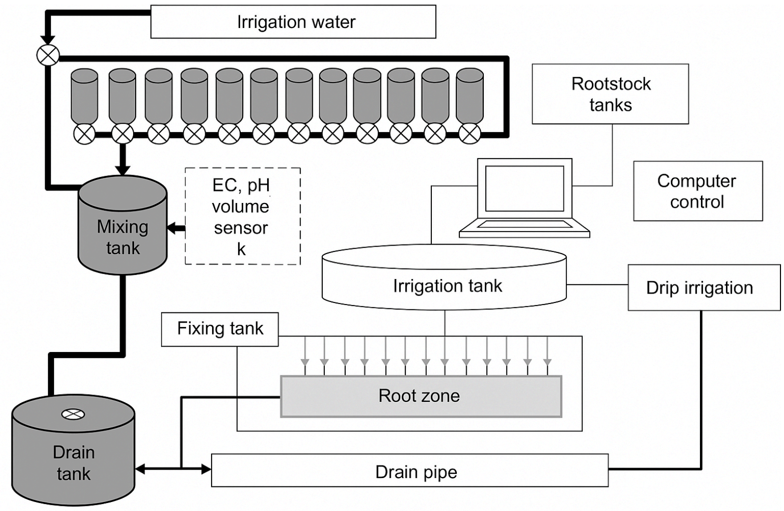
In soil-less cultivation, closed systems can also be used to minimize environmental pollution from run-off nutrient solution (drainage) (15). In addition to significant savings in irrigation water and nutrients, high yields and improved water use efficiency allow for more cost-effective cultivation overall (16). However, the accumulation of ions that are rarely taken up by plants can cause partial runoff to control salinity in root zones, thereby reducing the effectiveness of closed-cycle systems to prevent groundwater contamination. Intelligent automation systems based on mass balance models can be used to minimise the need for recycled effluent discharge, thereby reducing groundwater contamination (17).

The biggest risk factor in soil-less cultivation is undoubtedly the disinfection of drainage water, without which even a single diseased plant can infect the whole stand. It is the cost of disinfection that is most expensive in closed systems. There are a number of different methods of disinfection available, including pasteurisation, UV irradiation, chemical treatment, sand filtration and sterilisation filtration by reverse osmosis equipment (13).

Water detection sensors

Proper EC and pH levels are key factors for healthy culture growth. The Priva control computer and dual EC and pH sensors, you can automatically monitor and control EC and pH levels. By including a water flow sensor, the correct EC and pH levels can be determined - a pre-calculation that only Priva can provide. The control computer then corrects for deviations from the desired values based on the readings from the dual EC and pH sensors. And pressure sensors facilitate optimal water management in the reservoir and nutrient solution storage tanks.

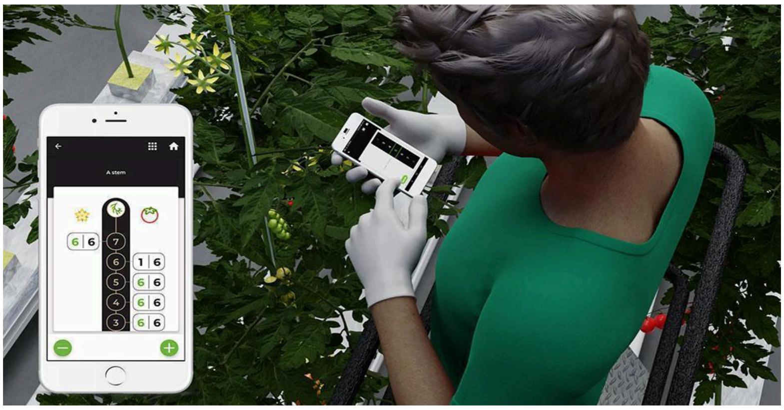
When growing on substrate, you can accurately measure the amount and EC value of drainage water with the drainage sensor. Using the Priva Growscale scale, you can automatically adjust the water dosage according to the growing conditions and the condition of the plant and the substrate, based on the needs of the plant.



Construction of an irrigation system for soil-less cultivation

7. FITO MONITORING

For continuous monitoring of plant health, non-destructive sensors are already available that can be used to monitor real-time parameters of characteristics that are visible to the naked eye (stem diameter, leaf number, quail number) or not visible to the naked eye (leaf surface temperature, photosynthetic activity). Gremon Systems' in-house developed solution is the Crop Monitor, which works in conjunction with the Trutina system mentioned above. It records plant vitality based on stem diameter, main shoot growth and flowering cluster spacing (internode length). It determines the leaf area index (LAI), based on the length, width and number of leaves, and the vegetative/generative balance of the plants, based on the number of clusters, flowers and tied berries, as well as vegetative parameters.



Graphical user interface of the Gremon Systems Fitomonitoring system

8. Phytotechnical works and harvesting

Not only in vegetable production, but also in almost all sectors of horticulture, the demand for manual labour is high, which nowadays presents practising horticulturists with an almost insurmountable challenge.

Phytotechnology, i.e. direct intervention on plants, may include, in the case of continuous-growing vegetable species: plant clipping, shoot positioning, removal of axillary shoots, leaves, flowers and fruit stems. A number of manufacturers offer tools for these operations. Self-operating robots have been developed for removing the lower leaves of tomatoes, which can also work efficiently at night.

The Priva Deleafing (mailing) robot

In the case of continuous-growing vegetable crops, the most important tool for implementing phytotechnology is the cultivator trolley, which is used to move between the rows. It is a height-adjustable, stationary structure powered by a battery-operated electric motor. Phytotechnicians can control its progress and change the height of the stand on which they can carry out their work while standing.

Self-propelled, lift truck, electric picker

Although it does not fall under the heading of phytotechnical work, harvesting cannot be done without touching the plants, which is one of the biggest jobs, especially for continuous-growing vegetable crops. For vegetable species (leafy vegetables, root vegetables, brassica, asparagus) that can be harvested in a single pass, usually for their vegetative part, a number of automatic, even driverless, solutions are already available.

Harvesting, in the case of crops grown for their generative part, is carried out several times, even several times a week, and therefore care should be taken to minimise damage to the crop. Examples of such vegetable species are tomatoes, peppers and cucumbers, where manual harvesting can account for up to 30% of the total production cost, for example, in the case of long-cropped, high-hectare tomato crops, the harvesting period is usually from early March to the end of December, for about 10 months. The development of robots with artificial intelligence (Metomotion, Panasonic tomato harvesting robot), which can be applied to harvesting operations, offers a solution to this problem. The success of precision vegetable production depends on the extent to which it can be properly adapted to manage and harvest the continuous needs of plants in space and time.

MetoMotion's self-powered tomato harvesting robot

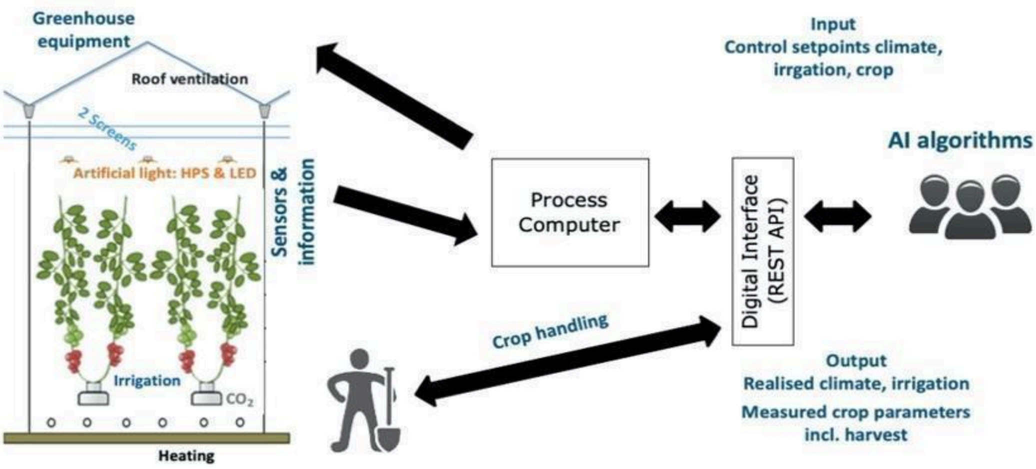
9. Fitness Technology Administration (Gremon Systems Insight Manager)

However, the highly costly and labour-intensive phytotechnical and harvesting work needs to be monitored precisely, on a worker-by-worker basis, so that performance-related pay can be implemented. Gremon Systems' Insight Manager software, which identifies workers with a unique magnetic card, is a solution developed for this purpose. Card readers in the plant house track individual performance, which can then be transmitted to payroll.

Card reader and graphical user interface for Gremon Systems, Insight Manager administration system

10. Autonomous (self-operating) greenhouse

Artificial intelligence (artificial intelligence (AI) has made significant breakthroughs in many fields, but not yet in horticulture. The creation of the Autonomous Greenhouse aims to combine horticultural science and artificial intelligence to achieve breakthroughs in the production of fresh food with more efficient use of resources. A team of scientists, technicians and students with different horticultural and artificial intelligence expertise will develop solutions to grow vegetables under remote (sensor) control. The growing equipment must of course be computer-controllable, in terms of heating, ventilation, shading, lighting, humidification, CO_2 supply, water and nutrient supply. The control of the greenhouse can also be operated remotely by an industrial computer if the various sensors continuously collect data via a digital interface. By comparing the results obtained in AI-controlled greenhouses with those of a manually operated reference greenhouse, it can be concluded that in terms of detailed results (yield, resource utilization efficiency, net profit) in terms of yield, resource utilization and net profit achieved, AI generally performed well in greenhouse control and was able to outperform conventional technology (18).



Autonomous greenhouse operation (18)

11. Vertical Farm (Plant Factory)

To solve the triple problem of food, resources and the environment, transdisciplinary methodologies based on new concepts need to be developed to significantly improve the yield and quality of food crops with less resource use and less environmental degradation than current crop production systems (31). Plant Factory with Artificial Light (PFAL) is expected to be one such crop production system to achieve this mission (32). In European countries, the term "Vertical Farm" is the preferred term, while in Asia the term "Plant Factory" is accepted when referring to intensive plant production systems with vertically stacked or vertically tilted shelves (Den Besten, 2019). The popularity of the term "Vertical Farm" (VF) is related to the fact that European consumers prefer the term "farm" rather than "factory" for fresh produce.

The advantages of VF include improved resource use efficiency (RUE), high productivity and the production of better quality crops without the use of pesticides (33). The use of LED light sources in horticulture is a more environmentally friendly and economically viable solution than HPS lighting (Paucek et al, 2020).

Interest in fresh, functional foods is growing, driven by consumers' increasing demand for diets that support health and longevity. Microgreens have enormous potential for micro-adaptation of leafy vegetable production and for improving the quality of human diets (34).

When properly designed and used, VF has the following potential advantages over conventional farming:

a. It can be built anywhere because it needs neither sunlight nor soil;

b. Growing conditions are not affected by the external climate and soil fertility;

c. Production is continuous throughout the year and productivity exceeds that of open field technologies;

d. The quality of production, for example the concentration of phytonutrients, can be improved by manipulating environmental parameters

a The light quality can be better than in the open air;

e. The product is pesticide-free and does not need to be washed off before meals;

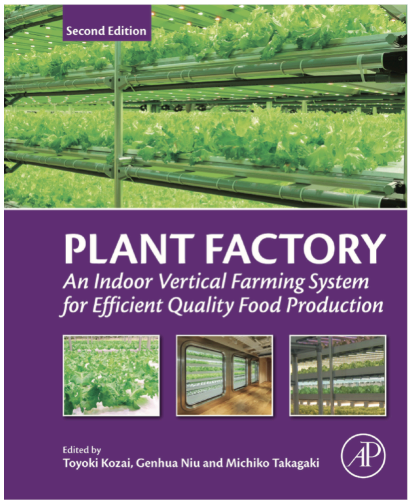
f. The product has a longer shelf-life, as the bacterial load is usually less than 300 colony forming units (CFU)/1, which is 1/100-1/1000th of the production of field crops;

g. Transport costs can be reduced by deploying VFs near urban areas;

h. High resource use efficiency (water, CO2, fertiliser, etc.) is achieved by minimising the release of pollutants into the external environment.

Even in soilless cultivation of VF, the nutrients that are essential for plant growth are supplied in the form of nutrient solution, as the media used to support the plants contain no or minimal amounts of nutrients. According to researchers, the nutrient requirements for nutrient solutions used in VF systems can be summarised as follows requirements for the use of VFs (35):

- It contains all the essential nutrients (except carbon) in ionic form, including the so-called macro-nutrients (oxygen, hydrogen, nitrogen, phosphorus, potassium, calcium, magnesium, sulphur) and the micro-nutrients (iron, boron, manganese, copper, zinc, molybdenum, chlorine, nickel, cobalt),
- The concentration of ions should be at an optimal level and uniform for plant growth,
- It must not contain substances harmful to plants or pathogenic micro-organisms,
- pH should be uniform between 5.5 and 6.5,
- Contain sufficient dissolved oxygen for the respiratory activity of the roots.



Greensense Farm's indoor plant production and Plant Factory book cover

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5. DIGITISATION OF THE MICROCLIMATE IN GREENHOUSES

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1. Climate control of production equipment

The use of cultivation equipment has two main purposes. Firstly, to protect the crops from external environmental factors (extreme temperatures, wind, hail, heavy rainfall, etc.) and secondly, to create a microclimate that creates the optimal environmental conditions necessary to achieve the desired growing objective. The production objective is most often to maximise the yield of a raw crop that can be harvested for fresh consumption.

To achieve the former, we aim to control the climate of the growing equipment, optimise light (irradiation), temperature, humidity and CO_2 concentration.

(Lighting is discussed in Theme 6.)

1.1 Temperature

The temperature available in the plant essentially determines whether or not a particular crop can be grown at a particular time. One of the most important characteristics of the growing equipment is the so-called ΔT value, which expresses the difference between the internal and external temperature that can be achieved by using the equipment. In principle, equipment intended for continuous operation over long growing seasons should be designed for a ΔT of 30-35°C, so that the +10°C threshold temperature for the development of heat-sensitive crops can be achieved even in the event of frosts of -20°C or below in winter.

The temperature can be further increased by using heating, the main types of which are ground heating, hot air injection, air space heating and vegetation heating. The latter two are mainly used in large airspace installations. Vegetation heating is the most efficient, with pipes usually placed on the floor near the root zone and the warm air flowing upwards through the leaves of the plants. The tubes can be made of plastic (polypropylene), usually black in colour, 3-4 cm in diameter, with a ribbed surface for more efficient heat transfer, and are placed near the root zone of the plants. The metal (usually iron) tubes are placed on a scaffolding a few centimetres high, the width of which corresponds to the gauge of the metal wheeled trolleys used for harvesting and phytotechnical work. They have a smooth surface and are originally painted white, but this wears off with constant use. Water (20-25°C) flows in the pipes, often using thermal water for heating, but also natural gas and renewable energy sources (wood, wood chips, etc.) are used as heating fuel. The technical solution for air space heating is very similar, with a smooth surface and usually white, but here the pipes are placed at the height of the plant stand and are therefore less efficient as the root zone is not heated. For heat-demanding plants, the temperature of the root zone is also important.



Energy screens are used to reduce the energy loss at night due to lack of sunlight, acting as a reflective surface to reduce long-wave thermal radiation, and can produce heat losses of up to 15°C. They are usually made of woven polyethylene with aluminium fibres. They are also suitable for shading, but unfortunately they cannot reduce the high temperatures of summer days.

Temperature reduction plays an important role in the summer climate control of production facilities, and there are a number of methods that can be used. The cheapest is ventilation, which can be used to control not only temperature but also humidity and CO_2 . Therefore, the proportion and positioning of the ventilation surface is an important consideration when designing growing systems. Large air-space growers usually use roof vents, the proportion of which is influenced by the size and proportions of the unit (length, width, height), the prevailing wind direction and the natural or built-in wind shade. Generally speaking, increasing the surface area of ventilating windows increases the ventilation efficiency but also the likelihood of ingress of harmful organisms. In addition to ventilation, the use of shading screens, shading paints, cooling walls, heat pumps and fogging to reduce temperature is also known. A combination of the above solutions is usually used to prevent excessive heating of the plant in summer, e.g. ventilation, shade painting, humidification irrigation.

1.2 Air movement, even climate

In greenhouses, it is very important to have a good air distribution to ensure an even temperature throughout the growing space. This prevents the crop from growing differently because it is too hot or too cold in the corners of the greenhouse. The air circulation in the greenhouse is ensured by fans, also known as ventilation towers, which help to improve the ventilation and homogeneous climate in the greenhouse. The ventilation tower also provides important aerial support for plant protection treatments with fogging agents. The fan is also an essential part of humidity control.

The first step in creating a uniform climate is to assess the current situation, i.e. how uneven the climate in the greenhouse is. Climate sensors can be used to map the temperature and humidity at different points in the greenhouse to see where there are hot/dry or cold/humid spots. Once the survey is complete, the causes of the imbalance should be identified and steps taken to address the problem. The most common causes of an uneven greenhouse climate are a defective envelope (broken window or unsealed), other openings in the greenhouse, a damaged energy screen, or insufficient air space heating along the side walls.

Use of energy umbrella in the nurturing of kencia palms

A common technical solution is the use of fans to provide internal air circulation in the greenhouse, which will result in a more even temperature, humidity and CO_2 concentration. By creating air circulation, the evaporation of the plants can be increased. Continuous air movement will result in more uniform but higher humidity, which can cause problems in some crops (e.g. Ca deficiency symptoms and fungal diseases).

In such cases, another technique, a dehumidification system, can help, which, like fans, also provides air circulation but also ensures that the air in the greenhouse is dehumidified without reducing the indoor temperature. There is therefore no energy loss, as the energy consumed is returned to the greenhouse in the form of warm air and the extracted water can be used as industrial water.

Source:
https://royalbrinkman.hu/legfrissebb-hireink/muszaki-projektek/a-noevenyhazak-klimajanak-joevedelmezo-optimalizalasa

To measure the above climate elements, portable and fixed measuring devices, sensors are available that measure the temperature, humidity and CO_2 concentration of the greenhouse environment and interior and send the data to the climate controller, which calculates the values needed for the optimal performance of the crop.

1.3 Humidity

Plants continuously evaporate water (transpiration) through their gas channels (stomata), increasing the relative humidity (RP%) of the air. This process is based on diffusion, so the 100% RH air in the space inside the gas channels is exchanged with lower RH air in the environment. The greater the difference between the outside and inside of the gas loop, the faster this process is, which also promotes water uptake through the roots. Therefore, for practical purposes, the relative humidity is replaced by the water vapour pressure deficit (VPD%), which is the difference in relative humidity between the inside and outside of the gas loop. Low humidity increases the closure of the gas stomata, thereby also reducing assimilation and transspiration camel activity. High humidity can increase the likelihood of fungal and bacterial infections and reduce the efficiency of evaporation, thus reducing assimilation. A not insignificant aspect for crops that require pollination and are grown for their yield (tomatoes, peppers, eggplants) is that low humidity can dry out the pollen pollen, resulting in a loss of fertilisation and yield. And if the humidity is too high, the pollen grains may stick together, also negatively affecting the efficiency of fertilisation.

Humidity control can also be achieved most cheaply by ventilation. Humidity can be increased by using a humidifier with special spray nozzles and reduced by using an active dehumidifier.

Source: https://www.indiamart.com/proddetail/greenhouse-misting-system-23036596297.html?pos=7&pla=n

1.4 CO_2

Plants use large amounts of CO_2 for assimilation, and ventilation is also the cheapest way to replace it. The most modern cultivation equipment is already equipped with CO_2 fertilisation. Mainly due to human activity, concentrations in the outside air have been increased to an average of 400 ppm (0.04%) (6), 700-1000 (7), and in other cases up to 1200 ppm in the equipment, maximising assimilation (8). Commercially available tank CO_2 is usually used for this purpose. Using mixing fans is important to maintain homogeneous air quality in the greenhouse in order to ensure that adequate concentrations are uniformly available throughout the greenhouse.

Forrás: [https:// royalbrinkman.com/mechanical-equipment/measuring-equipment/co2-meters/co2-concentration-meter-0-3000-ppm-0-20-ma-081300018](https://royalbrinkman.com/mechanical-equipment/measuring-equipment/co2-meters/co2-concentration-meter-0-3000-ppm-0-20-ma-081300018)

1.5 Meteorological station, weather (external) sensors

Measuring sunlight, temperature, humidity, wind speed and direction, and rainfall are very important for creating a stable climate in the greenhouse. The irradiance sensor also measures the heat output from the outside of the greenhouse, and to prevent heat loss, the energy shade can close earlier when the sky is clear. This saves energy in particular. A condensation sensor can automatically control the ventilation openings to maintain an optimal indoor climate. An external humidity sensor can measure the relative humidity of the air outside the greenhouse, which is important because it can differ significantly from the indoor humidity. The meteorological station sends all the measured data to the control computer, which automatically regulates the processes based on its calculations taking the data into account.



Forrás: [https:// royalbrinkman.com/mechanical-equipment/measuring-equipment/co2-meters/co2-concentration-meter-0-3000-ppm-0-20-ma-081300018](https://royalbrinkman.com/mechanical-equipment/measuring-equipment/co2-meters/co2-concentration-meter-0-3000-ppm-0-20-ma-081300018)

Internal climate sensors

The conventional climate sensors measure temperature and relative humidity, but can be supplemented with an optional CO_2 module. The CO2 monitor is a digital instrument that measures and monitors the concentration of carbon dioxide inside the greenhouse. The CO_2 -monitor draws in air for measurement, which can be performed at multiple locations using a CO_2 -valve.



Source: https://richel-group.fr/produits/ordinateur-climatique/

PAR sensor

The photosynthetically active radiation (PAR) sensor measures light in the 400-700 nm wavelength range. It needs to be placed above the crop and transmits data via a wireless link at adjustable intervals of a few minutes. Based on the amount of light measured by the PAR sensor, the control computer calculates how to adjust shades, carbon dioxide levels and grow lights for maximum results.

Source: https://royalbrinkman.com/mechanical-equipment/measuring-equipment/light-sensors/par-sensor-with-holder-868mhz-085901218

An infrared camera (plant temperature camera) can measure the surface temperature of the leaves regardless of distance, giving an indication of the evaporation rate and water availability of the plant.

In modern agriculture, the general spread of technological developments has transformed the methods and possibilities of crop production. Greenhouses, or glasshouses, play a key role in controlled crop production and the sustainability of food production. However, in order to further improve the efficiency and effectiveness of greenhouse production, the industry is continuously improving and digitising the control and monitoring of greenhouse microclimates.

The chapter "Digitalisation of greenhouse microclimates" aims to give an overview of the importance and benefits of digitalisation of greenhouse microclimates. The introduction of digital technologies and automated systems allows for a more efficient and precise management of crop production processes, thus increasing production efficiency and yields.

2. Sensors and data collection in greenhouses

Modern crop production in greenhouses increasingly relies on automated technologies and data collection. Sensors and data collection systems have revolutionised agricultural production, especially crop production. With the help of these technologies, growers are able to monitor more accurately the climate and condition of crops in their greenhouses, optimise production processes and increase yields.

2.1 Detection and monitoring of environmental parameters (e.g., temperature, humidity, brightness, etc.)

Maintaining an optimal microclimate is a key element for efficient crop production in greenhouses. This requires monitoring and control of various environmental parameters such as temperature, humidity, light intensity, wind speed and other climate characteristics. With the help of sensors and sensors, these parameters can be measured continuously and accurately, so that the greenhouse environment can be controlled on the basis of the data.

Temperature sensors monitor the air temperature, which is critical for plant growth. Humidity sensors monitor the moisture content of the air, which affects the transpiration and water uptake of plants. And light intensity sensors monitor the amount of sunlight entering the plants, which is also crucial for photosynthesis and plant metabolism. This data is collected and recorded, allowing growers to analyse the data and, if necessary, adjust the climate to ensure that the plants grow in the best possible conditions.

2.2 Detection of plant parameters (e.g. soil moisture, plant stress, nutrient levels, etc.)

Monitoring environmental parameters is not enough for successful crop production; it is also necessary to monitor the condition and development of the plants. In this case, sensing soil moisture, nutrient levels, plant stress and other plant parameters become important.

Soil moisture sensors allow the measurement of soil moisture content, which is crucial for the design of appropriate irrigation systems and water management. Nutrient sensors monitor soil nutrient levels, which helps to establish optimal nutrient replenishment so that plants receive the right amount and type of nutrients. Plant stress sensors monitor plant stress levels, which can be an early warning of disease or environmental stressors.

The data generated by the sensors will be integrated into digital platforms so growers can monitor the condition and needs of their crops in real time. This enables timely interventions and optimal plant care, increasing yields and reducing risk factors.

The choice of sensor technologies and sensors is essential for the efficient operation of digital greenhouses. In this chapter, we will walk through the available technologies and sensors and present their advantages and limitations.

When choosing the right sensors, you need to take into account the growing objectives, the plant species, the size of the greenhouse and the expected data points. This chapter provides an overview of the different types of sensors, such as optical, electrical, mechanical and temperature sensors. It also discusses in detail installation procedures and optimal sensor placement for reliable and representative data collection.

3. Automatic climate control and regulation

Modern crop production in greenhouses increasingly relies on automated systems and smart technologies to increase efficiency and effectiveness. The chapter "Automatic climate control and regulation" aims to illustrate the importance of automatic climate control and regulation in greenhouses and to examine the benefits and applications of using such systems.

In conventional crop production, climate control and regulation of environmental parameters often require manual intervention, which is time-consuming and prone to human error. Automatic climate control and regulation technologies allow continuous monitoring of the greenhouse climate and automatic regulation through intelligent algorithms.

3.1 Intelligent climate control and adaptive regulation in greenhouses

Automatic climate control and adaptive regulation are revolutionising crop production in modern greenhouses. Intelligent climate control allows automatic and continuous regulation of environmental parameters (temperature, humidity, light intensity, etc.) based on preset optimum values. Adaptive control means continuous data analysis and flexible adaptation to changing conditions, so that plants can always grow in the most suitable conditions.

Automatic climate control requires continuous data collection from sensors and sensors. Based on the information collected by the sensors discussed in the previous chapter, the intelligent control system is able to optimise the climate. For example, when the temperature rises, the system automatically starts the cooling system or ventilation to prevent plants from suffering from heat stress. This type of automated climate control significantly improves plant health and crop productivity.

Automated heating, cooling and ventilation systems

Automated heating, cooling and ventilation systems are key to efficient and stable climate control in greenhouses. Sensors continuously monitor environmental parameters and the control system automatically intervenes when parameters deviate from predefined values.

Automatic heating systems automatically switch on in cold weather to maintain the optimum temperature for your plants. Similarly, automatic cooling systems act to prevent overheating, for example in summer when temperatures can be higher. And ventilation systems ensure a flow of fresh air, which is particularly important for plants as it promotes CO_2 uptake and photosynthesis.

Automated climate control and regulation is not only good for the plants, it is also economical. Energy savings reduce operating costs and give growers more flexibility to monitor and optimise their crops on a continuous basis.

3.2 Automatic response to environmental changes and parameter optimisation

Automatic climate control means not only returning to set values, but also allowing automatic response to environmental changes. Sensors continuously monitor environmental changes, such as weather conditions or the condition of plants. If the changes are such that they could affect plant growth or the optimal microclimate, the control system automatically reacts and adjusts the environmental parameters.

The optimisation of parameters will be possible as a result of long-term data collection and analysis. Automatic climate control continuously learns from the data and adapts to changing growing conditions. This allows the system to fine-tune parameters for optimal crop growth and development.

Automatic response to environmental changes and optimisation of parameters helps growers to better understand crop needs and optimise crop production processes. Effective climate control and regulation in greenhouses contributes to more stable cultivation and higher yields, while minimising environmental impacts and energy use.

4. Using climate models in projections

In order to cope with the effects of climate change and to promote sustainable crop production, modern crop production in greenhouses is increasingly relying on the use of climate models for forecasting and simulation. The chapter "Climate Models in Forecasting" aims to illustrate the role and importance of climate models in optimizing and decision-making in greenhouse production processes.

Climate models are mathematical models and simulation systems that can be used to model the functioning and changes in climate systems. These tools allow the prediction of future climatic conditions and environmental changes that have a major impact on crop production and the microclimate of greenhouses.

4.1 Greenhouse climate models and virtual simulations

Climate models and virtual simulations are revolutionary methods for predicting and optimising greenhouse microclimates. These tools allow growers to anticipate environmental changes and understand plant responses to different climate scenarios through simulations.

Greenhouse climate models are computer models that simulate environmental parameters and plant processes in greenhouses. Fed with data from sensors, these models can predict plant growth, development and yield under different climatic conditions. This enables growers to design optimal climate conditions and predict crop production processes.

The virtual simulations allow growers to simulate different climate scenarios, such as extreme heat waves or cold spells, and see how plants respond. This allows growers to develop the best climate management strategies and prepare for changing weather conditions.

4.2 Integration of weather forecast data and climate models

The integration of weather forecast data and climate models represents a major step forward in the field of crop production. The combination of weather forecasts and climate models allows short and long term forecasts of greenhouse climate.

Weather forecast data refer to current and near future weather conditions. And climate models provide answers to longer-term climate changes. By integrating the data, growers can get more accurate forecasts of greenhouse climate and upcoming weather conditions.

Integrated forecasts help growers to prepare for upcoming weather changes and optimise crop growth through timely climate control. This increases crop production efficiency and minimises production risks.

4.3 Climate models to help optimise crop production processes and decision-making

Climate models can greatly assist crop growers in optimising production processes and decision-making. Predictions and simulations provide growers with information on how crops will respond to different climate conditions, allowing them to develop the best climate management strategies.

Climate models allow growers to test different climate scenarios in a virtual environment without risking real crops. This allows growers to efficiently plan crop production and optimise climate control systems.

Based on the forecasts, growers can intervene early and prevent critical situations such as heat stress or water shortages. Climate models can also help in environmentally friendly crop production by enabling energy-efficient climate control and optimised water management.

5. Artificial intelligence and machine learning in greenhouses

In the field of crop production, automated processes and digital technologies are becoming more and more common, and artificial intelligence (AI) and machine learning (ML) solutions are opening up new dimensions in greenhouse cultivation. AI and GT are empowering growers to analyse data, manage climate intelligently and make adaptive decisions, enabling more efficient, effective and sustainable crop production.

5.1 Machine learning algorithms for data analysis and interpretation

Modern greenhouses accumulate large amounts of data from sensors and other sensors that continuously monitor the climate and the condition of plants. However, this data is not worth much on its own. This is where machine learning algorithms come into play.

Machine learning is a branch of artificial intelligence that allows systems to learn from data without having to be explicitly programmed. Machine learning algorithms used to analyse and interpret data can recognise patterns, identify correlations and make predictions. For example, machine learning algorithms can be used to analyse crop data from previous years to predict the expected yield for the following year.

5.2 Application of artificial intelligence in climate control and optimisation

The use of artificial intelligence allows the development and optimisation of climate control systems for greenhouses. AI systems continuously monitor and analyse data from sensors and make climate control decisions based on this information.

AI algorithms can identify the optimal climate requirements of plants at different stages of growth. For example, a plant may need higher temperatures and humidity when it is younger, while other environmental parameters become important at later stages of growth. AI systems collect this information and adapt it to the current needs of the plants, optimising climate control for the specific plants.

5.3 Intelligent decision-making and adaptive climate control in greenhouses

The use of AI and GT enables intelligent decision-making and adaptive climate control in greenhouses. AI algorithms continuously analyse data on plants and environmental parameters and adapt climate control systems based on the information obtained.

Intelligent decision-making allows climate control systems to respond quickly and efficiently to changing environmental conditions. For example, when outdoor temperatures rise suddenly, the AI system can automatically switch on the cooling system and optimise ventilation to protect plants from heat stress.

Adaptive climate control allows the system to learn and adapt to changing environmental conditions and the condition of the plants. AI and GT algorithms continuously update models and decision mechanisms, resulting in optimised and efficient climate control and maximising production efficiency.

The role of AI and GT in greenhouses is growing and is key to promoting sustainable, efficient and effective crop production. Through intelligent decision making and adaptive climate control, growers are able to better anticipate crop needs and minimise environmental impacts, leading to long-term success in crop production.

6. Greenhouse microclimate and productivity

The microclimate in greenhouses is one of the most important factors in successful and efficient crop production. Establishing and optimising the right microclimate is key to efficient plant growth, higher yields and high quality produce. In this chapter, we take an in-depth look at the effects of the greenhouse microclimate on crop growth and productivity, and show how microclimate can be optimised for different crop varieties and selection strategies. In addition, we will examine the impact of microclimate on crop quality and nutritional value, highlighting the importance of producing healthier crops with higher nutritional value.

6.1 Impact of microclimate on plant growth and production

The microclimate of greenhouses plays a critical role in plant growth and development. Temperature, humidity, light intensity and CO2 concentration are factors that are key to plant photosynthesis and nutrient processing.

Optimum temperature and humidity provide the right conditions for plants to photosynthesise. The right light intensity is also vital for photosynthesis, as plants use light from the sun to convert water and carbon dioxide into glucose and oxygen. The right CO2 concentration is also necessary for optimal photosynthesis.

An optimal microclimate allows plants to use energy and nutrients efficiently for growth and development. As a result, growers can expect higher yields and healthier plants.

Microclimate optimisation for different plant species and species selection strategies

Different plant species have different microclimate requirements. Some plants need higher temperatures and lower humidity, while others prefer a cooler environment and higher humidity. Light requirements and CO2 tolerance may also differ for different plant species.

Growers need to carefully study the microclimate requirements of the crop varieties and take these into account when selecting species. Providing an optimal microclimate for the needs of the crop will significantly increase crop efficiency and yield.

Advanced sensor technologies and data collection allow growers to monitor a range of parameters such as soil moisture, temperature and light intensity. Analysing and interpreting the data allows a more accurate microclimate to be developed to suit the needs of the crop.

6.2 Impact of microclimate on crop quality and nutritional value

The microclimate affects not only the growth and production of plants, but also the quality and nutritional value of the crop. Temperature, light intensity and humidity can affect the colour, flavour, nutrient content and texture of a crop.

Ensuring an optimal microclimate allows for the production of high quality produce, which also makes the products attractive to consumers. Crops with adequate nutritional value increase the competitiveness of growers in the market and contribute to the availability of healthier food.

It is important to stress the importance of optimal design and management of the microclimate in greenhouses for successful crop production. Ensuring an optimal microclimate allows for efficient plant growth, higher yields and the production of high quality and nutritious crops, which contributes to sustainable crop production and healthier food.

(For more on the relationship between microclimate and plant protection, see Theme 8.)

7. Sustainable energy and climate change

The issues of sustainable energy use and climate change are extremely important for the sustainability of crop production and greenhouses. In this chapter, we review energy-saving solutions and sustainable energy sources that can help reduce the energy consumption and environmental footprint of greenhouses. In addition, the impacts of climate change on the greenhouse microclimate and adaptation strategies are examined. Finally, the role of the greenhouse microclimate in addressing the challenges of climate change will be presented.

7.1 Energy-saving solutions and sustainable energy sources in greenhouses

Traditional greenhouses consume significant amounts of energy, especially for heating and lighting. However, reducing energy consumption and using sustainable energy sources can improve the sustainability of greenhouses.

Energy-saving solutions include efficient insulation, solar technologies, LED lighting and energy-efficient heating and cooling systems. Such solutions reduce energy use and help minimise environmental impact.

Sustainable energy sources include solar energy, wind power and geothermal energy. The use of renewable energy sources contributes to the sustainability of greenhouses and the reduction of greenhouse gas emissions.

Impact of climate change on greenhouse microclimate and adaptation strategies

Climate change is already having a noticeable impact on the greenhouse microclimate. Global temperature rises, extreme weather events, changes in rainfall all affect plant growth conditions and microclimate.

Developing adaptation strategies is vital to address the impacts of climate change. Sensors and data collection technologies allow growers to monitor microclimate and climate changes continuously. This allows weather forecasts to be taken into account and adaptive climate management to adapt to changing environmental conditions.

The role of greenhouse microclimates in addressing the challenges of climate change

The greenhouse microclimate is key to addressing the challenges of climate change. Ensuring an optimal microclimate allows plants to grow and produce efficiently, even in the face of the challenges of climate change.

Energy-efficient solutions and the use of sustainable energy sources reduce the environmental impact of greenhouses and contribute to the fight against climate change. Optimisation of microclimates according to the needs of crop varieties and adaptive climate control will enable growers to effectively address the challenges of climate change.

The role of the greenhouse microclimate is paramount not only in the success of growers, but also in promoting food safety and sustainability. In the fight against climate change, sustainable energy use and adaptive microclimate management are key tools to promote sustainable and climate-friendly crop production in the future.

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6. PRECISION IRRIGATION

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1. Introduction

Precision irrigation systems are most often designed using smart irrigation systems, which use technology and data analysis to optimise water use and improve the irrigation efficiency of plants and lawns. These systems go beyond traditional sprinklers, incorporating a variety of sensors and data-driven algorithms to make intelligent, informed decisions about when, where and how much to water. Unlike traditional irrigation systems, which are often based on fixed schedules or manual adjustments, smart irrigation systems use a variety of components and data sources to optimize water use and improve the efficiency of the irrigation process. Smart irrigation systems are an excellent way to automate and optimise irrigation processes, saving water, time and money while maintaining healthy plants. By using data analytics and adaptive irrigation, these systems can significantly reduce water waste, which is good for the environment and can lead to cost savings for users.

2. Irrigation and nutrient management

Before discussing irrigation technologies in greenhouses, it is important to mention two essential elements of irrigation:

Irrigation water

The systems listed below fall into the category of micro-irrigation for irrigation, where the quality of the irrigation water is very important. If suspended solids exceed 100ppm, there is a high risk of clogging, in which case coarse filters are used to filter out physical contaminants. The chemical properties of the irrigation water are more favourable if it is acidic (pH < 7). It is important that the iron and manganese content does not exceed 1,5 mg/l. Alkaline water (pH > 8.0) is more prone to clogging. The biotic requirement is low microbiological contamination (< 10,000 cells/ml).

Nutrients

Depending on which of the elements are involved in plant structure, they are called macro-, meso-, micro- and trace elements:

Macronutrients are nutrients that are present in plants in a proportion greater than 0.1%. Macronutrients include the three main non-mineral nutrients, carbon, oxygen and hydrogen, which make up the bulk of the plant organism. These elements are usually always available to plants in sufficient quantities from air and water. Of the mineral nutrients, nitrogen, phosphorus and potassium are classically considered to be macroelements. In terms of concentration, calcium, magnesium and sulphur are also considered macroelements among the essential elements. The latter three nutrients are often referred to as meso-elements in crop production textbooks.

From a crop production point of view, essential nutrients are considered to be micronutrients if they are present in plants in concentrations of less than 0.1%. These include boron, iron, manganese, zinc, copper, molybdenum, chlorine, nickel, and cobalt. Trace elements present in very low concentrations, usually less than 0.4-0.5%, include selenium, titanium, caesium, lithium, fluorine, iodine, bromine and vanadium.

Nutrient solutions

In soilless cultivation, mineral nutrients are applied as a nutrient solution through the irrigation system. Water-insoluble fertilisers, also known as irrigated or nutrient-soluble fertilisers, have been developed for this purpose. Due to their higher cost, these should only be used for fertilising with nutrients and foliar fertilisation.

Their criterion is that only 0.02% of them can remain as insoluble matter after dissolution, so they do not clog the filters of micro irrigation systems. If the proportion of water-insoluble residues is higher than the above, the fertiliser is considered to be a low residue-soluble fertiliser, which is usually precipitated by calcium. They are also suitable for nutrient leaching after thorough filtration. Fertilisers with a high level of sediment solubility should not be applied through irrigation systems, although they are cheaper, but are not suitable for nutrient solution.

Fertilizers

According to their composition, we distinguish between individual or also known as mono-, compound and complex fertilisers.

Mono-fertilisers contain a compound with one or more nutrients as the active ingredient. Fertilisers (e.g. urea, ammonium nitrate, potassium sulphate, superphosphate, calcium nitrate, various micro-nutrient chelates) and inorganic fertilisers of natural origin (e.g. limestone and dolomite grindings, gypsum, elemental sulphur) contain a number of such substances. The advantage of mono-fertilisers is that they are relatively inexpensive and can be combined to achieve the desired nutrient ratio, but their disadvantage is that when applied they require special attention to the supplementation of meso- and micro-nutrients, which requires considerable expertise.

Complex fertilizers contain the complete essential nutrient series as active ingredients and are therefore suitable for the nutrient fertilization of shoots. Fertilisers that are fully water soluble for this purpose do not usually contain calcium due to their well-known precipitation, but in practice these fertilisers are also considered complex. Their advantage is that they can be used to safely replenish the meso- and micro-nutrients in the herd, even at low technological and professional levels. Their disadvantage is their relatively high price and the fixed nutrient ratio already mentioned for compound fertilisers.

3. Main characteristics of irrigation systems, their construction

In soilless cultivation, nutrient fertilisation and irrigation cannot be separated, as the medium for the former is irrigation water. The most important characteristics of the nutrient solution are the electrical conductivity (EC) and the pH. The former is proportional to the dissolved nutrient content, measured in mS/cm, and can have an average value of 2-3 depending on the plant species, corresponding to a concentration of 2-3 g/l. The chemistry of the nutrient solution is usually adjusted to a value below 6. Optimisation of the irrigation strategy can save up to 15% of water and fertiliser.

An irrigation/refrigeration system should have the following features: double filtration system (100 and 300 micron), freshwater and system pump, large mixing tank (stable pH), double EC and pH measurement and control, multiple nutrient solution recipe management, can be operated as a stand-alone unit, irrigation start based on light metering.

Source: https://royalbrinkman.hu/tudasbazis/tudasbazis-muszaki-projektek/viztisztitasi-technologiak-a-kerteszetekben

The parts of irrigation and nutrient management usually include:

- Biomass measurement to support cultivation decisions based on real-time plant biomass observations with the highest possible accuracy.
- Measurement of drainage water (water run-off from the substrate) and continuous measurement of the characteristics of the nutrient solution (EC, pH and temperature).
- Smartphone compatibility, on any mobile operating system, you can view key metrics in real time on your mobile device.
- Warning system, if a parameter falls below a certain level, a message is automatically sent.

Source: https://gremonsystems.com/hu/termekek/trutina/

Precision irrigation systems are most often designed using smart irrigation systems, which use technology and data analysis to optimise water use and improve the irrigation efficiency of plants and lawns. These systems go beyond traditional sprinklers, incorporating a variety of sensors and data-driven algorithms to make intelligent, informed decisions about when, where and how much to water. Unlike traditional irrigation systems, which are often based on fixed schedules or manual adjustments, smart irrigation systems use a variety of components and data sources to optimize water use and improve the efficiency of the irrigation process. Smart irrigation systems are an excellent way to automate and optimise irrigation processes, saving water, time and money while maintaining healthy plants. By using data analytics and adaptive irrigation, these systems can significantly reduce water waste, which is good for the environment and can lead to cost savings for users.

The essence of precision irrigation systems is the quest for perfect irrigation. It is safe to say from the outset that there is no such thing as perfect irrigation, only the quest to achieve it. Most irrigation manufacturers are experimenting in their laboratories to find the most precise way of applying water.

Source: [https://royalbrinkman.hu/tudasbazis/altalanos-noevenytermesztes/mi-a-kueloenbseg-a-kozetgyapotos-es-a-kokuszrostos-termesztes-koezoett (?)](https://royalbrinkman.hu/tudasbazis/altalanos-noevenytermesztes/mi-a-kueloenbseg-a-kozetgyapotos-es-a-kokuszrostos-termesztes-koezoett)

Even with overhead sprinklers in a given greenhouse, we cannot achieve 100 % spray uniformity according to the parameters specified by the manufacturers. Drip systems work with much more efficient water delivery. Existing irrigation systems can be easily upgraded with a small investment, resulting in much more precise irrigation.

4. Types of irrigation systems in greenhouses

Micro sprinkler overhead irrigation

Source: https://www.growspan.com/news/understanding-your-greenhouse-watering-system-and-irrigation-management/

When designing overhead irrigation in a greenhouse, it is advisable to determine in advance for which plants, which technology and which greenhouse you want to install overhead irrigation or humidification.

Top micro sprinkler irrigation for even watering of demanding plants

Cabbage lettuce, month-old radishes grown on soil without drip supplementation or in tray seedling production require the highest uniformity of 92-95%. These crops show the slightest lack of uniformity magnified.

Independent overhead irrigation for less sensitive plants

It is rarely used on its own because, mainly for nutrient fertilisation and to keep the foliage dry, growers often supplement it with drip tape. One example is the irrigation of peppers and cabbages. The price and cost of the drip tape is well worth the investment. The sprinklers are preferably used to replenish the soil moisture in greenhouses before planting, or for refreshing watering at planting and later 3-4 times a day. It is also known as greenhouse humidification, but here the water irrigates the soil and only the air is humidified during humidification, no water should be allowed to appear on the soil.

Source: https://www.agricolplast.it/irrigazione-ad-aspersione-per-agricoltura/

Drip irrigation in greenhouses

Source: https://greenhouseinfo.com/how-build-greenhouse-drip-irrigation-system/

Drip irrigation is an increasingly popular and effective method of watering plants in greenhouses. This method allows water to be delivered directly to the root zone of plants, reducing water waste and increasing irrigation efficiency.

The advantages of drip irrigation systems include the ability to precisely control the frequency and volume of watering, thus optimising plant growth and reducing the risk of over- or under-watering. Furthermore, as water is delivered directly to the root zone, the risk of disease and weed growth is reduced. Drip irrigation is an effective way to reduce the spread of pathogens and weed growth as it does not wet the leaves, which can create a favourable environment for fungal and bacterial diseases.

Rigid-wall drip tube, in operation (drip.mov)

However, the cost of installing and maintaining drip irrigation can be a challenge. Setting up the system requires a material investment, such as pipes, drippers, filters and controllers, as well as labour costs during installation. In addition, drippers and filters can become clogged, reducing the efficiency of the system, and regular maintenance and cleaning is required.

Some plants, especially those that develop shallow root systems or require high humidity, may not benefit as much from drip irrigation. It is important to understand the specific needs of plants before deciding on the type of irrigation system.

Irrigation in soil-less growing systems

In soilless growing systems, such as hydroponic systems, different irrigation methods are used. These include floating root systems, such as deep water culture, which is excellent for growing small crops such as lettuce. In this system, the roots of the plants are completely covered by the nutrient solution, and therefore the oxygen content of the solution must be carefully controlled (see 4.5).

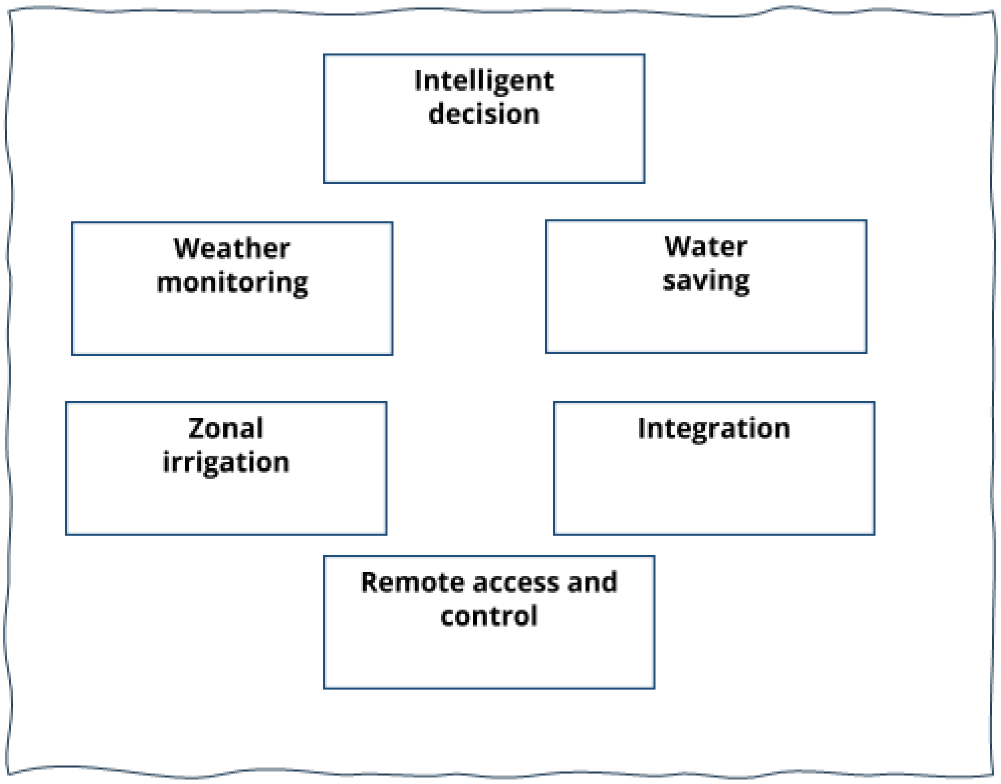
The drip irrigation system, similar to traditional drip irrigation, allows excess water to be recycled, making the irrigation system more efficient. This system consists of separate water reservoirs, water pumps and small pipes that feed the plants at certain intervals.

Another common method is the nutrient film technique (NFT), in which plants are continuously supplied with nutrients by circulating water.

The aeroponic system uses less water, where the roots of the plants are suspended in the air and sprayed with a nutrient solution.

When setting up hydroponic systems, it is important to know the right light conditions, to control the concentration and pH of the nutrient solution and to enrich the water with oxygen. The cost of the system varies, depending on the type and size chosen

5. Main features of smart irrigation



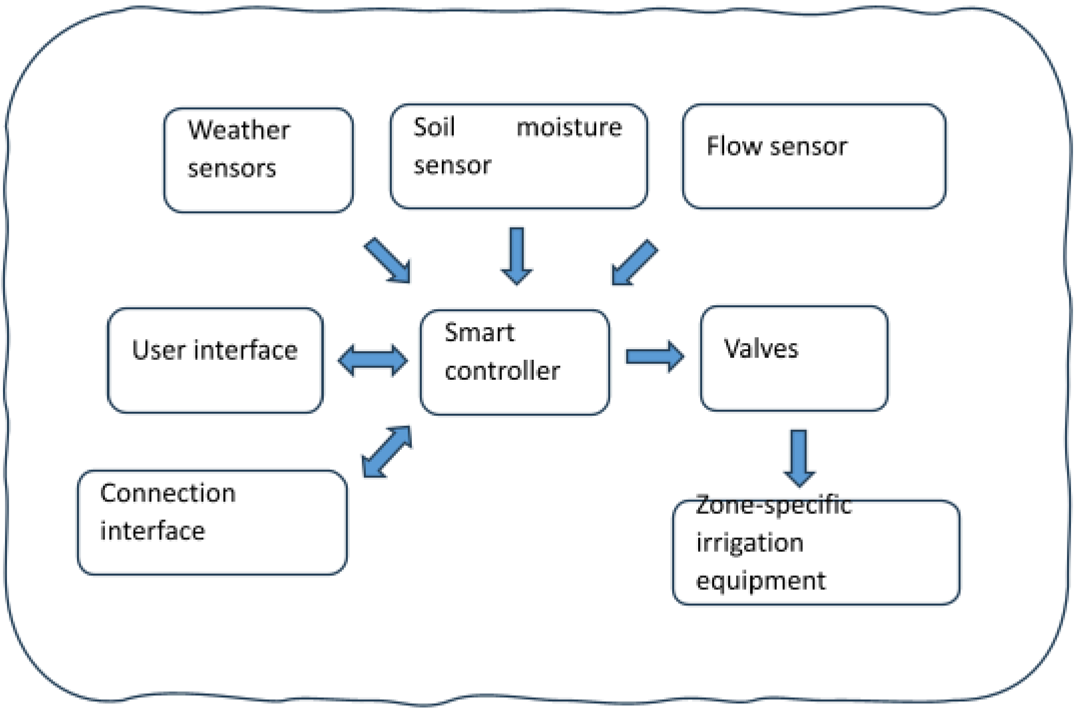
Features of intelligent irrigation equipment

- **Weather monitoring:** smart irrigation systems are often equipped with weather sensors or connected to online weather services. By monitoring real-time weather data, the system can adjust irrigation schedules based on current and predicted weather conditions. For example, if the weather is cloudy, the system can delay irrigation to avoid unnecessary watering.

- **Intelligent decision**: the intelligent decision unit analyses data from different sensors and uses predicted or actual weather conditions to determine the optimal irrigation schedule and duration for each zone of the irrigation system.
- **Zonal irrigation**: a smart irrigation system is usually divided into several zones, each representing a specific sub-area of the area to be irrigated, with different water requirements. By zoning the system, water can be directed to specific areas, preventing over-irrigation in some regions and under-irrigation in others.
- **Remote access and control**: many smart irrigation systems offer remote access via mobile apps or web interfaces. This allows users to monitor and control the irrigation system from anywhere, making adjustments as needed. For example, if a user notices that a certain area is receiving too much or too little water, they can manually adjust the settings via the app.
- **Water saving:** the primary goal of smart irrigation systems is to save water by using it more efficiently. Using real-time data and intelligent algorithms, these systems can reduce water waste.
- **Integration with smart home systems:** some smart irrigation systems can be integrated into larger smart home systems, allowing them to communicate with other smart devices in the home. For example, they can coordinate with irradiance sensors to prevent watering on overcast days, or humidity sensors to adjust watering based on atmospheric conditions.

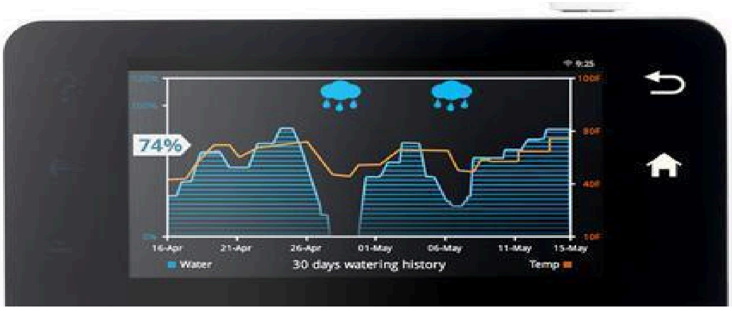
6. Design of the intelligent irrigation system

A smart irrigation system typically consists of several key components that work together to optimise water use and automate the irrigation process. These components vary depending on the specific make and model of the system.



Intelligent irrigation system design

- **Smart controller**: smart irrigation systems use smart controllers that act as the central brain of the system. These controllers receive input from weather and climate sensors, soil moisture sensors and other connected devices. The controller algorithms and data analysis are used to create an optimized irrigation schedule based on factors such as climatic conditions, soil/root medium moisture levels and crop types.
- **Weather sensors**: weather sensors such as rain sensors, wind direction and wind speed sensors, barometric pressure and temperature sensors provide real-time weather data to the intelligent controller. This information is crucial for indoor climate control and optimal water supply.



Weather sensor graphical user interface

- **Soil moisture sensors**: soil moisture sensors are an essential component of smart irrigation systems. They measure soil moisture levels. These sensors are placed in the soil or root medium and provide data to the smart controller about how dry or wet the soil is in each zone. The data helps the system determine when irrigation is needed and at what rate.

Soil moisture sensor

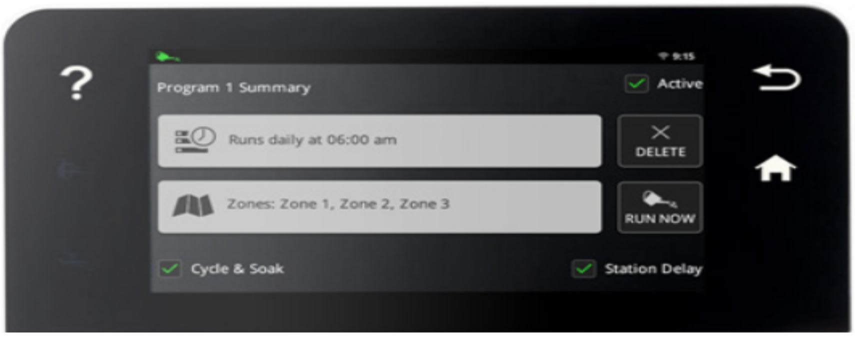
Flow sensor

- **Flow sensors**: flow sensors monitor the flow rate of water through the irrigation system. They help detect leaks or other problems in the system and can provide valuable data for tracking and conserving water use, while allowing the system to use this information to automatically shut off the water supply if a leak is detected, preventing water loss.

- **Water pumps**: often essential in irrigation systems, but not always necessary. There are different types. Commonly used are submersible pumps, which are designed to be submerged in water. Commonly used in wells and other deep-water pools.

Electronically controlled valve

- **Valves**: valves control the flow of water to the different zones of the irrigation system. Each zone typically has its own valve that allows water to be directed to specific areas. The smart controller communicates with the valves and opens and closes them according to the irrigation schedule.



User interface

- **User interface**: most smart irrigation systems have a graphical display, which can be a touchscreen, mobile app or web interface that allows users to monitor and control the system remotely. Through the app or interface, users can modify irrigation schedules, view irrigation history, and change system settings.

Drip irrigation system

- **Zone-specific irrigation**: conventional irrigation systems use zone-specific irrigation equipment, such as sprinklers, drippers or rotating nozzles to deliver water to different areas of the landscape. These devices are commonly found in smart irrigation systems and work in conjunction with the smart controller to provide precision and efficient irrigation.
- **Connectivity interface**: the smart irrigation system can be equipped with wired or wireless connectivity options to connect to climate control services, receive software updates and connect to smart home systems for integration with other devices.

These ingredients work together to create a smart and efficient irrigation system that optimises water use and keeps plants healthy. In addition, some systems may also have additional features such as integration with weather services, voice control through virtual assistants for additional water conservation and management.

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7. DIGITALISATION OF ARTIFICIAL LIGHTING IN GREENHOUSES

Author:

- Pék Zoltán - Magyar Agrár- és Élettudományi Egyetem

1. The role of light in plant life

Light is the range of electromagnetic radiation visible to the human eye (VIS) (400-780 nm), with the following spectra in focus: 400-420 nm - violet; 420-490 nm - blue; 490-540 nm - green; 540-640 nm - yellow; 640-780 nm - red. The same range plays an active role in photosynthesis in plants. **Photosynthesis** is the biochemical process whereby living organisms use the energy of sunlight to convert inorganic matter into organic matter (1). Looking at the intensity of the sun's rays reaching the earth in terms of wavelength, it is in this visible range that the most intense radiation is found (2). Plants have therefore evolved to use the most intense radiation (**Figure 1**). This is called Photosynthetically Active Radiation (**PAR**).

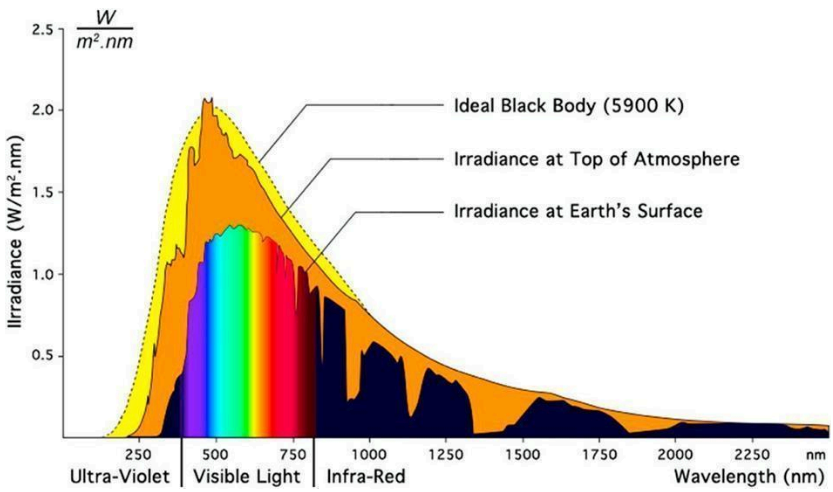

Figure 1 The total solar spectrum at the Earth's surface and at the top of the atmosphere (2).

Photosynthetically active radiation accounts for about 40-48% of the Sun's radiant energy spectrum, depending on the characteristics of the atmosphere (opacity, relative humidity, atmospheric pollution) and the geographical location (latitude). The remaining 52-60% of the radiant energy is predominantly long-wave thermal radiation in the infrared (**IR) region. In addition, ultraviolet** (**UV)** radiation also exerts biological activity (3).

Leaves are the organ that plants have evolved to use light, and their ability to absorb light depends on their size and location. Leaf size is expressed as leaf area (LA). Under optimal conditions, the larger the leaf area, the more light a plant can use. In a plant population, however, increasing leaf area increases light utilisation only up to a certain limit, because mutual shading of plants inhibits it beyond a certain level. In a crop stand, the leaf area of the vegetation should be measured not only in absolute terms but also in relation to the growing area (At). The ratio between the two is called the leaf area index (LAI=LA At-1). Depending on the plant species, increasing the leaf area index also increases light utilisation only up to a certain limit, above which self-shading occurs, i.e. the lower leaves do not receive sufficient light for photosynthesis (4).

Different plant species have different light requirements. In addition to the amount of illumination, the duration of light exposure to plants should also be taken into account when assessing light requirements. Species requiring more light include: tomatoes, peppers, watermelons, cantaloupes. Cabbage, kale, beans, beetroot and onions are considered medium light-demanding. Shade-tolerant plants include: celery, carrots and rhubarb. Today, the light requirements of most cultivated vegetable species are quantified by the DLI (Daily Light Integral), the amount of photons (daily light integral) incident on a given surface in a day, measured in $mol\text{-}m^{-2}\text{-}d^{-1}$, which can be calculated from data provided by modern photometric sensors ($\mu mol\text{-}m^{-2}\text{-}s^{-1}$) (5). Thus, for example, to grow light-intensive crops such as peppers or tomatoes, a minimum of 22 $mol\text{-}m^{-2}\text{-}d^{-1}$, for less light-intensive iceberg lettuce, 11.5 $mol\text{-}m^{-2}\text{-}d^{-1}$, (6-9).

The response of plants to the ratio of time spent in light to time spent in darkness is called photoperiodism. Developmental characteristics subject to photoperiodic regulation include flowering, bud dormancy and leaf senescence. Three groups can be distinguished in this respect, as follows (10):

1. The floral initiation of short-day plants occurs when the daily photoperiod lasts up to 12 hours. Longer photoperiods inhibit or completely stop flower formation. Our crops fall into this group: soybeans and sweet potatoes.

2. Flower initiation in long-day plants occurs when the daily photoperiod length is at least 9-14 hours, but the more the photoperiod exceeds this critical value, the faster flower formation. Includes: peas, spinach, radish and Chinese cabbage.

3. The development of diurnal plants is independent of the length of the day, also known as a photoperiodic plants. Some plant species are short-day and some are long day. These include lettuce and tomatoes.

These groups can also be found within individual plant species, so when choosing a species, it is essential to know which one to choose for a given growing season or length of light (11).

Lighting is the number one environmental factor that affects plant growth and development, and growing indoors depends largely on the quality of light. Natural light is the most important factor in greenhouse cultivation. In the temperate zone, in long-growing, the amount of incoming sunlight is optimal only for a short period, and is the most important for the plants' anabolic processes (assimilation). According to the so-called 1% rule formulated by Dutch researchers, 1% more irradiation generally results in 1% more yield (12). Equipment is therefore being developed primarily to improve the use of light, of which the cover material is only one key factor (see Table 3 in Module 1).

Since the response of plants to light, **photomorphogenesis, is** highly dependent on genotype and developmental stage, the light requirements of different developmental stages need to be determined for different varieties to achieve maximum yield (13).

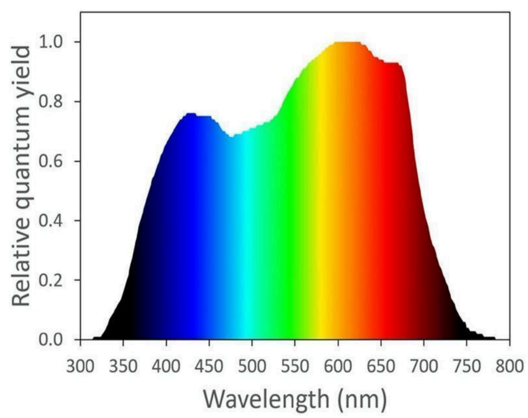

Figure 2 Normalized action spectra of the maximum quantum yield of CO_2 assimilation at narrow wavebands from ultraviolet to far-red wavelengths (15)

The photosynthetic efficiency of different spectra has been investigated by many researchers, one of the most accepted being the McCree curve (14).

Plant species, and even cultivars, respond differently to different spectral illumination, but there is agreement that red light is important for the photosynthetic apparatus and affects the transport of assimilates (16).

In photosynthesis, blue light affects the development of chloroplasts, chlorophyll formation and plant content, but the response of plants is highly dependent on the dose of blue light (17).

The effect of green illumination is like that of blue, being involved in photosynthesis through phytochrome and cryptochrome pigments (18). Too much red-light illumination leads to the so-called "red light syndrome", which is manifested in poor morphology of micro-vegetables, with defective gene expression (18,19). The combination of red light and other light sources, especially blue light, can effectively regulate stomatal aperture and improve carbon uptake by plants, thus preventing the formation of "red light syndrome" (20,21).

In addition to photosynthesis, light also affects other plant processes, such as **photomorphogenesis**, which involves the growth and developmental responses of plants to light. Photomorphogenetics describes light-induced growth and developmental responses that are not necessarily directly related to photosynthesis. In this case, light acts as a signal that activates plant photoreceptors, influencing plant growth, flowering, root development and other developmental processes.

These photoreceptors are part of complex signalling networks that influence gene expression and development in plants. By sensing light types, intensities and exposure periods, plants adapt to environmental conditions, optimise photosynthetic activity and growth, and develop strategies for survival.

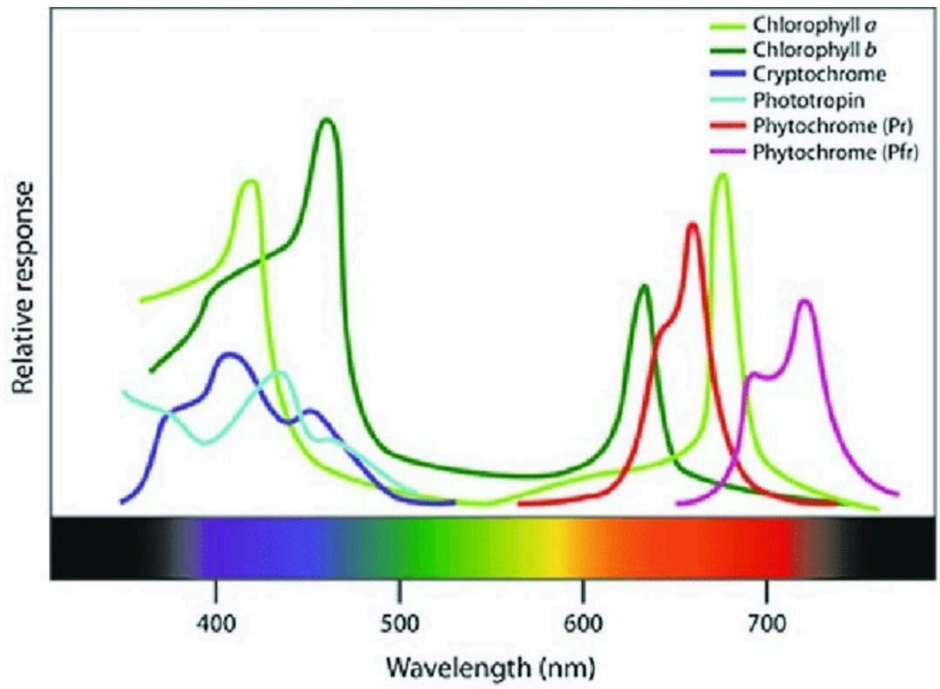

Figure 3 Relative absorption curves of light-absorbing molecules as a function of wavelength

The precise role of each photoreceptor and the signalling pathways they mediate are still being actively investigated and the field is evolving dynamically. The photoreceptors are (22). They have two forms, Pr (red light absorbing) and Pfr (far-red light absorbing), between which they are transformed by light. They regulate plant growth, flowering, germination and other developmental processes. Cryptochromes sense the UV-A and blue light spectrum (about 320-500 nm). They are involved in regulating the circadian rhythm of plants, the timing of flowering and shoot growth. UV light causes the plant's joints to shorten. Phototropins are particularly sensitive to blue light (about 400-500 nm). Their main role is in phototropism, which is the mechanism by which plants bend towards light, and they regulate opening organ movements such as the opening and closing of stomata. UV-B photoreceptors detect UV-B light (280-320 nm). They regulate defensive responses, such as defence against UV-B, and may influence plant growth and morphology.

2. Artificial lighting

The study of plants grown under artificial light began about 150 years ago, and from 1971 onwards, space research gave a major boost to research in this area (23). The light sources were initially fluorescent tubes with different light intensities and spectra, high pressure sodium (HPS) lamps (24), and from the 1990s onwards light emitting diodes (LEDs) (25). In the temperate zone, it is mainly used in the production of vegetable plants and in some ornamental and herb production equipment. In recent years, it has also been implemented in tomato plants, allowing harvesting in January-February. To reduce irradiation in terms of light reduction, there is little need in the temperate zone.

3. Types of artificial light sources

In recent years, the use of artificial supplementary lighting in greenhouses has become increasingly common. This was previously essential for some ornamental plants, but is now also used for food production in vegetable crops. Vertical farms do not use natural light at all, but only electric light sources. This latter method of plant production has been used in the past in so-called phytotrons, for research purposes only (26).

The light sources used for growing plants are: fluorescent tubes: traditional fluorescent tubes, such as T5, T8, and T12 tubes, are still popular, especially for growing young seedlings and small plants. These light sources are excellent for even light distribution over large areas. Compact Fluorescent Lamps (CFLs) and High Pressure Sodium (HPS): These lamp types offer longer life and better light output, but produce more heat, requiring temperature control. LED Lighting: LED (Light Emitting Diode) lamps are becoming increasingly popular in crop production because they are energy efficient, long-lasting and allow control of the light spectrum. LEDs in different colours, such as red and blue, are particularly useful for certain stages of plant growth. The following table compares the advantages and disadvantages of artificial light sources (27).

Light source Type	Benefits	Disadvantages
Fluorescent tubes (T5, T8, etc.)	Uniform light distribution, lower initial costs, less heat generation	Higher power consumption than LEDs, more frequent replacement than LEDs

Compact fluorescent lamps (CFL)	Energy efficiency, easy procurement and installation	Heat management required, not ideal for large areas
High Pressure Sodium Lamps (HPS)	High light intensity, good for supporting flowering	High heat production, spectrum not balanced
Metal halide lamps (MH)	Good for supporting vegetative growth, broad spectrum	High heat output, requires frequent replacement, less energy efficient than LED or CFL
LED	Low power consumption, long lifetime, low heat generation, spectrum controllability	Higher initial costs, limited brightness in some cases

Table 1 Advantages and disadvantages of artificial light sources

LED-based light sources, due to their improved cost-effectiveness (25,28,29), have also given a major boost to artificially lit crop production in the last decade (30). Their use has made it possible to produce crops at times and in places where previously it was not possible, which is particularly important for crops such as year-round leafy vegetables (25,31).

Figure 4 High pressure sodium vapour (HPS) lamp, HPS light emitting diode (LED) with interlight, top LED lights

4. Comparison of HPS and LED light sources

A prerequisite for the efficient operation of modern greenhouses is the provision of adequate and energy-efficient artificial (supplementary) lighting. Research and development in this area has also made great strides in recent years. For plants, it is not the total amount of light received that is of greater importance, but the photosynthetically active radiation (PAR) (32). In the visible light range, photosynthetic pigments in plants are best able to utilise radiation at wavelengths of around 450 nm on the one hand and 660 nm on the other. In addition, they can also detect light ranges that are invisible to the human eye (33). Because LED light sources can precisely control the spectrum of light emitted, they offer a more effective way of enhancing plant performance than other light sources. Even in greenhouses that previously had HPS or other artificial lighting, lamps are being replaced with more modern LED-based light sources.

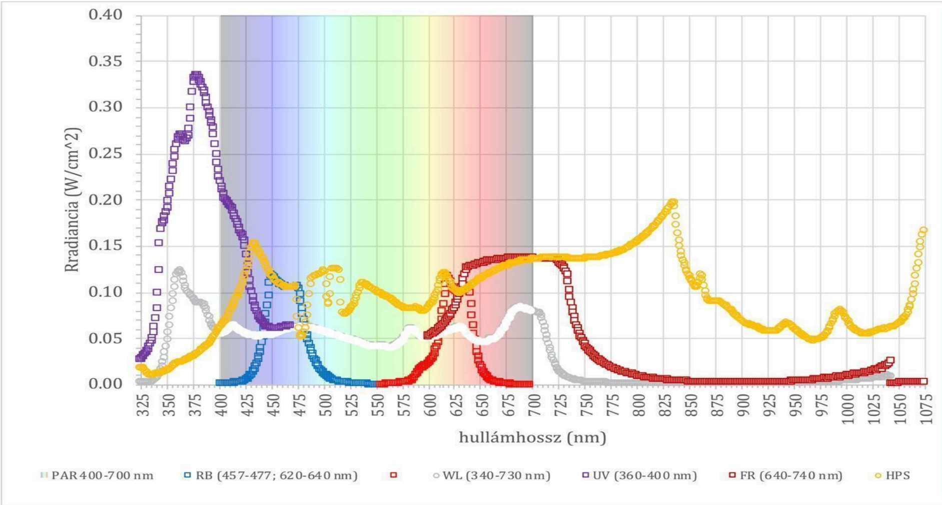

Figure 5 Spectra of HPS and different colour (blue/red: RB; ultraviolet: UV; near red: FR) and compact white (WL) LED light sources in relation to the photosynthetically active region (PAR)

The wavelength and intensity of light has a strong influence on the vitality and productivity of plants. With LED lamps, we can always provide the optimum spectral composition and amount of light, adapted to the life stages of the plants. Experiments have shown that for most plants, the blue light range stimulates vegetative growth, red light stimulates generative processes and far red is suitable for inducing flowering (34). When growing leafy vegetables, it is very important to avoid nitrate accumulation in the plant body, and this can be achieved with an optimal light spectrum. In experiments with spinach grown under different light conditions, the plants showed different stem length, leaf area, biomass production and also different nutritional composition. For example, far-red light increased the iron content of leaves (35).

An HPS, LED comparison experiment showed that the proportion of energy used varied significantly (between 45% and 85%) between different climates for HPS-lit greenhouses (**Figure 5**). The energy savings predicted by switching to LEDs were between 10-25% of total energy use; the outdoor climate was the most important factor determining how much energy could be saved. It was found that transpiration of plants is higher under HPS lamps, resulting in greater energy loss, and the need for dehumidification through ventilation was increased. The higher heat demand of LED greenhouses was most pronounced in winter, when the excess heat from the lamps in HPS-lit greenhouses reduced the load on the heating system. In summer, both HPS and LED greenhouses had low heating requirements, while HPS greenhouses required more ventilation (36).

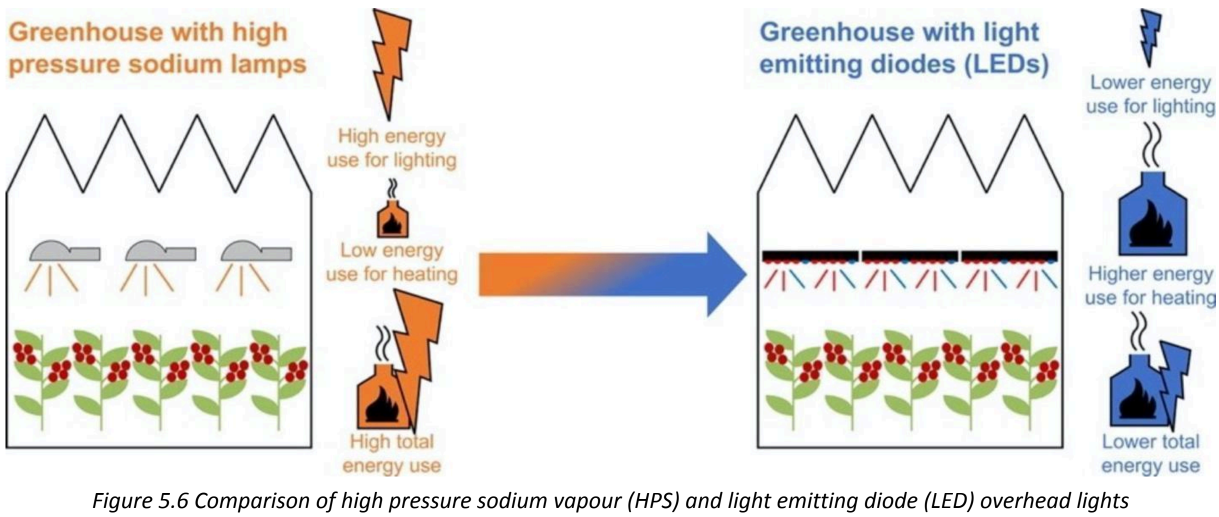

Figure 5.6 Comparison of high pressure sodium vapour (HPS) and light emitting diode (LED) overhead lights

A similar conclusion has been reached by researchers comparing HPS and LED lamps in sprouted cucumbers. In autumn and spring, the lower heat load of LED lamps allows for higher CO_2 concentrations due to lower ventilation requirements, but in summer the reduction in heat load is not large enough to significantly affect CO_2 concentrations. Above 60°N, the irradiance of LEDs must be increased above 300 μmol-m^{-2} -s^{-1} to replace PS lamps (37).

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8. PRECISION GREENHOUSE CROP PROTECTION

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1. Foreword

The huge technological advances and innovations in crop production and crop protection have had a significant impact on the sustainability of agriculture, yields and crop quality. Precision greenhouse cultivation methods enable more precise and efficient crop protection, minimising environmental impacts and improving economic outcomes. This course is for those interested in modern agriculture and seeking a broader knowledge of the latest tools and strategies for crop protection.

The aim of the course is to provide an overview of the key issues and challenges that are coming to the fore in the field of precision pest management. It will cover, among others, innovative techniques and tools such as automated sensors, artificial intelligence and genetic modification that enable early detection of pests and diseases and effective control and management.

The structure of the curriculum focuses on the following topics:

- Monitoring and early detection of pests and pathogens
- Precision plant protection and targeted interventions
- Environmentally friendly plant protection products and methods in greenhouses
- Managing resistance to pests and pathogens
- Greenhouse climate effects and plant protection
- Plant protection and sustainability

Each chapter discusses the topic in more depth, presenting the latest research, practical examples and challenges in the field. Our aim is that this curriculum will help you to better understand and apply the tools and principles of precision agriculture.

2. Monitoring and early detection of pests and pathogens

Early detection of pests and pathogens and the symptoms they cause is the basis of precision pest management. If the damage caused by a disease or pest population can be controlled at an early stage, it can save the farmer significant crop losses, not to mention minimise the cost of control.

2.1 Application of automated sensors and image processing to identify pests and diseases

The technological revolution in the agricultural sector is increasingly transforming the field of plant protection. Advances in automated sensors and image processing allow for more efficient and accurate pest and pathogen identification, making a significant contribution to the realisation of precision crop protection.

Automated sensors installed in precision greenhouses and vertical farms continuously monitor the environmental parameters of the plants. These sensors are able to measure temperature, humidity, light intensity, CO2 levels, leaf surface moisture, and other important parameters that can affect the incidence of pests and pathogens. The collection of data in real time allows for rapid response to potential threats. Early identification of pests and pathogens or the symptoms they cause is invaluable in crop protection.

Advances in image processing offer further opportunities for crop protection. The cameras and image processing algorithms used collect detailed visual information about plants. Damage caused by pests, disease symptoms and other abnormalities such as wilting and yellowing can be easily identified. Pests in particular, but also certain groups of pathogens, can be said to produce so-called typical symptoms on damaged plants. Examples are the white mycelial coating characteristic of powdery mildew fungi (Figure 2.1) or the sooty mould that colonises aphid droppings. Automated systems can quickly process large amounts of data and identify anomalies, allowing early detection and targeted intervention.

Distinctive symptoms of powdery mildew infection on the leaf surface (8.1.1)

The use of automated sensors and image processing has many advantages:

- It reduces the need for human intervention and manual monitoring, saving time and resources.
- Continuous and accurate monitoring of the plants allows early detection of problems, thus minimising damage and control costs.
- Accurate data can be used to develop tailored and effective protection strategies that can improve plant health and yields.

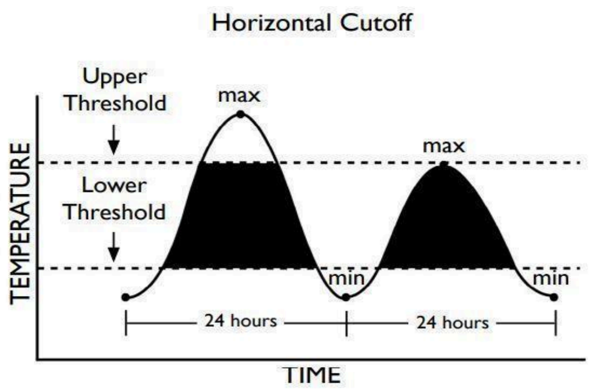
The use of automated sensors and image processing is a major advance in crop protection. Further developments and innovations in this field are expected in the future, making precision crop protection even more efficient and sustainable, contributing to global food security and sustainability.

2.2 Pest and disease risk assessment and monitoring in greenhouses

Crop production is an ever-changing, dynamic environment in which pests and diseases caused by pathogens are one of the most important challenges facing farmers and growers. The timely identification and effective management of pests and diseases is essential to maintain yields and quality. Risk assessment and monitoring play a key role in the successful implementation of precision pest management.

Pest and disease risk assessment involves identifying potential threats and areas at risk. The identification of areas will take into account the sensitivity of plant species and varieties, weather and environmental factors, and experience from previous years. The assessment of sensitive areas allows for more effective planning of preventive measures and helps to prevent the spread of pests and diseases. Just as in the field, pests do not appear everywhere at once in the greenhouse, so monitoring of sensitive areas is strongly recommended.

Risk monitoring is based on regular monitoring of the processes and condition of the plants in the greenhouses. This can be done using sensors or by manual data collection. Sensors collect information on changes and values of temperature, humidity, soil moisture and other critical parameters such as leaf surface moisture duration. The storage of the collected data allows not only monitoring of current conditions, but also the analysis of time series data and the calculation of different values (e.g. heat sums) (Figure 8.1.2). These data are compared with predefined thresholds and alarms are generated when they are reached or approached. These alarms can be sent either via GSM SMS or push message in case of a suitable mobile application. This allows rapid intervention before pests or diseases cause serious damage.



Temperature monitoring to monitor conditions for pathogen growth (2..2)

Monitoring the risk of pests and pathogens can be done not only by observing and monitoring the conditions but also the actual pests. This can be done by means of catching devices such as spore traps or sticky traps, which can be operated by image processing in more advanced systems and by manual control in less advanced systems.

The benefits of automated risk assessment and monitoring include: enabling a proactive approach to crop protection that minimises damage from pests and diseases. Either preventive or early curative treatments or measures are much more effective than late or ill-timed interventions. Accurate and real-time data allows targeted and effective interventions to be planned and implemented. The evaluation of the data also provides an opportunity to plan the following year's control activities. Timely alerts reduce material losses and expenditure as well as chemical use, contributing to sustainable crop production.

Overall, automated risk assessment and monitoring is a key tool for the successful practical implementation of precision pest management.

2.3 The role of artificial intelligence in the development of early detection systems

One of the most important challenges in crop protection is the early detection of pests and diseases and the development of effective protection against them. In modern agriculture, however, technological advances are opening up new opportunities in this area, and the use of artificial intelligence (AI) is revolutionising the development of early detection systems.

Artificial intelligence is a set of algorithms and systems that can learn and make decisions based on data, similar to human intelligence.

Artificial intelligence plays a prominent role in the development of early detection systems in many areas:

The first and most important is data processing and analysis: processing and analysing data on plants and environmental parameters would be an impossible task in terms of human resources. However, artificial intelligence is capable of processing large amounts of data (big data) quickly and efficiently. It identifies correlations and patterns that may indicate the presence of pests and diseases, first by learning and then by itself. The design of an image recognition, pattern recognition system starts with data collection and continues with training the algorithm. This is called labelling, or tagging. This task is the key to the algorithm's and the AI's subsequent success. This process is labour-intensive, since, for example, all the images captured must be manually labelled with the symptoms of the disease or the applicant, and their severity, so that the system can later recognise them and not send false alarms, or worse, fail to recognise the symptoms in time.

Predictive models: artificial intelligence can be used to develop predictive models that can be used to predict the likelihood of pest and disease occurrence. Given environmental conditions, weather and other factors, AI can help refine risk estimates.

Automated monitoring: sensors and image processing systems controlled by AI continuously monitor the condition of the plants and their environmental parameters. Based on predefined patterns and changes, the system can send an alert when signs of pests or diseases appear. It should be noted here that such a system can play a major role not only in crop protection but also in the management and control of other agrotechnical operations (e.g. irrigation, air management).

Decision support: AI can help growers and farmers to develop optimal conservation strategies. AI-based systems can take into account current and historical data, information and risk factors to aid decision-making.

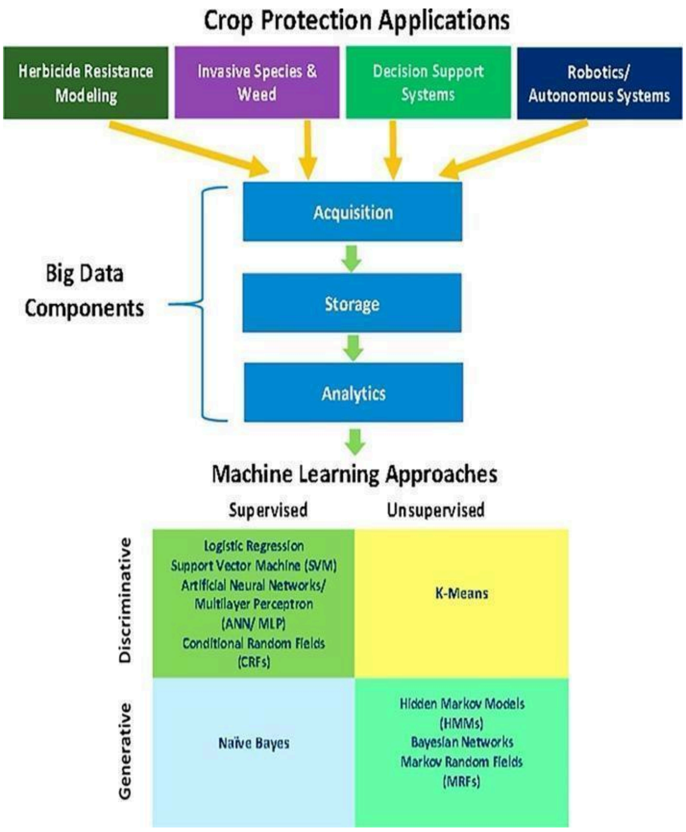
The use of artificial intelligence in the development of early detection systems has huge potential for precision crop protection. AI-driven systems enable rapid response and effective interventions, minimising damage and increasing the sustainability of crop production. Further developments in AI are expected to lead to even better and more accurate early detection systems, contributing to global food security and sustainable agriculture.

3.Precision plant protection and targeted interventions

3.1 Combining data-driven decision making and precision pest management

The combination of data-driven decision-making and precision crop management has revolutionised agriculture, enabling farmers and growers to create a new dimension of efficient and sustainable crop protection. This linkage allows crop protection strategies to be precisely adapted to crop conditions, environmental conditions and other relevant factors.

Data-based decision making is based on data, sensors and measurements that monitor the condition of plants, soil/media and environmental factors (Figure 8.2.1.). These data record in real time plant development, the presence of pests and diseases and environmental changes. By processing and analysing the data, data-driven decision-making leads to more accurate and effective crop protection.



Overview of crop protection applications and their links to Big Data and machine learning approaches

Based on the principles of precision plant protection, treatments are targeted and applied to the area needed. Data-driven decision making allows farmers to accurately identify areas at risk and to carry out plant protection interventions only in those areas. This minimises chemical use and reduces environmental impact, while preserving yield and quality.

The benefits of a combined approach are felt in many areas:

More precise and effective crop protection: data-driven decision-making allows targeted and timely interventions against pests and diseases. Precision crop protection methods can be used to effectively apply these interventions to problem areas, minimising unnecessary chemical use.

Environment: a data-driven approach helps reduce environmental pressures by reducing chemical use. Through more accurate crop protection, environmental impacts can be minimised, contributing to sustainable agriculture.

Economic efficiency: the combination of data-driven decision making and precision farming allows for more efficient use of resources and reduced costs. Precise interventions can improve yields and quality, increasing farmers' incomes and reducing costs.

The data on which plant protection relies most heavily:

Temperature: air temperature has a big influence on the appearance of pests or pathogens. In the case of pests, for example, the rate of insect development (speed, number of generations) is very strongly linked to temperature. For pathogens, temperature can determine the germination of fungal spores and the incubation period. Too high or too low a temperature can also alter the effectiveness of pesticides, so it is important that treatments are carried out at the right temperature for the product.

Relative humidity and leaf surface moisture: the temperature of plants is always lower than air temperature due to evaporation. If the humidity in a greenhouse rises to 90% or above, there is a high probability of condensation on the cooler surfaces of the plants, which will form a thin film of moisture. This moisture, sometimes invisible to the naked eye, is sufficient for spores to germinate.

Combining data-driven decision-making with precision crop management is therefore a key element in the development of modern agriculture. New technologies and approaches will enable sustainable and efficient crop protection, contributing to global food security and environmental sustainability.

3.2 Targeted spraying and pest control only in the affected areas

Traditional crop protection in agriculture often requires significant amounts of pesticides applied over vast areas regardless of where and how severely the pest or disease is present (Figure 3.2). However, modern technology allows a radical change in crop protection and the implementation of targeted spraying and pest control only in the affected areas.

Self-propelled, greenhouse spraying robot and spraying wheel for ultra-low rates of plant protection products

Targeted spraying is based on data-driven decision making and precision crop protection. Sensors can be used to continuously monitor plant health and environmental factors. The data can be analysed to identify areas that are under real threat from pests or diseases. Spraying is applied in these areas, minimising the use of chemicals.

In greenhouses, monitoring of pests and diseases can be automated with such systems, and even the application of pesticides can be managed through centralised systems (e.g. irrigation). In precision pest management, the treatment is targeted at the infection hotspots.

THIS HAS MANY ADVANTAGES:

Environmental sustainability: targeted spraying reduces the environmental impact of chemicals by applying them only to areas at risk. This minimises the risks of soil, water and food contamination.

Chemical savings: targeted spraying in the affected areas allows for more efficient use of chemicals, as they are only applied where needed. This can result in significant savings for farmers and growers, as well as reducing the risk of resistance development.

Cost-effectiveness: the combination of data-driven decision making and targeted spraying can improve yield and quality by protecting crops from pests or diseases at exactly the right time and place.

Time and labour savings: automated systems and targeted interventions minimise the unnecessary work and time that would be required to manage the entire area under conventional crop protection.

Targeted spatial management based on risk assessment and pest control is a cornerstone of precision pest management. Modern technology and data-driven approaches enable sustainable and effective crop protection, improving economic outcomes.

3.3 Evaluation of the effectiveness of precision pest management and benefits of savings

Precision crop protection not only aims to control pests and diseases effectively, but also offers many other benefits to farmers and growers in the production process. Evaluating the effectiveness of the technologies and data-based approaches used is an important step in system design and development.

There are several ways to evaluate the effectiveness of precision crop protection. Efficiency can be measured in terms of crop quantity, quality, changes in the amount of pesticides used and the number of treatments, changes in labour input and, of course, savings.

The most obvious metric is the level of damage: precision pest management allows more effective control of pests and pathogens, which can be traced back to lower damage levels. Efficiency can be assessed by plant condition, development and yield. The level of damage can be both a qualitative and quantitative indicator, so its definition and quantification requires precise methodological knowledge per plant and per pest. Quantitative damage is perhaps the easiest to assess, where the extent of damage can be clearly quantified in terms of the number of damaged crops, for example tomatoes or peppers. The degree of qualitative damage may refer to indicators of nutritional value, taste, smell or deterioration of storage life.

Pesticide use: targeted interventions reduce the amount of pesticides used. Reduced pesticide use contributes to environmental sustainability and water quality, food security, the survival of natural enemies and beneficial organisms, and the maintenance of biodiversity.

Labour savings: automated systems and targeted interventions reduce the amount of manual work required, which can result in significant labour savings. It should be noted, however, that automated systems often require a highly skilled workforce to operate, monitor or troubleshoot the system, or an operational contract with a service provider.

Cost-effectiveness: data-driven decisions and targeted interventions can improve yields and quality while reducing costs. Increased economic efficiency contributes to the profitability of farming, which allows farmers to invest and improve further.

The benefits of savings are felt on many levels:

- Reducing costs: lower pesticide use and targeted interventions reduce crop protection costs, resulting in significant savings for growers.
- Resource efficiency: precision crop protection allows resources to be used more efficiently, reducing unnecessary expenditure and waste.
- Environmental protection: by using less pesticides and environmentally friendly methods, precision farming contributes to reducing environmental pressures and to sustainability.
- Increasing profitability: more efficient production and reduced costs improve farmers' profitability and competitiveness.

Evaluating the effectiveness of precision crop protection and the benefits of the savings will therefore contribute to sustainable agriculture and economic efficiency on a broad scale. By integrating data-driven decision making and modern technology, the benefits of crop protection will further contribute to global food security and sustainable agriculture.

4. Environmentally friendly pesticides and methods in greenhouses

Agriculture and crop production have come a long way towards environmentally friendly crop protection, but even today, growers are still under attack for their crop protection practices. On the one hand, there is the social and regulatory pressure on farmers to produce in a more environmentally responsible way, and on the other, the simple but all the more pressing task of protecting crops. The modern integrated pest management toolbox includes a number of environmentally friendly solutions.

4.1 Biological control and use of natural enemies in pest management

Biological pest management is an effective and environmentally friendly approach to pest and disease control that exploits natural ecological processes and interactions between organisms to promote plant protection. The use of natural enemies and biological agents to protect against hostile pests and pathogens allows pest populations to be controlled and minimised. The use of biological control and natural enemies the advantages of:

- **Environmentally friendly:** Biosecurity relies on natural processes and living organisms, minimising the use of chemicals and reducing environmental impact.
- **Long-term effectiveness**: the introduction and support of natural enemies can provide long-term protection against pests and diseases, as these organisms keep pest populations under control.
- **Reducing the risk of resistance:** biological control minimises the risk of pests and pathogens developing resistance to conventional pesticides by not creating selection pressure.
- **Maintaining environmental balance:** supporting natural enemies helps maintain environmental balance and biodiversity.

Placement of parasitoid quail wasp eggs in an aphid imago as host (4.1)

Biological pest management and the use of natural enemies include the use of parasitoids and natural enemies, the introduction of beneficial organisms, the use of microbiological agents, the use of pheromones and baits (Figure 4.1).

Parasitoids are organisms that kill pests such as aphids or caterpillars. A typical example of parasitoids is the quail wasps, which lay their eggs in the pest with their ovipositor, and the larvae that hatch from the eggs in the prey consume the pest from the inside. Prey parasites can be natural predators of pests, such as ladybirds used as enemies of aphids or predatory mites and bedbugs.

Introduce beneficial organisms: insects such as bees or butterflies that help pollinate and pollinate plants, improving yields.

Use of microbial agents: the use of natural soil bacteria or fungi in a way that prevents the spread or growth of pathogens while helping plants to grow. Examples might include loop-feeding fungi (Arthrobothrys sp.) or various genera of bacteria (Pseudomonas, Azotobacter, Bacillus).

Use of pheromones and baits: chemicals, or pheromones, produced by pests to attract or deceive pests, helping to control populations. Pheromones are used to lure males with the pheromone of a female pest, which then flies them into a trap, so that the population can be kept under control. In the case of decoys, the pest animals also fall into a trap or emerge from their hiding places where they can fall prey to predators.

However, the difficulties of biological control must also be mentioned, since those who opt for this method of control cannot use chemical control, as it can also have a damaging effect on natural enemies. The release of natural enemies requires good timing, because predators without prey will either die or become pests of plants.

For interested farmers, biological control and the use of natural enemies offer an excellent opportunity for sustainable and environmentally friendly crop production. With thorough knowledge, proper planning and care, biological control can be an effective tool in the fight against pests and pathogens, helping to increase yields and the sustainability of crop production.

4.2 Use of environmentally friendly pesticides and organic spray products

The use of environmentally friendly crop protection and organic sprays is an approach that reconciles effective control with environmental and sustainability concerns. This approach conserves natural resources and minimises environmental pressures, while protecting plants against pests and diseases.

The benefits of using environmentally friendly pesticides and organic sprays can be summarised as follows:

- **Reducing environmental pressures:** organic and environmentally friendly materials tend to decompose faster and have less impact on soil and water sources. The decomposition products of these materials are also natural substances. In the case of conventional (chemical) pesticides, the main environmental problem is often not the active ingredient but its degradation products.
- **Sustainability**: organic pest management offers a more sustainable solution in the long term, as it minimises the risk of developing resistance to pests and pathogens. The structural composition of organic materials is complex and therefore difficult to build up resistance in pests.
- **Preserving nutritional value:** organic crop protection helps to preserve the nutritional value and quality of plants, which also benefits consumers.

The use of environmentally friendly pesticides and organic spray products can include:

- **Plant extracts:** For example, garlic, tomato or peppermint extracts, which may naturally contain substances that are effective against pests. The secondary metabolites formed in these plants have a natural repellent effect, i.e. they repel pests.
- **Natural oils:** such as neem oil, rapeseed oil or essential oils, which can help protect against pests and pathogens. Oils can provide physical protection against sting-sucking pests, but their inappropriate application (e.g., when applied at high temperatures) can lead to crop damage or loss of efficacy.
- **Bacteria and fungi:** Certain bacteria and fungi can be useful in controlling pests and pathogens. Examples include *Bacillus thuringiensis* and Trichoderma species. The bacterium Bacillus thuringiensis produces a toxin called Bt, which is fatal to some insects if ingested. The toxin binds to the animal's intestinal wall and causes a hole to open, killing the animal. Some species of the fungus genus Trichoderma find persistent forms of pathogenic fungi (e.g. Sclerotinia) in the soil and consume them.

The use of organic sprays and environmentally friendly crop protection is key to sustainable sustainable agriculture and crop production. Such approaches help conserve natural resources, minimise adverse environmental impacts and improve crop production quality, while contributing to global food security and sustainable agriculture.

4.3 Optimisation of pesticide use and principles of pesticide-free crop protection

Optimisation of pesticide use and the principles of chemical-free crop protection represent an approach that puts environmental protection and sustainability at the forefront of crop protection. They encourage farmers and growers to reduce the use of chemicals and to favour natural and sustainable methods instead. Optimizing the use of pesticides is the aim of integrated pest management.

The benefits and main objectives of the principles of optimisation of pesticide use and chemical-free crop protection are:

- **Environmental sustainability:** optimised pesticide use and chemical-free methods minimise environmental impact, reducing the risk of soil and water contamination. Modern crop protection does not aim at the total elimination of the damaging population, but at keeping the population below the threshold of damage. Most modern plant protection products are now specific, i.e. developed to target only 1 or 2 pest groups. The number of broad-spectrum pesticides is steadily decreasing and their use is subject to increasingly stringent conditions.

- **Maintaining a natural balance**: pesticide-free crop protection helps to maintain a balance of natural organisms and ecological processes, which can help to control pests and diseases in the long term. In many cases, chemical plant protection has led to the disappearance of beneficial organisms and natural enemies from an area, while pests have reappeared year after year.
- **Reducing the risk of resistance:** optimal pesticide use and chemical-free methods minimise the risk of pests and pathogens developing resistance to pesticides.
- **Preserving nutritional value and quality:** natural and sustainable methods help to preserve the nutritional value and quality of crops, which also benefits consumers.

Optimising the use of pesticides and implementing the principles of pesticide-free pest management means using the following methods:

Integrated Pest Management: the integrated use of different control methods and measures, such as agrotechnical, biological, chemical, biotechnological control methods and measures against pests and pathogens. Agrotechnical may include species selection (e.g. resistant) and biotechnological may include the use of pheromone traps.

Biotechnology and resistant varieties: the use of biotechnology to promote the development and use of resistant plant varieties against pests and pathogens.

Nutrient and soil management: nutrient replenishment and soil management carried out in a timely and appropriate manner helps plants to develop healthy growth and resistance to pests and diseases.

Prevention and agro-technical measures: good plant care practices, such as regular and correct pruning, weed control and mulching, can inhibit the spread of pests and pathogens.

Optimising pesticide use and the principles of pesticide-free crop protection are key to promoting sustainable agriculture and crop production. These methods help conserve natural resources, minimise environmental impacts and improve crop quality.

5. Management of resistance to pests and pathogens

One of the keys to effective pest and pathogen control is the development and use of resistant plant varieties that are naturally resistant or more resistant to pests and pathogens. Resistant plant varieties and variety development strategies enable more sustainable and less chemical-dependent crop production. In the case of resistance, we must mention resistant and tolerant plant varieties. Resistant varieties mean that a pest is unable to infect the plant, while a resistant plant is one where the infection occurs, but the symptoms do not develop or are not severe enough to cause quality damage.

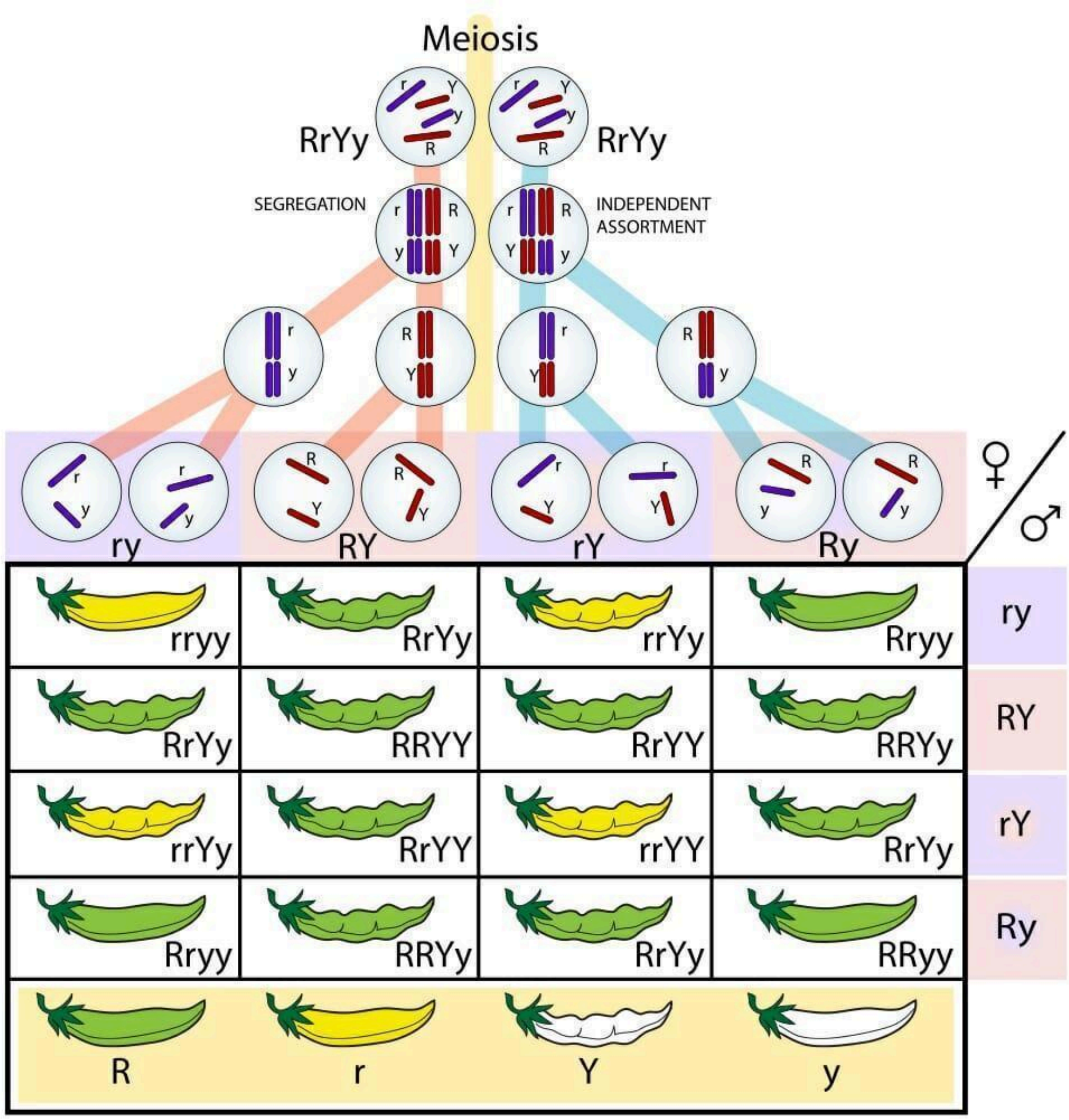
5.1 Use of resistant plant varieties and variety development strategies

Benefits of using resistant plant varieties and variety development strategies:

- **Reduced chemical use:** resistant crop varieties are less likely to be infected by pests and pathogens, so less pesticide use may be sufficient to protect them.
- **Environmental sustainability**: the natural resistance of resistant crops reduces the environmental burden of chemical pollution.
- **Economic efficiency:** resistant crops can lead to higher yields and better quality, improving economic results.
- **Reducing the risk of developing resistance:** as for resistant crops Reducing the risk of pesticide resistance in pests and pathogens.

Resistant plant varieties and variety development strategies can be applied in the following ways:

Selection and traditional crossing: crossing and selecting between different plant varieties to produce plants that are more resistant to pests and pathogens (Figure 5.1). It is a slow and expensive process, but varieties bred in this way are allowed in countries where GMO crops may not be grown.



Cross-breeding process (5.1)

Molecular methods: modern biotechnological methods such as gene editing or gene modification allow the targeted introduction of resistance genes into plants. The process starts with the discovery and identification of the gene responsible for resistance, followed by its localisation and identification. This is followed by targeted delivery of the gene and testing of the expected effect. If these are successful, the next step is variety approval.

Preserving genetic diversity: maintaining genetic diversity and cross-breeding resistant varieties can help maintain long-term resistance. Resistance to some pathogens and pests is encoded by multiple genes, so conservation and natural mixing of genes can improve the degree of resistance.

The use of resistant plant varieties and variety development strategies is an essential part of modern agricultural practice, enabling sustainable and efficient crop production. There are species for which improving resistance is key to their survival and cultivability. The cultivation of resistant or hardy varieties contributes to reducing chemical use, improving economic outcomes and improving agricultural productivity.

5.2 Resistant crops and genetic manipulations for effective pest and disease control

Resistant crops and genetic manipulation offer an effective and innovative approach to pest and disease control that can increase crop yields and quality while reducing chemical use and environmental stress. Advanced biotechnology allows targeted modification of genes to increase plant resistance to pests and diseases.

The advantages of using resistant crops and genetic manipulations are summarised below:

- **Targeted resistance:** genetic manipulation makes it possible to introduce genes into plants that have specific effects against pests or pathogens. These genes are usually found in nature, in the ancestors of plants grown now or in varieties grown in the past.
- **Reducing the use of pesticides**: resistant crops require less pesticides to control pests and pathogens, thus reducing negative impacts on the environment.
- **Economic efficiency:** resistant crops can lead to higher yields and better quality, which can increase agricultural profitability.
- **Reducing the risk of resistance:** as lower pesticide application rates are sufficient for resistant crops, the risk of pesticide resistance in pests and pathogens developing in populations is reduced.

General methods for the use of resistant plants and genetic manipulations include:

- **Gene introgression:** the introduction into plants of foreign genes that encode proteins or substances that promote resistance. This method is also called genetic transformation. The introduction of a gene sequence encoding resistance or an individual trait can be done by gene gun, where the amplified gene sequence on a carrier is injected into the plant tissue using compressed air with the aim of getting it into the right place and expressing it.
- **Gene editing:** the transformation methods described earlier involve the relatively imprecise, random insertion of an existing gene. In contrast, gene editing is based on the ability to build resistance or resistance in an existing gene in a plant by changing just 1 nucleotide in the gene. This is the case, for example, with the CRISPR-Cas9 system, which was discovered in 2020.
- **Cross-breeding:** creating new varieties from crosses of different plant varieties by traditional cross-breeding. In this method, one parent carries the gene or genes responsible for resistance and the other carries other positive traits (e.g. high yield).

The use of resistant crops and genetic manipulations is a way forward for sustainable agriculture and crop production. Resistance and pathogens or hosts evolve together naturally. If resistance to a pathogen or pest develops in a plant, it is highly likely that a strain of the pest will evolve in the future to break through this resistance and the process will start all over again.

5.3 Sustainable resistance management and prevention of resistance

Sustainable resistance management and prevention of resistance development are key to the control of pests, pathogens and weeds. Effective measures against resistance development and the maintenance of resistance will ensure sustainable and effective crop production in the long term.

Sustainable resistance management is a set of methods that focus on breaking down or bypassing resistance already established in pests. Preventing the development of resistance requires conscious pest management decisions and practices.

The reasons for the development of resistance are usually due to inappropriate pesticide treatments. Resistance to certain pesticides can develop in pests for several reasons. The first is when **the pesticide is not applied at the permitted dose**. Pesticides are expensive and growers sometimes choose to apply lower doses than recommended for financial reasons. In this case, certain individuals of the harmful organism may survive the treatment and become habituated to the active ingredient because of the low dose.

A similar situation may result if the same active substance or group of active substances is applied several times in succession at the permitted dose **but without any serration**. The authorisation dossier for a plant protection product will always include the technology proposed for the crop, the dose and the maximum number of applications. Without following these instructions, individuals of the pest may develop resistance in themselves, leading to the emergence of resistant populations. Insect pests can spread across continents in different ways, so a resistant strain developing anywhere in the world poses a threat to crop protection as a whole.

If a resistant strain of the pest has already emerged, it can be kept under control in the herd by appropriate treatment.

In a greenhouse (as opposed to a plantation), the option is to replace the stock, i.e. if resistance develops in a pest that only infects tomatoes, the solution may be to replace the entire stock with another crop. This requires a serious economic decision, as in many cases the grower has the technology to grow one crop, but it is also a very effective solution to the problem.

Rotation of pesticide active substances is a suitable method for managing resistance and preventing its development. If a pest is resistant to an active substance or a group of active substances, it should be removed from plant protection and other pesticides with different modes of action should be used. In crop protection, this option is becoming more and more limited as the availability of active substances is decreasing, so a switch to biological control may be an option, as ladybird-resistant aphids have not yet evolved.

The prevention of resistance and the sustainable management of resistance can be achieved through complex methods, including the use of integrated pest management, which includes the use of resistant crops, judicious and well-grounded chemical pest management, biological and biotechnological methods.

Sustainable resistance management and prevention of resistance development are key to long-term and sustainable crop protection. These measures help to minimise damage caused by pests and pathogens.

6. Greenhouse climate impacts and plant protection

Greenhouse climate control is a cornerstone of indoor plant production. One of the biggest differences in cultivation compared to outdoor growing is the minimisation of risks from weather factors.

6.1 Effect of climate change on the occurrence of pests and pathogens in greenhouses

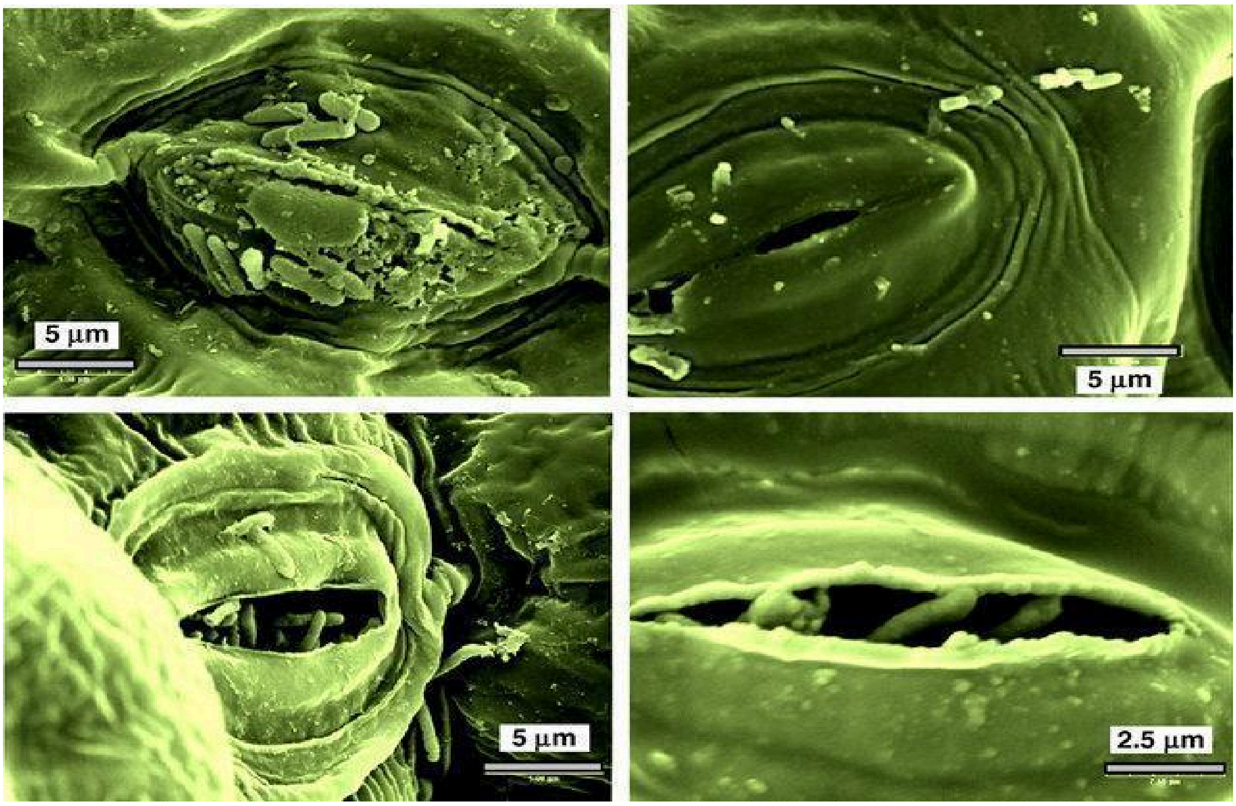
Variations in temperature and humidity affect the occurrence of pests and pathogens, influence the ecological balance and can help or hinder effective pest management.

The effects of temperature and humidity on the occurrence of pests and pathogens in greenhouses:

Changes in pest activity: rising temperatures increase pest activity up to a certain level. The development of pests, especially insects, is strongly influenced by external temperature, as these organisms cannot regulate their own temperature. In their development, we distinguish between developmental threshold temperatures, developmental optimum temperatures and developmental maximum temperatures. The speed of their development, and thus the number of generations that develop, depends on the air temperature.

The relationship between pests and humidity is less clear. Some pests are inhibited by high humidity, such as spider mites, which multiply in greenhouses during dry, hot weather. High humidity, for example, is particularly attractive to ants.

Pathogens: the most common pathogen groups are plant pathogenic viruses, bacteria and fungi. The most common pathogenic viruses are pathogenic bacteria and fungi. The spread of viruses depends largely on the activity of the vectors, but in the case of bacteria and fungi, high temperatures and high humidity are generally conducive to infection. Bacteria are able to move actively in humid environments, so they can easily reach the point of infection on wet leaves, which is often one of the gas vents (Figure 5.1). Fungal spores also require a certain amount of moisture on the plant for germination. After germination of the spores, the fungus starts its damage either on the surface of the plant or in its tissues.



Gas vents in the leaf as primary infection points (6.1)

Symptom appearance: symptoms caused by pests may vary at different temperatures and humidity levels. Some viral symptoms are masked in high heat, while they are easily seen at lower temperatures. In the case of bacterial diseases, the appearance of bacterial slime on spots is usually associated with high humidity.

Changes in occurrence areas: monitoring the greenhouse climate is important because initial infestations can be localised. If the farmer is familiar with the microclimate of the greenhouse, he can expect a sporadic initial appearance of a disease or pest, so that he can carry out preventive treatment in the area.

Control challenges: rapidly changing weather patterns in the greenhouse can make it difficult to control in time, which can increase the risk of spreading pests and pathogens. Automatic monitoring systems, discussed earlier, and data analysis can be of great help in this. The most important element of this is climate monitoring, where several parameters are measured, recorded and analysed by sensors at several locations.

Plant health prediction: research has resulted in more and more evolutionary models describing the biology and evolution of pests and pathogens. These models often use weather data to calculate the current developmental shape of the pest or the probability of its emergence. In greenhouses, the use of such systems is an obvious solution, as the system can send warnings when it detects weather factors favourable to the emergence of the pest. Such a system can help to plan timely control and to predict the spread of pests and pathogens.

6.2 Optimisation of greenhouse microclimate to create conditions unfavourable to pests and diseases

Optimisation of the greenhouse microclimate is a strategy aimed at creating an environment in the greenhouse that is not favourable to pests and diseases, and at creating an optimal environment for plants. Such measures help reduce pest populations and the spread of pathogens, contributing to effective plant protection and sustainable greenhouse production.

Leaf symptoms of mite infestation (6.2)

From a plant protection point of view, the main objective of optimising the microclimate in the greenhouse is to help control pests and pathogens. Creating an optimal microclimate for plants helps their development and, when combined with adequate nutrient replenishment, vigorous plants are less likely to be infected by pests because the plant's defence mechanisms can be activated in time. If a plant population is sufficiently ventilated, humidity can be kept at an optimum level, reducing the chances of pathogen emergence. At the same time, pests have fewer places to hide from chemical treatments or their natural enemies.

Optimizing the microclimate in the greenhouse is very important, for example, in controlling mites, but grey mould infestation can also be avoided by proper ventilation (Figure 6.2).

6.3 Strategies for optimizing the greenhouse microclimate:

Temperature and humidity control: set the optimum temperature and humidity to create conditions that are not harmful to pests and diseases. For example, dehumidifiers can be used to avoid excessive humidity.

Ventilation and airflow: providing adequate ventilation and airflow can help reduce moisture and the spread of pathogens. Automatic ventilation systems provide fresh air exchange, and often outside air also helps to regulate greenhouse temperatures.

Light intensity control, shading: these are devices designed to ensure optimal light conditions for plants. Some pests and diseases prefer darker, shadier environments, so controlling light intensity can inhibit their development. Shades can help avoid excessive temperature rise, sunburn and excessive cooling at night (energy shades). They are one of the most basic means of controlling temperature and humidity.

Optimising water management: controlling water supply and irrigation can also help to create the right microclimate. Excessive moisture can contribute to the spread of diseases, especially soil-borne and water-borne pests.

The aim of these examples is to demonstrate how different factors in the greenhouse microclimate can be controlled to create unfavourable conditions for pests and diseases. Adjusting the optimal microclimate is an effective tool for plant protection, reducing the use of chemicals and promoting sustainable crop production.

6.4 Managing changes in greenhouse climate with precision pest management

Climate control in greenhouse production is essential to optimise plant health and yields. However, the effects of climate change can make it difficult to maintain a stable greenhouse environment. A precision pest management approach can effectively help manage and optimise greenhouse climate variability.

Challenges in greenhouse climate management:

- **Temperature and humidity fluctuations:** temperature and humidity are closely related factors. Humidity and moisture relations are closely related. Temperature fluctuations due to climate change can have a negative impact on plant growth and disease susceptibility. Strong warming during the day favours insect development, but can also keep humidity low, while a rapid cooling can lead to condensation on the plant surface, which favours the emergence of pathogens.
- **Changes in light conditions:** extreme light conditions can affect photosynthetic activity and stress levels in plants. For example, high light intensity can shock newly planted seedlings, which need to be acclimatised to greenhouse conditions.

Tools for precision crop management to cope with climate change:

- **Data-based monitoring:** automated sensors allow you to continuously monitor the greenhouse climate, temperature, humidity and other parameters.

- Realistic weather forecasts - Precision crop protection can use real weather data to make more accurate predictions of upcoming changes and help you prepare for potential threats.
- **Targeted interventions:** based on data-based monitoring and weather forecasts, we can take targeted measures to optimise the climate in the greenhouse. For example, we can increase ventilation or adjust shading systems before temperatures rise.
- **Precision irrigation**: based on the data, you can set the automatic irrigation system to ensure that plants always get the right amount of water, reducing problems caused by excessive moisture.
- **Pest and disease monitoring:** precision pest management allows early detection of pests and diseases so that immediate action can be taken.

By using precision crop protection, growers can be better prepared for changing climates and crop protection. Data-driven decision-making and targeted interventions can optimise greenhouse climate, minimise stress and increase yields.

7. Plant protection and sustainability

Crop protection is a fundamental part of modern agriculture, designed to protect plants from pests, diseases and environmental stress. However, the methods used for protection often have an impact on sustainability. The link between crop protection and sustainability is of paramount importance for the conservation of biodiversity and ecological balance.

7.1 Integrating sustainability considerations into crop protection strategies

Key aspects:

1. Reducing pesticide inputs: excessive use of pesticides can lead to environmental pollution, damage to non-target species and the development of resistance in pests and pathogens. The use of Integrated Pest Management (IPM) strategies, which combine agrotechnical, chemical, biological and biotechnological operations, can minimise adverse environmental impacts.

2. Biodiversity conservation: integrated pest management takes into account the conservation of natural enemies, pollinators and other beneficial organisms. Biodiversity-friendly practices in and around farmland can help maintain ecosystem balance, with many long-term benefits.

3. Resource efficiency: sustainable crop protection optimises resources. Data and technology-driven precision agriculture techniques enable the application of targeted conservation measures, minimising waste and environmental impacts. The use of smart, forecast-based, targeted crop protection is important.

4. Taking climate change into account: as climate change affects pests and pathogens, sustainable crop protection methods need to adapt to new challenges. The use of resistant crop varieties, the adoption of climate change adapted practices and the integration of advanced monitoring technologies can increase success and lead to sustainable management.

The Benefits of Plant Conservation and Sustainability:

1. Long-term yield stability: sustainable crop protection methods contribute to stable and consistent yields, ensuring food security and economic stability.

2. Ecosystem and health: promoting biodiversity and reducing the use of chemical pesticides maintains ecosystem health and contributes to food security.

3. Reduced environmental footprint: integrated approaches reduce the negative impacts of agriculture on air, soil and water quality.

4. Economic viability: sustainable practices often improve resource management, reduce costs and increase farmers' profitability.

5. Climate adaptation: sustainability-focused approaches facilitate adaptation to changing climate conditions, allowing farmers to mitigate climate-related risks.

In summary, crop protection and sustainability can combine to create a resilient and ecologically balanced agricultural system. Using integrated, science-based approaches and technological innovation, agriculture can thrive while preserving the environment for present and future generations.

7.2 Impact of plant protection products and methods on the environment and water quality

Plant protection is a key issue in crop production, but the impact of the pesticides and methods used on the environment and water quality is a major concern. In order to maintain ecological balance and promote sustainable agriculture, crop protection must be consistent with the principles of environmental protection.

Main effects of chemical pesticides:

Water hazard: Pesticides that are not used or stored properly can leach and seep into groundwater or water bodies, contaminating them. Plant protection products are classified into water hazard categories. To distinguish between water hazard categories, the unit of measurement of the lethal concentration (LC50) (mg/l) and the measured safety distance (m) are used. The lethal concentration indicates the concentration of the substance that kills 50% of the fish. The safety distance is the distance in metres from standing water within which the use of the pesticide is prohibited.

classificationLC50 (mg/l)Safety distance (m)

Specifically dangerous:< 0,1200

Moderately dangerous:0,1 - 550

Moderately dangerous:6 - 5020

It is not dangerous:> 505

Bee toxicity: certain pesticides can have toxic effects on bees, affecting pollination and bee populations. Before a product with a specific active substance is placed on the market, its effects on bees, as the most important pollinating insects and non-target organisms, are monitored. Three factors are taken into account:

Lethal Dose LD50 (mg/kg): The amount of plant protection product, expressed in milligrams per kilogram body weight of test animal (rat), which kills 50 % of the test animals after oral administration. Direct contact toxicity (CDT): the percentage of bees killed by direct contact. Contact Residual Toxicity (RTR): how long the active substance retains its toxicity (bees are colonised every hour in this case).

Based on these indicators, the three bee risk categories are:

They are particularly dangerous for bees: products containing these active substances cause 90-100% bee mortality on direct contact and retain their toxicity for about 12 hours. Their use is prohibited in flowering crops, when the crop or its surroundings are covered with a mass of flowering honey plants, or when the crop is visited by bees for other reasons.

Moderately hazardous to bees: agents containing these active substances cause 60-100% bee mortality on direct contact and retain their toxicity for about 8 hours. During flowering, their application may be started one hour before sunset, after the end of the daily flight of bees, and should be stopped before 23:00.

Not harmful to bees: The use of the active substance as intended does not pose a risk to bees. It is not harmful to bees. It can be used in flowering crops and in the vicinity of bees, but the restrictive measures, if any, indicated in the authorisation document must be observed.

Biological plant protection:

Effects of introduced predators or parasites: Interventions used in biological control may have undesirable effects, such as excessive overgrowth of introduced predators or parasites. A good example is the emergence and spread of the harlequin ladybird in Hungary. In such cases, the ecological balance is upset. If the new organism finds a suitable environment and has no predators or is more viable than competing species, there is no limit to its reproduction for some time.

Organic plant protection:

Environmental degradation: organic pesticides tend to degrade more quickly in the environment, reducing the residual effects. However, they can also have environmental effects, especially when used in large quantities.

Efficacy: the efficacy of organic plant protection products can be variable and can be sensitive to application dates and methods.

Environmentally friendly plant protection to preserve water quality:

The integrated pest management approach combines different control methods to minimise environmental impacts and reduce the use of chemicals. The use of spraying techniques and additives can reduce the evaporation of pesticides, thus reducing the environmental impact. Data-driven decision making and targeted interventions reduce the use and harmful effects of pesticides by applying them only where and when needed. In order to reduce the impact of plant protection and promote environmental sustainability, crop production practices should be in line with sustainability principles, in order to preserve ecological balance and water quality.

7.3 Environmentally friendly crop protection and the role of agrobiotechnology in sustainable greenhouse production

Sustainable greenhouse production is of paramount importance for global food production and for maintaining ecological balance. The integration of environmentally friendly crop protection and agri-biotechnology is key to promoting sustainable agricultural practices and increasing crop production efficiency.

Environmentally friendly plant protection:

- **Biological control:** the use of natural enemies and predators helps to control pests without the need to use large quantities of chemical products. This reduces environmental stress and supports ecological balance.
- **Organic pesticides:** organic pesticides used in crop protection are less harmful to the environment because they degrade faster and leave less lasting effects.
- **Precision crop protection:** data-driven decision-making and targeted interventions allow for more precise and efficient use of pesticides and methods, minimising the release of unnecessary chemicals into the environment.
- **Integrated Pest Management:** the use of crop production tools for crop protection (a combination of agrotechnical, chemical, biological and biotechnological methods).

The role of agricultural biotechnology:

- **Genetically modified crops:** agro-biotechnology offers the possibility of genetically modifying crops, for example to develop resistance to pests and pathogens. The use of resistant or tolerant varieties can reduce the use of chemicals and environmental pressures.
- **Nutrient and water efficiency:** agri-biotechnology can help develop crops that use nutrients and water more efficiently, reducing the amount needed and minimising environmental impacts.

The combination of environmentally friendly crop protection and agri-biotechnology opens up new dimensions in sustainable greenhouse production. These approaches allow effective control of pests and pathogens while minimising environmental pressures and supporting biodiversity. In future agriculture, these solutions are essential to ensure the sustainability and stability of global food production.

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CHAPTER 3

INNOVATIVE TEACHING METHODS

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1. Introduction

The aim of the module is to present innovative teaching methods of the 21st century, and among them, especially the project method, which is particularly recommended both in vocational education and higher education. In vocational training, the project method is excellent because it allows students to translate learned theoretical knowledge into practical projects and apply it in real-life situations, solving real-life problems. In the curriculum, we will demonstrate through practical examples that in addition to developing professional competences (expertise, professional skills, professional confidence), the project method also promotes the development of so-called transversal skills of the 21st century.

2. Innovative teaching methods in the 21st century

In a traditional classroom, the teacher stands in front of the class on the pulpit and explains, and the lesson is predominantly one-sided communication, the teacher speaks, the students listen and, in the best case, listen. Feedback is minimal.

"I think it's an exaggeration, but there's a lot truth in saying, that when you go to school, the trauma is that you must stop learning and you must now accept being taught." Seymour Papert 2000, *http://www.papert.org/articles/freire/freirePart1.html*

The lecture and explanation takes place, the students listen to it and give an account of the acquired knowledge based on the textbook. The primary goal of learning is a successful exam! Success in the exam remains important, but with the help of active learning and teaching methods, the focus changes. During study, students should not only focus on successful exams, but should not aim for passive acceptance of knowledge. We encourage them to get involved and become active participants in the learning process.

The conditions for the use of active learning methods are laid down in the XIX century. According to reform educators of the XIX century:

- an inclusive and open atmosphere in class that awakens inner curiosity,
- curriculum related to students' previous experiences and lives,
- a community climate conducive to the development of social and democratic behaviour.

Forrás: Shutterstock

There are many pedagogical tools that support active learning, ranging from simple classroom work such as group work to more complex methods such as flipped classrooms. Some of the most well-known and widespread active learning methods include:

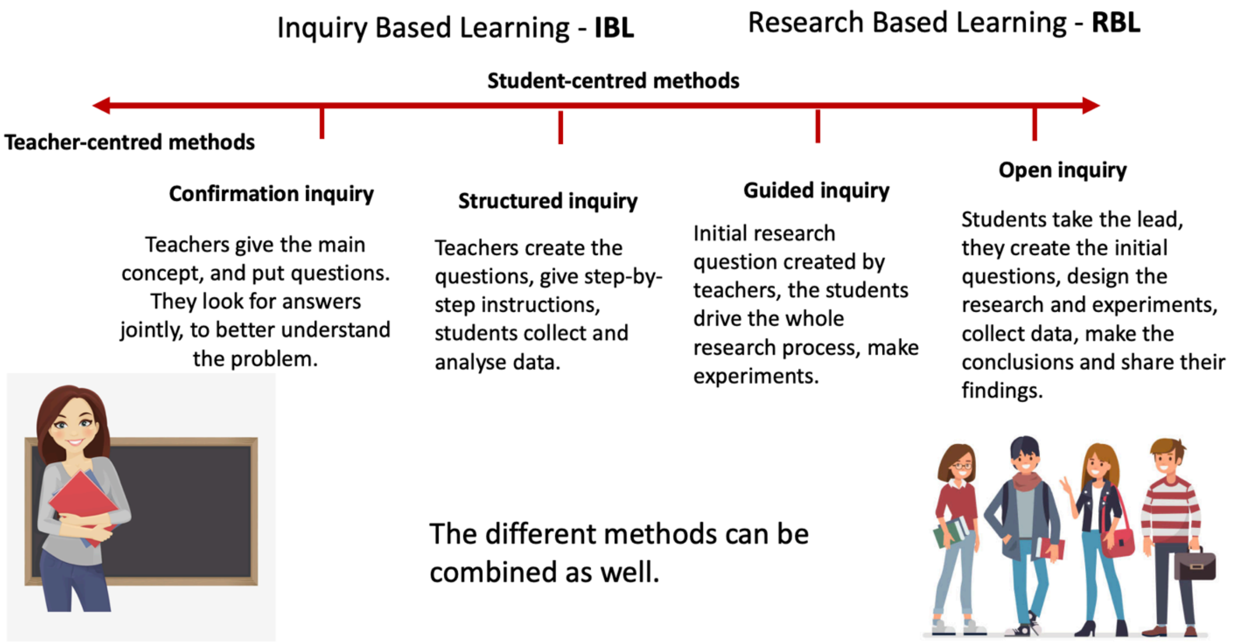
- project-based learning,
- reversed classroom method,
- experiential learning,
- exploratory learning,
- inquiry-based learning.

https://www.youtube.com/watch?v=OOSQFjzsnGY&t=14s

More videos about the flipped classroom method in Flip-IT! YouTube channel!

Students are placed in the center of the learning process, but the responsibilities and tasks of the teacher are not reduced. Stepping out of the usual role of knowledge transferor, taking a bit of a back seat, he occasionally transfers control to students. An active, group-work class requires more preparation than a traditional lecture. The teacher needs to pay attention to several things at once in order to involve students in the processing of the curriculum. Without careful planning, without control and control, the watch can easily descend into chaos.

Is it worth the extra work, the extra investment? While external control decreases, students' autonomy increases and independent work comes with greater responsibility. Students decide on certain issues independently, and they can only blame themselves for mistakes and shortcomings. Through one's own experiences and pitfalls, knowledge will be more deeply entrenched than sitting quietly listening to the teacher's explanation.



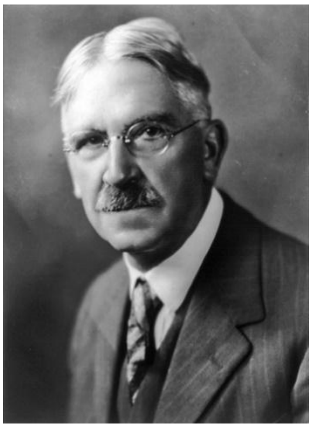
Source: [Digital menu]
The Digital Menu website also describes other active learning methods.

3. Active learning – historical background to the project method

The project method that appeared at the beginning of the nineteenth century was a kind of reaction to the failures of mass education and rigid educational systems created to serve the industrial revolution.

Forrás: Shutterstock

The first comprehensive description of the active learning approach was made by the American philosopher of education [1] John Dewey, who formulated the pedagogical principles of "learning by doing" that are still valid today. According to Dewey, education should relate to students' daily lives and experiences and focus on solving real-world problems.



John Dewey (Wikipedia)

Dewey's student, William Heard Kilpatrick, was the first to use the term "project method" in a practical guide for teachers. According to him, the essence of the method lies in cooperation between students. At the time, there was considerable opposition to the idea that students should not sit back in class. The traditional, strict and authoritarian educational system was not open to the subversive pedagogical principles propagated by Dewey and his colleagues.

The technological explosion and accelerated economic development of the 21st century make the renewal of education unavoidable, and among the methods suitable for pedagogical turnaround, the project method plays a prominent role.

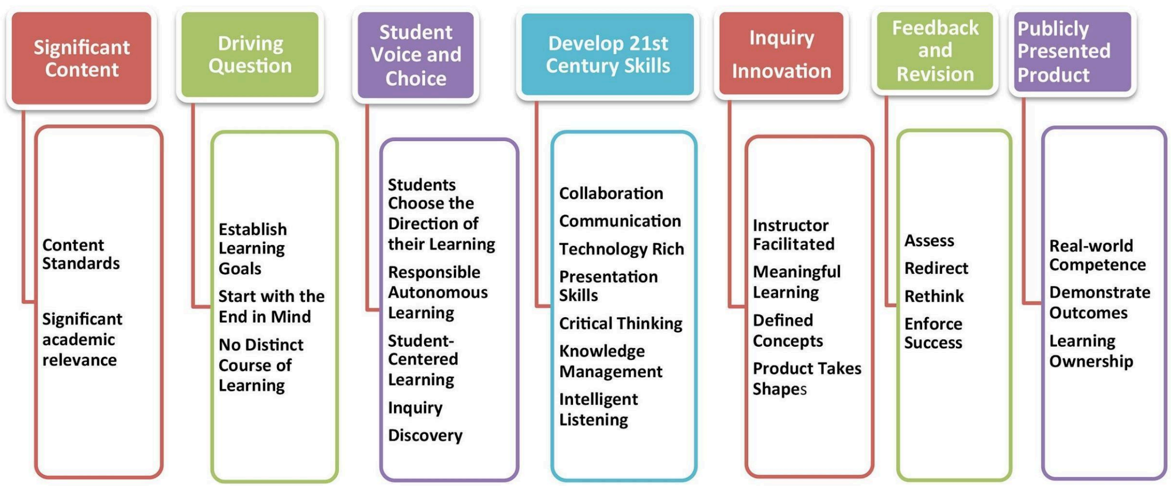
What are the most basic expectations of education in the 21st century?

- Shift the focus from memorizing the curriculum to developing skills (e.g. critical thinking, problem-solving, creativity, highly adaptability, etc.). Knowledge is acquired through the application of knowledge rather than merely engraving facts and figures.
- Leverage digital tools, online resources, and technology in classrooms to improve learning experiences. Preparing students for the digital world, improving their digital literacy and developing their competences through the use of educational software, interactive learning modules and platforms supporting distance learning.
- Tailor education to students' individual learning styles, needs, and pace. Adaptive learning technologies, flexible curricula, and differentiated educational strategies to ensure that all students can learn effectively.
- Preparing students to thrive in an increasingly interconnected world, collaborate with others, integrate a global perspective, encourage language learning in curricula.

[1] John Dewey (1859–1952) was a decisive thinker of his era, American philosopher of education, psychologist, and reform educator. He famously said, "Education does not prepare you for life, education is life."

- Incorporating sustainability into curricula in order to enable students to become familiar with environmental challenges, the principles of sustainable living, and consciously strive to preserve the environment.
- Accepting learning as a way of life, a lifelong process beyond formal schooling. Adult education, continuing vocational training, online learning platforms, adapted to the changing needs of the workforce.
- Moving away from traditional standardized testing towards more diverse forms of assessment that can accurately measure students' skills and knowledge. This may include portfolio evaluations, peer reviews, and real-world problem-solving tasks.

The project method offers a number of opportunities that help the school meet the expectations of education in the 21st century. This is supported by the diagram summarizing the most important characteristics of the project method.



Source: Center for Project Based Learning, Sam Houston State University, USA
http://www.shsu.edu/centers/project-based-learning/images/PBL-Essential-Elements-Revised20130802.jpg

- **Learning content:** knowledge adapted to the curriculum, scientific sophistication. Teachers start the project with an action that piques students' interest and encourages them to ask questions. The action can be playing a video, talking, guest speaker, field trip, laboratory experience, etc.
- **Lead question:** After discussion and brainstorming, students formulate a central question that defines the purpose of the project. The question should be provocative, open, complex and related to the curriculum and the expected learning outcomes.
- **The "voice of the students",** their choice: students are interested in challenging tasks of their choice. The results of projects (e.g. project report, digital and oral presentations, visual demonstrations) are designed by students.
- **21st century skills:** collaboration is central to the project method. The project should provide students with the opportunity to develop valuable 21st century skills such as collaboration, communication, critical thinking and the use of digital tools to help them in later jobs and life.
- Interest and innovation: brainstorming helps students generate new ideas and questions.
- **Feedback and review:** as students develop their ideas and products, teams see, evaluate and criticize each other's work and review it. The teacher checks notes, sketches and plans and monitors progress.
- Publicly presented product: teams of learners present their results, conclusions and solutions to audiences such as peers, parents, representatives of community, business, government organizations, and professionals from various industries.

The project method helps students connect the knowledge acquired in different subjects and put them into practice. It promotes active learning, connects the curriculum with real-life problems, encourages cooperation, develops critical thinking and communication skills in debates, solving tasks and problems together. It is customary to say that the 21st century is the century of projects, the project approach is present in all segments of economic life, which makes the application of the project method especially topical today.

In the following chapters, starting from the basic concepts of projects in economic life, we will get to pedagogical projects in order to get closer to labour market expectations by incorporating the methods of business projects.

4. Basic concepts of business projects

Firms and enterprises can only remain competitive in a dynamically changing economic environment if they are able to respond to market needs with innovative developments at the appropriate speed. Individual and one-off developments require a completely different attitude and working method from the management and employees than the usual daily routine tasks.

A project is a non-recurring sequence of tasks that are limited to a specific time interval. It is a series of goal-oriented, coordinated and controlled activities, framed by deadline, cost and resources.

In tractor production, the production of parts and their assembly take place in well-defined work stages, the workflow belongs to everyday operational tasks. In contrast, developing, designing and bringing to market a new model of tractor is a project task that requires one-off work processes that differ from normal daily tasks.

The operational tasks serve the smooth operation, while the project is a unique innovation, it means getting out of the usual daily work tasks, which always involves risks.

The number of people involved in project design and development is determined by the size of the project: selecting project team members and building an organization is one of the most important steps in starting a project.

The peculiarity of the projects is the so-called "triple bondage", which is symbolized by the project triangle known from the literature.

Project triangle (Farkas et al., 2012, p. 7)

The components of triple bondage are:

- objectives and intended results,
- the time available, and

- resources (asset, money, labor, etc.).

The three components are closely linked: if one changes, at least one of the other two must change, or if not, the **quality** of the intended results will suffer. Some examples include:

- if it is necessary to work with fewer employees than planned, then it will take longer,
- if the deadline is shortened, costs are likely to increase,
- if the financial envelope is reduced, the achievement of the objectives will be jeopardised,
- If the deadline is brought forward, the planned quality cannot be guaranteed unless another resource (such as the financial envelope) is increased.

Project stakeholders

Project stakeholders are people who have some interest in the results of the project, are affected in some way by the success or failure of the project. Detailed planning is always preceded by identifying stakeholders: who will use the results directly, who can be hoped for support, or who may have an interest in creating obstacles to development.

Among stakeholders, the target group **and the** project promoter **play a particularly important role**. The target group includes people and social groups who will directly use the results of the project. They are the ones who must be involved in monitoring and evaluating results throughout the project period from planning to completion.

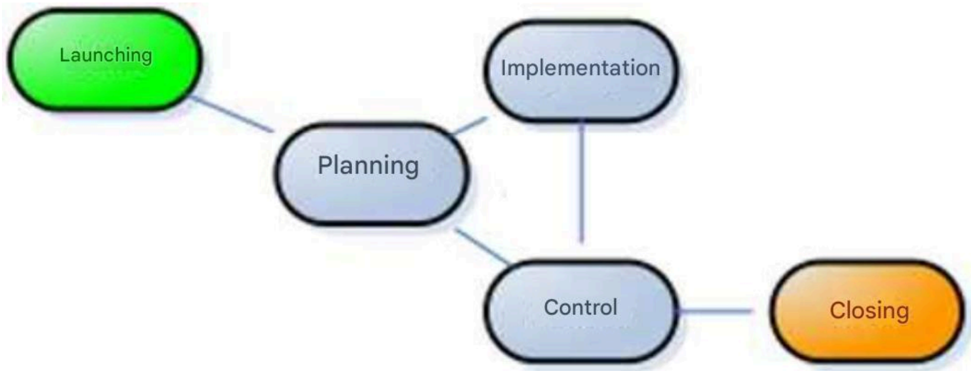
The project promoter is the person or institution that provides resources, tools and money for the implementation of the project. No special justification is needed to explain how important it is for the project promoter to be informed about all events and problems taking place during implementation.

Depending on the size, the project involves one or more **teams under the direction of** the **project manager or management team**. Management and control are the tasks of management, success is largely determined by the competence of project managers. The success of a project requires a team that combines a wide range of expertise, abilities and skills. Success depends on the quality of cooperation, division of labor, internal and external communication, continuous monitoring, evaluation and feedback, and the ability to "redesign" quickly, flexibly and expedient when needed.

The project manager or management team coordinates and controls the works, assesses and manages potential risks, and tries to resolve potential problems and conflicts. The quality of the final result depends to a significant extent on the competence of the experts and professionals involved in professional management.

5. Project life cycle

The work phases, i.e. the life cycle of even the most complex project, can be described with the following simple scheme:



Project launching, planning

The life cycle of the project begins with the birth of the idea, the project proposal, from which a realistically feasible work plan must be developed during planning. Before larger projects, a feasibility study is carried out with a situation assessment and needs analysis, justifying in detail that the planned development is really necessary and realistically feasible.

Parts of the project plan

- Brief, comprehensive presentation of project objectives (why, what, to whom, how, what, when)
- Introducing the project team
- Detailed work plan
  - A detailed description of milestones, stages of work, tasks and activities, and planned results.
  - Estimate task durations, schedule tasks, set milestones, and assign resources.
- Financial perspective
- Division of labor, definition of responsibilities.
- Basic rules of cooperation and communication.
- Control procedures and rules, quality assurance plan.
- Risk analysis, risk management plan.

Indicators

The planned results should be described in concrete figures, qualitative and quantitative indicators, so-called **indicators**. For example, if the intended outcome will be a new study, specify the length, format and languages in which it will be produced.

If there is no indicator in the project plan, then there is nothing to measure the results of the project, evaluation becomes meaningless, and it is doubtful whether it is possible to talk about a result at all.

Implementation, implementation

During implementation, it often happens, since the preparation of the detailed project plan, certain internal or external conditions and circumstances have changed. Unexpected internal problems that directly affect goals are inherent in innovations, as external conditions (such as weather) can also hinder progress according to plan. Regular reviews of original plans and modifications as required are inevitable, especially for longer, multi-year projects.

Audit, evaluation, continuous control

During the implementation, the monitoring (control, evaluation) of the works is continuous. All work phases must be supervised and all partial results must be checked, since if the result of a given work phase is not satisfactory, the result of the work based on it is also doubtful. Evaluation and intervention as needed are essential steps in closing milestones.

The cyclical repetition of quality control is described by the PDCA[2] Management Method method. The workflow (do) is followed by the check, when the result of the stage is compared with the one described in the plan based on indicators. If a deviation is detected, intervention must be taken (act), and in case of a larger deviation, the plan must be reviewed and modified before the cycle is restarted.

The PDCA cycle is based on EQAVET (European Quality Assurance for Vocational Education), the framework recommended by the EU for quality management system in vocational education, which you can learn more about in the video below:

Source: What is EQAVET?
https://www.youtube.com/watch?v=wH5BKAEkqgY

Project closure

Project closure is one of the most difficult mainly administrative tasks of management, which includes the following subtasks:

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[2] EQAVET (European Quality Assurance for Vocational Education), the EU's quality assurance framework for vocational education, builds on this cycle. It can be used in the quality management system of the school, in teacher work and in pedagogical planning.

- Final evaluation covering all results and partial results
- Wide presentation of the results achieved.
- Preparation of administrative and financial reports.
- Impact analysis: presentation of the expected impact of project results.
- Demonstration of the long-term sustainability of the results.

The project owner (sponsor) rightly expects that the end result will be perfectly in line with what is described in the plan. In the final evaluation, it is not enough to demonstrate that the numerical indicators have been achieved, but also to demonstrate that the result meets the expectations of the target group and that the project meets the planned quality criteria. The presentation of the results achieved to a wide audience, but primarily to the target group, serves to prepare for the market introduction of a new product or service. For larger, multiannual projects, an analysis of the direct and long-term impact and sustainability of the results should not be neglected, especially when the results address a wider community or social need, but also when the aim was to develop a new product, since sustainability is in the economic interest of the company.

Documentation and communication

The quality of documentation is a fundamental determinant of the success of the project. One of the most important tasks when starting a project is for team members to agree on the means of communication and documentation, on what digital platform they will collaborate. In this case, the management creates a unified template repository that will be used for evaluation and protocols.

6. Projectmethod

Basic concepts

In project-based learning, students are active actors, learning and developing their skills through various projects or real-life problems. A pedagogical project may be related to the creation of a specific product (for example, software), but it can also be the study of a social problem or research on a specific topic.

Project-based learning is a method of learning, teaching and organising learning, in which students learn together with varying degrees of teacher assistance (not only in individual work) and create tangible results and products by applying the methods of planning, organizing and working projects in the general sense, which in most cases serves the interests of a wider community.

6.1 Benefits of the project method

- While participating in projects, students encounter real-world problems that require creative thinking and the development of problem-solving skills to solve. The project method encourages students to think critically, generate new ideas, and find effective solutions to emerging challenges
- Students choose topics on their own and work on the project. Activity has a motivating effect on them, as their personal interests and passions can also appear in the learning process. Active participation helps overcome feelings of boredom and passivity and increases enthusiasm for learning.
- It promotes experiential learning as students acquire knowledge and develop skills through experience. In connection with problems taken from life, they put what they have learned into practice, resulting in deeper understanding and more lasting knowledge.

- The project method promotes cooperation between students. Students need to work together, share ideas and tasks, which develops communication and social skills and prepares them for work in the work environment.
- The project method provides an opportunity to differentiate learning objectives and content according to the individual needs of students. Through the variety of projects, students can choose a topic that suits their own interests and abilities, which increases their motivation to learn.

The project method has proven to be more effective than traditional frontal teaching in developing 21st century skills. The emphasis will be shifted from teaching to learning, the teacher will stay in the background and direct the events, the main role will be taken over by the students, in addition to mastering the curriculum in successful project work, they will be able to:

- formulate critical issues related to the problem together;
- draw up independently a "research" work plan;
- select appropriate means of information and processing;
- produce project products, text summaries in the form of analyses, presentations;
- develop a constructive learning community;
- in collaboration with peers, present their ideas, concepts and ready-made project products;
- evaluate their own and joint products and learning outcomes.

Overall, the project method offers an enjoyable, experiential and creative way of learning that develops students' critical thinking, problem-solving skills, collaboration and communication skills. Interactive and hands-on learning helps students apply information in real-life situations, preparing them for successful and full-fledged adult life.

6.2 Business project vs pedagogical project

Undoubtedly, business and pedagogical projects have many common features, we will see that the difference lies in the details. The project method was a pedagogical innovation at the beginning of the 20th century precisely because it helps to bring schools closer to real life.

Common criteria

- Both are challenging, in the sense that project work means stepping out of daily routine and providing extra work for the organization's staff involved in the project.
- Potential risks cannot be excluded from any of them.
- Both are time-constrained and resource-limited.
- Both have well-defined goals.
- Success requires a team of diverse skills and organised communication.
- The work stages of the life cycle are identical: planning, implementation, evaluation and closure.
- The correct division of labor, planning and scheduling of activities are key issues in both.
- In both, continuous evaluation, feedback (the PDCA cycle is required.
- The intended results shall be described and supported by measurable indicators
- Project stakeholders should be kept informed, especially at launch and closure.

Added value

In addition to common criteria, it is even more important to identify the potential of business projects that add value in improving the quality of learning:

- development of a project approach,

- familiarise yourself with basic project concepts (e.g. resource, stakeholders, target group, life cycle, etc.),
- raising awareness of the importance of planning and preparation,
- identifying roles needed for the success of the project,
- learning project management basics (for example: milestone, deadline, division of labor, indicator, documentation),
- development of transversal skills,
- development of personal competences, behaviour, debate culture, self-knowledge, self-evaluation.

Of the 21st century soft skills that can be developed through experience gained in project tasks, here we will focus on only four skills that are considered to be of paramount importance: critical thinking, collaboration, creativity and communication. 4K is a priority[3]

Critical thinking	Communication
Students examine complex problems and decide for themselves what they want to find solutions to within the given topic. They do research individually or in groups: they collect the necessary information, documents and jointly select authoritative sources. Under the guidance of the teacher, students can express their opinions in discussions and discussions, they need to treat resources critically. They need to learn how to convince others of their own righteousness, and together they must draw conclusions and draw lessons for them.	In the digital age, communication cannot be identified only with face-to-face interactions, communication has become part of "conversation" in virtual space, social networks, e-mail, and messaging on mobile. Communication requires a number of 21st century skills: digital skills are essential, but analytical and evaluative skills are also needed, for example, to be able to filter out spam. Communication skills develop at the end of the project, when the results need to be presented to a wide audience and a convincing presentation must be given.
Creativity	**Collab**
The development of creativity is served by brainstorming, joint design and "production" of concrete project products, design and production of digital content. All this can very rarely be incorporated into ordinary class work. Not all project teammembers can be expected to be equally creative, but each teammember can provide useful ideas for co-planning. It depends on the pedagogical qualities of the teacher how successfully he succeeds in getting students who usually express themselves less often in front of others to "speak".	During the planning and implementation of the project, they understand who has what strengths and weaknesses. They recognize how useful "diversity" is, how useful it is when individual strengths complement each other. In project work, precision is just as important as creativity, technical acumen, high-level digital skills, organizational skills and good communication. Teamwork increases students' sense of responsibility, they learn to appreciate each other's abilities, listen to each other, and respect each other's opinions. Problems arising during the project help to develop conflict tolerance and conflict resolution skills.

[3] English 4C (critical thinking,

6.3 Design of pedagogical projects

Project-based learning undoubtedly benefits students, but it undoubtedly gives teachers considerable extra work compared to preparing for average lessons. The success of the project largely depends on how thorough and detailed the planning was, whether there is help, whether there is a colleague in the teaching staff who is happy to take part in the work, whether there are parents who can be counted on, and whether there are companies in the area where they are open for visits and professional advice.

The birth of the project idea

The first step in planning is the choice of topic. It is up to the teacher (teachers) to decide which of the learning objectives and expected results prescribed according to the curriculum at the end of the given learning phase (semester) is easier to achieve with the project method, which topics are usually difficult for students to master with traditional methods.

In the preparatory phase, it is advisable to discuss the project idea with the school management: do you support the launch of the project? Just like a business project, a pedagogical project means getting out of the usual daily routine, you may need different tools and loosening the strict timetable during the project period. This will not be easy without leadership support.

For consultation, it is advisable to prepare an outline project proposal in writing, for which the Digital Menu website helps, which provides a guide for planning. A form must be filled out, and when ready, it can be saved as a PDF.

Choose a theme

If the proposal gives us the green light from the school administration, we can start the first conversation about the project with the students:

- What within the topic are they really interested in?
- How can the project relate to their individual lives, their future profession?

At this point, we can capture their imagination, whether we can arouse their interest with an "effective" introduction, provocative, controversial statements, introductory questions, all enhanced by spectacular video, pictures and media elements.

Source: Shutterstock

It is advisable to involve students already in this work phase, as they will be really motivated if they can feel that the planned outcome and topic of the project is their own. Within the given topic, we can raise several specific topics, but the main thing is that the final decision is made together with the students.

It is also a common task to formulate some problems within the topic that need to be answered in the project.

EXAMPLE of choosing a topic

The class participates in farmer training, the students prepare for vegetable growers. In grade 11, the number of lessons in the Crop Production subject is 200, and within this the class is on the topic "organization of crop production work, precision farming".

Precision farming is a modern topic, students are interested in it, as they hear the news daily that more and more new technological solutions are being used on farms.

Among the expected learning outcomes, the students liked the topic "lighting methods for growing vegetables in greenhouses" the most, and it was decided that they would learn this in the framework of a project.

Questions have been formulated along which the topic will be addressed:

What are the water requirements for peppers grown in a greenhouse? How is this different from peppers grown outdoors?

What precision solutions and technologies are available to supply the water needs of greenhouse plants? Which solution costs how much, what are its advantages and disadvantages?

Which of the latter is already used by surrounding farmers?

Practical ideas

It is in our common interest to take the next step only if the enthusiasm of the management, students and teaching colleagues is visible and perceptible. It's not too late to withdraw or postpone the project until later!

A good project answers a real problem, and identifying a problem begins with asking good questions. To make a decision, organize an experiment with the students: can they formulate real-life questions and problems together on the given topic? This will tell you whether the best way to find a solution is to use the project's working methods.

For the experiment, form groups.

1. Have each group write down a few questions about the topic.
2. Analyze and improve questions. If someone wrote a statement instead of a question, rephrase it into a question and open questions into open questions. Number the corrected questions so that the questions you think are best come first.
3. Each group should present its own questions and vote to choose the best ones.

Digital tools for brainstorming

For brainstorming, consider using a digital tool (for example, the LinoIt, which can also be used from phones and tablets).

By the end of the experiment, it will be clear whether the motivation is real, whether we managed to arouse the students' curiosity. At this point, decide with the class whether to start the project.

In case of a positive decision, detailed planning can begin according to the work stages of the life cycle.

Pedagogical design

After choosing a topic, one of the most difficult tasks of preparing project-based learning follows: you need to prepare an outline pedagogical plan in accordance with the framework curriculum and training program. The target (expected) learning outcomes by the end of the project should be described, what knowledge students will learn and what skills will develop during the project work, according to the requirements of the Hungarian Qualifications Framework (see in the Annexes).

EXAMPLE: Planned learning outcomes	
Knowledge	It summarizes the known information about the water requirements and irrigation of green peppers. It lists precision irrigation technologies used in greenhouse cultivation, presents their advantages and disadvantages. It shows what farmers in the area are using and why.
Skills	**Professional skills:** presents the physiological peculiarities of peppers grown in greenhouses, their water requirements. In the field, it identifies the components of precision irrigation technology, lists automatic adjustment options. **Project management**: lists the stages of the project lifecycle, formulates the basic concepts related to the project (product, deadline, documentation, etc.). **Transversal skills**: collaboration, communication, creativity, critical thinking. Digital sills: Data collection on the Internet. Collaborate in your chosen digital environment, share text and multimedia content. Making a presentation.
Attitudes:	Motivated to learn in project work.
Responsibility and autonomy	She works in groups, under the guidance of teachers, and performs her individual tasks independently.

6.4 Plan your project

We have reached the most important step of project-based learning, the detailed planning of the project. Two plans need to be developed. One of them is the actual **project plan**, which is compiled by the students with teacher support. A project plan, like a business project plan, includes milestones, tasks, deadlines, and responsibilities.

The other is the **pedagogical plan of the project**, which is drawn up by the teachers, but the details are also shared with the students: what you need to know by the end of the project, who will evaluate the results and how, etc. The pedagogical plan links the activities to the learning objectives set. Going point by point, it describes what new knowledge is acquired by carrying out each activity, what skills it develops, and how assessment is carried out.

The scope of both documents is determined by the duration of the planned project. For a smaller project designed to last a few hours, the two can be combined.

Project plan

A detailed work plan (milestones, stages of work, activities, schedule, etc.), tasks for project teams must be developed independently by students, but the help of teachers is also indispensable here. When working with 16-18 year olds, you can discuss business project knowledge with them: what it means to divide responsibilities, why continuous communication is important, how and how to check and evaluate results based on indicators.

Let's start with the end!

It is advisable to start planning from the final result by creating a list of products and results in a table that students will "put on the table" at the end of the project, and we can present them to the internal and external stakeholders of the project.

Results, products, indicators

For example, if the project is about IT students developing an application, the result will be a specific product, the software that works. If the chef learning teams in the project use a basket of raw materials to make a multi-course lunch, the product will be the lunch served. If the gardening students bring the grown vegetables to market at the end of a multi-month project, the product can be a basket of carrots, but the result will also include income.

These are possible, tangible products of project-based learning. During the implementation of the project, other types of results can also be obtained, documents, research summaries, presentations. To help you get an overview of all this, a table like this:

Name of the product, result	Description	Responsible person	Form	Indicators (pages, s etc.)	Performs the evaluation
Precision farming	A summary of the research findings produced by the project teams.	Team A Team B	Word document	min. 3 pages	peer review

The tabular overview has two advantages: on the one hand, it makes clear what the commitment is and what needs to be fulfilled, and on the other hand, basic concepts such as indicator and evaluation already come up here . Based on the table, the objectives set at the beginning of the project can be compared with the results achieved at the end of the project.

Gantt chart

One of the most difficult tasks of teaching work is to support students' independence to the fullest: to "refine" their ideas and suggestions until they are in line with the expected learning outcomes. While the essence of the project method is the independent work of students, it cannot be overemphasized that management and fine-tuning fall to teachers at all times. In this spirit, the Gantt chart should be developed together with the students, i.e. a detailed schedule of the students' project with a specific list of tasks, milestones and deadlines.

Project title: XXXXX												
Duration: xx weeks (day.month.year. – day.month.year)	1	2	3	4	5	6	7	8	9	10	11	12
Management tasks												
Project kickoff meeting												
Team meetings												
Activities												
Activity 1												

You can even create a Gantt chart using a spreadsheet program, such as Google Sheets.

Detailed pedagogical plan

In fact, pedagogical planning started with the choice of topic, as many issues (such as whether the project involves more than one subject) had to be decided even before defining specific goals. However, a detailed pedagogical plan can be developed only on the basis of a list of planned activities.

The pedagogical plan is nothing more than supplementing the list of activities given in the Gantt chart with learning outcomes linked to the activities: what new knowledge students will acquire by completing the given activity, what skills will be developed during the work, and how we will check and evaluate whether we have achieved the set learning goals.

In addition to curricular learning outcomes, the pedagogical plan should also cover the project management knowledge and skills acquired during the work, which were tabulated during the analysis of design aspects.

Activity				
Activity Description:				
	Knowledge, knowledge	Skill	Attitudes	Responsibility and autonomy
Professional learning outcomes				
Project management, learning outcomes				
Digital skills:				
Forms of work, methods, tools				
Check, evaluate, feedback				
During project work (professional, project, digital, or one of these)				
When the task is completed (professional, project, digital, or one of these)				

The lion's share of pedagogical planning is the responsibility of teachers, but in order for students to take responsibility for their own work, they also need to know exactly what they have to account for at the end of each activity.

Description of learning outcomes according to European and national qualifications frameworks

In the interest of transparency of qualifications, the European Council developed the European Qualifications Framework (EQF[4]), which provides uniform terminology for a clear and transparent description of learning outcomes in training. The current version was published in 2017. Based on the description of the standardised trainings, professions and diplomas acquired in different EU Member States can be compared.

Embed!

Hungarian: https://www.youtube.com/watch?v=clTl6rYtD2g

[4] English: European Qualification Framework (EQF)

The EQF aims to:

- **Facilitate comparability and recognition** for employers and educational establishments in different European countries.
- **Increase mobility of learners and workers in Europe**
  for individuals when looking for work or further training in another European country.
- **Promote and encourage lifelong learning** by consolidating descriptions of qualifications obtained in different forms of learning (formal, non-formal or informal).
- **Support quality assurance of education and training systems**
  by consistently describing the level of qualifications and learning outcomes.

The EQF is available in all European languages at European Union legislation public website. Language versions of the act repealing the 2008 version Council recommendation of 22 May 2017 document. Based on the EQF, each Member State develops a national framework adapted to its education system, which is introduced after EU approval.

The EQF is a framework for describing learning outcomes for eight levels of qualifications, from primary school to PhD[5].

Learning outcomes: statements defined in terms *of knowledge, skills, responsibility and autonomy* about what learners know, understand and are able to do at the end of a learning process.

According to the EQF Recommendation, learning outcomes should be described according to the following characteristics, also known as descriptors:

- Knowledge
- Skills
- Responsibility and autonomy

Knowledge:	the result of mastering information through learning. Knowledge is a set of facts, principles, theories and practices related to a field of work or study. The EQF describes knowledge in theoretical and/or factual terms. (In Bloom's cognitive taxonomy: memory, understanding, analysis)
Skills:	the ability to apply knowledge and use know-how to complete tasks and solve problems. The EQF describes skills in cognitive (use of logical, intuitive and creative thinking) and practical (manual dexterity and use of methods, materials, tools and instruments). (In Bloom's taxonomy: cognitive field: application, evaluation, creation, psychomotor field:)
Responsibility and autonomy:	the ability of the learner to apply knowledge and skills autonomously and responsibly.

[5] Annex 1 of the document contains the terms used in the Recommendation and Annex 2 describes the eight levels.

In the Hungarian framework (MKKRin)[6] applied to the three EQF characteristics: (knowledge, skills, autonomy and responsibility) is complemented by the characteristic "attitudes" (knowledge, skills, attitudes, autonomy and responsibility).

In the table of the Hungarian framework, "attitude" contains the goals of developing an attitude to learning, work, peers and one's own actions.

Let's look at an example of describing training and output requirements:

- Name of sector: Agriculture and forestry
- Profession title: Gardener
- European Qualifications Framework level: 4

Knowledge	Skills, abilities	Expected behaviors and attitudes	Degree of autonomy and responsibility
It lists meteorological measuring instruments and explains how they work.	It observes Hungary climatic features.	It strives for accurate readings of meteorological data.	It interprets meteorological data independently.

The formulation of learning outcomes usually begins with this introduction: "By the end of the learning phase, the learner will be able to ... ", where the dots are replaced by **a verb meaning action,** for example: explain, list, present, etc. Choose a verb that shows that the result can be evaluated.

Suggested verbs for formulating the expected learning outcomes in the field of knowledge, acquired knowledge:

- Interpret
- group
- compare
- summarize
- deduce
- Supplement
- explain
- identify
- recognize
- recall
- determine.

The wording can be simpler if you omit the beginning of the sentence, because it makes sense that the learning result should be achieved by the end of the lesson, course or project.

Examples:

- Recognizes and names meteorological measuring instruments.

[6] Further reading about MKKR: https://www.magyarkepesites.hu/dokumentumok

- It recites notable dates in the nation's history.
- Groups instructions in the programming language by function.

Incorrect formulations, **non-recommended verbs:** to know, to believe, to understand, to understand, to be aware of something.

These verbs only seem to imply action.

"The student knows the rules of labor protection."

The verb "knows" does not refer to action. The definition needs to be further and more detailed. How deep do you know it? Do you remember it? Can you list and apply the rules? How can learning outcomes be assessed if all we know about them is that they are "familiar" with the subject?

Similarly, there is no indication of action to say:

"The student understands the importance of tillage." It is not clear what this means: can you justify it? Can you list any aspects? Can you explain why it's important?

Suggested verbs for formulating the expected learning outcomes in terms of skills and abilities

Skills and abilities refer to the ability of the learner to apply the knowledge and knowledge acquired. For example, an application can mean that students put together knowledge elements in a new way, create a new shape or product. The app is correlated with students' previous learning experiences, which often requires creativity. This also includes when students design and create, for example while writing, painting, building, etc., combining the acquired knowledge and knowledge elements according to their own ideas.

Suggested verbs:

- carry out
- realize
- check
- appreciate
- plan
- prepare
- develop
- produce
- create,
- compile
- compile,
- systematize, etc.
- perform.

Examples

- He draws up a landscaping plan, carries out the necessary soil work. He prepares the plants and creates a garden according to the plan.
- In the learned programming language, he writes a program that implements data management (data entry, modification, search, listing, aggregation).
- It checks the development of plants grown in the greenhouse based on weekly measurement reports and makes a forecast for the expected date of harvest.

- Creates a test plan, executes and documents module tests.

But here we can also describe learning objectives aimed at developing transversal skills (critical thinking, communication, collaboration, problem solving, etc.).

Examples:

- He argues convincingly in the debate.
- Collaborate with teammates
- Create an impactful presentation.

Digital skills formulation

Among the learning goals of 21st century education, the development of digital skills occupies a prominent place. The DigComp 2.2 a tool for a common description of your digital skills, the European Commission's Joint Research Centre[7] The latest version of the reference framework published in 2013, released in 2022, with many, many examples to the delight of curriculum developers and curriculum developers. The development of digital skills in learning objectives should be reflected in all qualifications, curricula and lesson plans, regardless of the field, level and form of training.

DigComp 2.2 divides learning outcomes into **5** areas of the framework, with additional topics depending on the area:

1. Information and Data Management (3 topics)
2. Communication and collaboration (6 topics)
3. Digital content creation (4 topics)
4. Security (4 topics)
5. Troubleshooting (4 topics)

It breaks down the areas of competence into themes, defining the four levels of proficiency:

- basic level,
- intermediate level,
- advanced level,
- master level.

Within each level, two more levels are distinguished. **Classification levels are *called* dimensions** in the document:

- Dimension 1: competence area
- Dimension 2: competency element
- Dimension 3: proficiency level (basic level 1.2, intermediate level 3.4, ..., master level 7.8)
- Dimension 4: description according to knowledge, skill and attitude
- Dimension 5: Use cases

Progressing by level, each skill receives several task descriptions, such as:

Dimension 1	Area of competence:	3. Digital content creation

[7] Joint Research Centre https://joint-research-centre.ec.europa.eu/index_en

<table>
<tr><td>Dimension 2</td><td>Competence element:</td><td>3.1 Digital content development (creation and editing of digital content in various formats, self-expression through digital means)</td></tr>
<tr><td>Dimension 3</td><td>Proficiency level</td><td>Intermediate level, including level 3: I can solve problems independently, clearly,</td></tr>
<tr><td colspan="3">● choose methods for producing and editing well-defined, well-defined, familiar content in familiar formats,
● expressing myself by creating well-defined, familiar digital content.</td></tr>
<tr><td>Dimension 4</td><td colspan="2">Examples of knowledge, skill and attitude:</td></tr>
<tr><td>Knowledge:</td><td colspan="2"></td></tr>
<tr><td colspan="3">● You know that digital content is presented in digital form, and there are many types of digital content (e.g. sound, images, text, video, applications) that are stored in different types of file formats.
● Know that AI-based systems can be used to automatically create digital content (e.g. text, news, essay, Facebook post, music, image) using existing digital content as a source. These contents are difficult to distinguish from man-made ones. (MI)
● ...</td></tr>
<tr><td colspan="3">Skill:</td></tr>
<tr><td colspan="3">● Be able to use tools and methods to produce digital content that is easily accessible to anyone (e.g. adding alt text to images, tables and graphs; using informatively labelled document structure appropriate for the purpose, accessible letters, colours and links) in accordance with relevant standards and guidelines (e.g. WCAG 2.1 and EN 301 549). (DH)
● You can choose the right format for digital content taking into account its purpose (for example, saving a document in an editable format, as opposed to a format that cannot be edited but is easy to print).</td></tr>
<tr><td colspan="3">Attitude:</td></tr>
<tr><td colspan="3">● Open to finding alternatives to digital content production.
● Ready to comply with official requirements and guidelines (e.g. WCAG 2.1 and EN 301 549) when testing web pages, digital files, documents, e-mails or other web applications. (DH)</td></tr>
<tr><td>Dimension 4</td><td colspan="2">Application cases</td></tr>
<tr><td>Work:</td><td colspan="2">elaboration of a short training material for colleagues on the application of the new procedure within the organization
● A colleague with advanced digital competence (who I can turn to for help at any time if needed)</td></tr>
<tr><td>Learning:</td><td colspan="2">compilation of a presentation to classmates on a given topic.
With the help of my teacher
● I can make a presentation of my work to my fellow students with digital animation in the video tutorial recommended by my teacher on YouTube
● Using.</td></tr>
</table>

The DigComp 2.2 framework is quite complex at first, but it is not intended as a reading, but rather as a manual, which is worth taking out to develop curricula, plan lessons and projects, and take inspiration from the examples to describe the learning outcomes and goals related to the development of digital skills.

The framework is available for download in an increasing number of European languages, including Hungarian: [Digital Competence Framework-DigComp 2.2.]

6.5 Implementation

If the planning was thorough and detailed enough, the implementation, that is, the planned activities, proceed according to schedule, in order.

The PDCA cycle also accompanies its implementation in pedagogical projects. The cycle is a simple guide for continuous monitoring, evaluation and feedback, covering project products, working methods, and especially how students are progressing towards their target learning outcomes.

In the implementation phase, the teacher's task is continuous observation (monitoring) and evaluation, which provides a basis for timely intervention and correction if something is not done according to plan.

At each stage of the project method, it is advisable to use digital tools – but only if the digital tool is really a "tool" of the project, not an end in itself. The third module contains quite a few ideas for this. When chosen correctly, digital tools facilitate collaboration and individual work, and improve participants' digital competences.

6.6 Evaluation

Evaluation of project-based learning outcomes requires methods that allow measuring student performance, learning outcomes and project success.

The following methods may be proposed to evaluate the outcome of the project methodology.

- The product (result) of the project must be measured and evaluated, which can be diverse: an application, a WEB-sheet, an exhibition, a presentation, a garden (e.g. because of frame construction), etc. If the design was thorough, then quantitative and qualitative indicators were defined in advance for the students' products**, which provide an excellent basis for evaluating the results**. If there is no indicator, then there is nothing to measure the result.
- The professional development of learners (expected learning outcomes, knowledge, skills, competences) should be measured and evaluated at the end of the project, based on a pedagogical plan in which the planned learning objectives (knowledge, skills, attitudes, responsibilities and responsibilities) are accurately described
- We can evaluate input knowledge, skills and competences.
- According to the PDCA cycle, developer evaluation and feedback are continuous during the implementation of the project. The evaluation during implementation should be simpler, quicker, even verbally evaluated and feedback, so that we megtörténhet.is can always see where we are in solving the targeted tasks and the students in development!

Some examples of assessment methods that fit into project-based learning

Project presentation and evaluation

Students can present their project to teachers, fellow students or other interested parties. During the presentation, they can present the project process, the results achieved and reflect on what they have learned and experienced. After the presentations, they can evaluate the effectiveness of the projects and the performance of the students.

Portfolios

Students create their own project portfolio containing their own objectives, achievements, and lessons learned, reflecting on their own learning process and progress.

Project documentation

Students can keep records that document the project process, problems solved, and outcomes achieved. This makes it easier for teachers to keep track of students' work.

Rating boxes

Evaluation rubrics are structured evaluation tools (see some in the annex) to help you make an objective and consistent assessment. The assessment rubrics contain the required skills, knowledge and outcomes and allow students and teachers to accurately assess their performance.

Reflection and self-evaluation

Students should have opportunities for reflection and self-assessment at the end of the project. Assessing their own performance and thinking about the learning process helps students develop personally and motivate them to learn.

Feedback and group evaluation

In the case of group projects, group members can also evaluate each other to judge their contribution to the success of the project. This promotes collaboration and teamwork.

External evaluation

For some projects, external evaluators may be involved, such as professionals or teachers from other schools, who can bring an objective perspective to the evaluation of projects.

The combination and application of the above methods allows a thorough and comprehensive assessment of the results of the project method. The assessment process should support student development and help teachers and students understand outcomes and identify opportunities for further development.

6.7 Challenges in applying the project method

While applying the project method, teachers and students alike can face many challenges. Here is a summary of some common difficulties:

Time requirements

The project method usually has a longer duration than traditional frontal education. Planning, implementing and evaluating projects can be time-consuming for both teachers and students.

Inequality of participation

During group projects, some students may be more actively involved while others are less active. It is important to pay attention to the active participation of all students in projects and to take into account individual differences.

Division of tasks

Students should be given appropriate assignments and roles in project teams. Some students may be overly dominant, while others may take a back seat. A fair distribution of tasks and cooperation between group members is important.

Teacher and student preparedness

To apply the project method, both teachers and students need to be well prepared. Teachers need to be aware of the project method and how to manage it properly, but students also need to be prepared to learn differently from traditional learning.

Finding balance

In the project methodology, a balance between teacher guidance and independent work of students is important. It is important to have control, but it is also important to give students freedom and responsibility in the learning process.

Lack of resources

Projects may require resources, tools, software, a laboratory, and sometimes even financial support. If these are missing, projects can become difficult to implement.

Rating and feedback

Evaluation and feedback are a major challenge in the project methodology. The results of projects should be objectively evaluated and students should be given constructive feedback to support their development.

However, these challenges can be addressed with proper planning, preparation and collaboration between teachers, students and the school community. Due to the advantages of the project method and the deeper learning experiences that students develop, these difficulties are often worth using an effective and valuable teaching method.

6.8 Digital tools in the project method

Today's high school students were born between 2006 and 2010, they are members of the digital generation, they use devices confidently and skillfully, computers and mobile phones have become integrated into their everyday lives. They buy movie tickets with their mobiles, they keep in touch with others on mobile, social networks are their natural living space. They are constantly "turned on", spend most of their free time in virtual communities, and cannot imagine the world without mobile internet and social media.

The strength of active learning methods lies precisely in the fact that they give teachers the opportunity to channel students' advanced digital competences into learning processes.

This new generation of students challenges the majority of teachers. It is no longer a question of whether or not technology should be used in education: the question is which online tools should be used and how.

6.9 Application of project method in vocational education and training

In vocational training, students primarily acquire professional knowledge and skills. The project method offers students the opportunity to use the acquired theoretical knowledge for application and transfer into practical projects. For example, a horticulture student might design and implement a landscaping project applying what they have learned in soil science, botany, and garden design.

The project method helps students gain deeper insight into their chosen profession and their own areas of interest. Students can experience what it's like to work in a profession through real-world projects and assess their own skills and interests. This can contribute to the development of professional self-awareness and the strengthening of career guidance.

Projects can be carried out in groups or even independently, giving students the opportunity to develop social and entrepreneurial skills. During group projects, students should collaborate, sharing ideas and tasks. This develops communication skills, conflict resolution and participation in teamwork.

The project method allows students to gain real and relevant experience. The projects are built on real problems and situations, providing students with hands-on learning experiences. This increases the value and usefulness of learning for students, as they can see how knowledge can be applied in real life.

The project method has clear goals and results that can be measured and evaluated. Evaluating students' project work helps both teachers and students to see their level of professional knowledge and skills. The assessment gives students the opportunity to track their progress and improve based on feedback.

Overall, the project method can be effectively applied in VET and offers many benefits for students and teachers alike. Projects based on real problems help deepen professional knowledge, develop professional self-knowledge and develop social skills. Practical learning experiences contribute to student motivation and increase the relevance of education.

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STUDENT PROJECTS – CASE STUDIES

INTRODUCTION

The target group of the Horticulture 4.0 project is teachers working in agricultural vocational training, while the direct beneficiaries of the project results are students in secondary and tertiary agricultural training, and in the longer term, agricultural enterprises that are looking for employees who are familiar with smart greenhouse technology.

The online training provided an opportunity to involve not only the members of the target group (teachers), but also future farmers – students – and agricultural labour market actors – businesses.

As a final assignment, the participating teachers were commissioned to choose a topic of their choice from the "smart greenhouses" curriculum and to prepare a project plan together with their students, preferably with the involvement of an agricultural company. Teachers thus had the opportunity to test the project method in their own educational practice, in a real-life situation, in cooperation with real partners.

The feedback from the participating teachers and students clearly confirmed that the project method effectively supports active learning. The students not only acquired theoretical knowledge from the world of agricultural digitalization and smart greenhouses, but they could also experience how state-of-the-art technologies work in practice through their own experience. This type of learning is not only knowledge-building, but also extremely valuable from a motivational and career guidance point of view.

Below are some examples of projects implemented by teachers, with a particular focus on learning processes, student involvement and experience gained.

Greenhouse Growing - Szerbia

Project figures

Target group:	Agricultural Technicians Grade 13
Institution and country:	Beszédes József Agricultural and Technical School Center Kanjiža, Serbia
External company involved in the project:	Vocational Secondary School Farm Site
Number of participating students:	12
Teachers:	Berec Ágota
Project duration:	8 weeks
The project work:	20 hours of preparation + 12 lessons of project work

Acknowledgments

We would like to say thanks to the professional management and employees of the school farm for their cooperation. Especially because of the possibility of using tools, equipment, and facilities, which greatly supported the implementation of the project. We are also grateful for providing the growing media and seeds used in the project. Special thanks go to the students who implemented the project for their enthusiastic and responsible participation, as well as to their teacher, Ágota Berec for the professional guidance.

The aim of the project

The aim of the project was to provide students with practical experience in the implementation of lettuce cultivation in different growing media, in a greenhouse environment with a foil tent. The emphasis was on learning about the physical and chemical properties of the growing media and observing the development of plants.

In addition to deepening practical knowledge of horticulture, the aim of the learning process was to develop skills for observation, data collection, responsible work and the creation of an environmentally conscious attitude in crop production.

Preparation

The first step was to form project teams and compile a project plan. The pedagogical plan was developed by the teacher leading the project together with the staff of the educational farm, taking into account the age characteristics of the students, their prior knowledge and the learning goals of the project. The project schedule has already been developed with the involvement of the students, thus encouraging them to actively participate and be independent.

In line with the goals of the project, special attention was paid to introducing the properties of the growing media during the preparatory phase. In the classroom, the students got acquainted with the basics of lettuce cultivation, the physical and chemical characteristics of different media, and their effects on the development of plants. The acquisition of theoretical knowledge was supported by illustrative materials and joint discussions.

After that, the students carried out preliminary measurements and a condition assessment on the environments available in the training farm. They learned to document the parameters important for cultivation (e.g. pH value, electrical conductivity, water holding capacity), and based on the data, they decided together which group would work with which growing medium.

An important element of the preparation phase of the project was the determination of the equipment and material requirements. The students actively participated in the census and preparation of the necessary tools (seeds, trays, measuring instruments, irrigation and nutrient solution devices). During the joint planning, the students' logical thinking and task planning skills developed, and they also gained insight into the organizational processes of greenhouse cultivation.

Implementation

The students carried out all activities under the supervision of the teacher, but independently, so the project served as a real learning situation, in which, in addition to the acquisition of practical knowledge, observation, responsibility and the foundation of a scientific approach played a key role.

At the beginning, the students received theoretical training on different growing media (peat, stone wool, perlite, potting soil), then they prepared the materials and tools necessary for greenhouse cultivation. Subsequently, the parameters (e.g. pH, EC) were documented, and in weeks 4 and 6 of the project, the student teams started sowing lettuce seeds in one of the chosen growing media (peat, stone wool, perlite or potting soil). When selecting the cultivation medium, the groups considered the different physical and chemical properties.

After sowing, each group monitored the development of the lettuce plants regularly and documented the growth processes: they recorded the changes with photos and notes to later evaluation and comparison. This stage played an important role in the development of empirical observation and scientific approach.

The groups watered the plants regularly, considering the water retention capacity of the growing medium and the water needs of the plants. The supply of nutrients was constantly monitored and, if necessary, nutrient solutions were applied so that the lettuce could develop in optimal conditions. Environmental conditions such as temperature and humidity control were also part of the caring tasks, which is especially important when growing plants indoors.

In week 7 – when the lettuces reached the appropriate stage of development and became ripe – the harvest season began, during which each group began to harvest their own grown plants. The date of harvest was determined based on the size of the lettuce, the colour, compactness and general condition of its leaves. In this phase, the efficiency of the individual cultivation methods was analysed and the results were discussed.

Success stories, failures, risks, impact

During the lettuce growing project, the students learned about the use of different growing media – peat, stone wool, perlite and potting soil – and gained practical experience of the steps of sowing, care and harvesting.

The learning outcome of the project lay primarily in the fact that the students learned the basics of crop production through active observation, while also developing their sense of responsibility, problem-solving skills and environmental sensitivity. Group work strengthened the ability to cooperate and promoted the development of a scientific approach.

At the same time, the project also carried technical and pedagogical risks. Inadequate irrigation, nutrient supply or environmental conditions, especially in some sensitive media such as perlite or stone wool, could easily lead to the death of plants. In addition, there was a risk that the motivation of the participants would decrease if they did not experience quick or spectacular results, or if the work was not distributed equally within the group.

The longer-term impacts of the project include raising interest in agriculture and sustainable food production, as well as laying the foundations of practical knowledge for later studies or independent attempts. All this can become useful if we do not value failures as a deterrent example, but as a learning opportunity. Thus, the lettuce growing project provided a valuable experience for the students not only from an agronomic but also from an educational point of view.

During the project, the students improved not only their professional but also their personal skills. They learned to take responsibility for their work, to cooperate with their peers, and to evaluate practical results on a scientific basis.

Conclusions and recommendations

The students learned about the complexity of lettuce cultivation through their practical experience. The comparison of different growing media and the evaluation of their own work helped them to approach crop production in a more thoughtful and environmentally conscious way.

One of the most important pedagogical conclusions is that practical, experiential learning, especially when accompanied by documentation and observation, is effective in developing students' knowledge and engagement. It has also been proven that mistakes and difficulties do not weaken, but rather strengthen the learning process if they are properly evaluated and discussed.

For the implementation of similar projects in the future, it is recommended to plan the preparations more carefully, with a special focus on nutrient supply and irrigation automation.

We have concluded that next time in the preparatory phase of the project, we will create more detailed guides and digital observation sheets together with the students, so that they can monitor the development of the plants even more consciously. The project can be extended to other vegetable species or combined with sustainability or food safety topics, thus offering an even more complex learning opportunity.

Precision Crop Protection - Hungary

Project details

Target group:	Agricultural Mechanical Technicians and Agricultural Technicians Grade 13
Institution and country:	Alföldi ASzC Galamb József Agricultural Technical and Vocational School Makó, Hungary
External company involved in the project:	Alföld Agricultural Sector Training Centre
Number of participating students:	12
Teachers:	Zoltán Horváth, Zsuzsanna Bókáné Bodó, Roland Borka, Richárd Nagy-György
Project duration:	8 weeks
The project work:	16 hours of preparation + 16 lessons of project work

Acknowledgments

We would like to say thanks to all the garden workers of the ASzC Galamb József Agricultural Technical and Vocational School and to the teacher colleagues who managed ad participated in the project for their dedicated work and high-level pedagogical performance. Finally, I would like to thank the staff of the Alföld Agricultural Sectoral Training Center for supporting the project.

Aim of the project

The aim of the project was to present the basics of precision plant protection and the application of digital technologies in the monitoring and control of pests and pathogens, with special regard to the school greenhouse environment for 13th grade graduating technicians. The project focused on environmentally friendly and sustainable plant protection solutions, as well as on the practical application of IT tools (sensors, image processing, artificial intelligence).

Learning Objectives

Learning modern methods of monitoring pests and pathogens: students learned how to use automated sensors and image processing systems for the early identification and localization of pests and diseases in the greenhouse.

Application of the data-based decision method: students understood how to evaluate the data collected (e.g. from sensors, images) to assess the risk of pests and diseases, and how to make informed decisions about control strategies.

Application of precision plant protection techniques: students learned to apply the methods of chemical use and minimization of environmental load with targeted spraying and local control procedures in practice.

Understanding the role of artificial intelligence: students practiced the conscious and expedient application of artificial intelligence to increase the effectiveness of precision crop protection, presenting early detection systems with AI solutions.

Recognizing the importance of environmentally friendly plant protection and agro-biotechnology: students obtained the basics of integrated pest management and biological control (with natural-based pesticides).

Preparation of the project

1. As a first step, the teacher colleagues defined the learning goals and competencies that the students had to acquire during the project (e.g. sensor use, data analysis, environmentally friendly plant protection, application of artificial intelligence, etc.). The teachers presented the students with the goal of the project and the expected results. Their motivation was strengthened by the fact that they were doing their own, tangible work in a real environment.
2. The students examined the current state of the plants in the school greenhouse together, under the guidance of the teacher. Based on the observation, they identified the problems for which precision plant protection can be a solution.
3. Teachers and students compiled the equipment requirements together:
   - sensors (e.g. temperature, humidity, soil moisture meters),
   - cameras and image processing software,
   - environmentally friendly spraying tools (e.g. handheld sprayer, robot),
   - data collection and analysis platforms (e.g. mobile app, web interface).
4. This was followed by the formation of groups of 3-4 people. Each group was given a specific sub-task: for example, setting up a sensor system, recording data, monitoring the health status of plants, developing intervention recommendations.

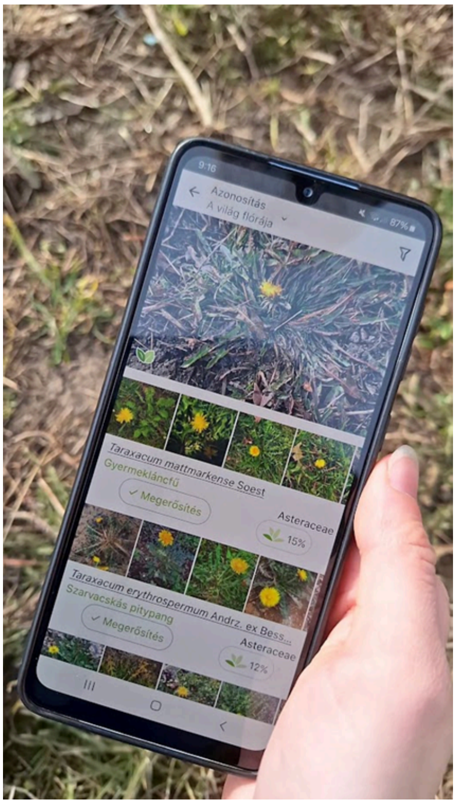
5. Students and teachers created a timetable together that included the distribution of classroom and practical activities over time. This project phase lasted for two weeks, with 3 lessons per week, followed by independent data collection and evaluation periods.

Implementation of the project

The project was integrated into the curriculum on a weekly basis in the school greenhouse, with the active participation of the students, according to the project method. Steps of implementation:

1. Defining tasks and selecting tools

The students formed small groups and decided together which parts of the greenhouse they would observe. Each group selected the tools necessary for the task (e.g. sensors, cameras, digital interfaces), taking into account the aspects learned in class and the condition of the plant stock.



2. Installing sensors and cameras

The selected tools were installed by the students at the designated points of the greenhouse. During the installation, the sensors and cameras were securely fixed, the correct direction was adjusted, and the basic calibration of the devices was carried out to ensure accurate operation.

3. Data collection and digital recording

During the project, the students collected data at regular intervals by measuring temperature, humidity, soil moisture and light conditions, as well as taking pictures of the condition of the plants. The collected data and images were uploaded to a cloud-based system, where they were further analyzed.

4. Image processing and malware detection

The analysis of the digital recordings was carried out under the guidance of the teacher with the help of an image processing software. Students learned to identify the early symptoms of aphids, thrips and other pests, as well as fungal diseases in the pictures.

5. Risk assessment and suggestions

The students analyzed the collected data together and assessed the risks of infections. Based on the risk maps and data analyses, recommendations for the necessary plant protection interventions were developed – taking into account sustainability and environmental aspects.

6. Implement targeted interventions

The groups implemented the plant protection procedures selected based on their own recommendations (e.g. biological control, point spraying) paying attention to the exact dosage, timing and safe implementation.

7. Tracking and evaluating results

At the end of the project, the students collected the data again and evaluated the impact of the interventions. They documented the changes achieved, drew conclusions and presented the results in a short presentation to their classmates and teachers.

Success stories, failures, risks, impact

During the project, the students gained experience about the application of digital technologies in agriculture in real-life situations. The use of sensors, cameras and data collection systems gave them the opportunity to get a deeper insight into the operation of precision crop protection and to apply their theoretical knowledge in practice. They were able to detect and successfully treat minor pest infestations at an early stage, reducing damage and chemical use.

The students experienced the benefits of data-based decision-making: based on the collected sensor data and visual information, they developed their own proposals, which they implemented independently or in groups. During the project, their environmental awareness developed, as they preferred sustainable, environmentally friendly approaches, such as biological control or targeted, point-by-point spraying. In addition, their problem-solving skills, willingness to cooperate and sense of responsibility necessary for practical work have also improved.

However, the implementation was not without challenges. From the very beginning, it was difficult to accurately calibrate automated devices and reliably collect sensor data. Recognizing pests and pathogens, especially in the early stages of infections, required considerable experience and practice. External environmental factors, such as fluctuating temperature and humidity, may also have influenced the measurement results and thus the protection decisions.

There were several risks during the implementation of the project. Possible failures of technical devices, software problems or failure to comply with security rules could compromise the accuracy of data collection and analysis. Inappropriate pesticide use and possible resistance of pathogens and pests were also considered potential threats.

Despite all this, the long-term impact of the project has been outstanding. The students have been enriched with up-to-date theoretical and practical knowledge, which contributes to their future professional success and increases their chances of employment in the modern agricultural sector. The school's greenhouse functioned as a real, living laboratory, where students could experience the use of the latest technologies and had the opportunity to independently research, observe and evaluate. The project has contributed greatly not only to the promotion of digital agricultural solutions, but also to the strengthening of a sustainable approach.

Conclusions and recommendations

Based on the experience of the project, we can conclude that the processing of the topic of precision crop protection with the project method proved to be an effective form of learning. The students not only deepened their knowledge of agricultural digitalisation but also gained real practical experience in the field of data-based decision-making, sensor technology and environmentally friendly crop protection solutions.

The project confirmed that the school greenhouse as a learning space provides an excellent opportunity to demonstrate the use of digital technologies while developing students' independence, observation and problem-solving skills. Group work has facilitated collaborative learning and contributed to the development of students' responsibility and environmental awareness.

As a recommendation, it is worth regularly incorporating similar projects into the VET curriculum, especially where the practical use of digital tools is possible. In future developments, it is advisable to use even more detailed monitoring protocols, digital logs and feedback systems, as well as the introduction of evaluation tools based on artificial intelligence.

Overall, it can be said that the project has significantly contributed not only to the professional development of the students, but also to the digital and sustainability efforts of the educational institution. The experience gained can strengthen the motivation and innovative approach of students in the agricultural career in the long run.

Precision Irrigation – Romania

Project details

Target group:	Horticultural Engineering, Landscape Architecture and Agricultural Engineering Bachelor's (BSc.) third-year university students
Institution and country:	Sapientia Hungarian University of Transylvania, Faculty of Târgu Mureș and Faculty of Sfântu Gheorghe, Romania
External company involved in the project:	Members of the Horticulture 4.0 project grant consortium
Number of participating students:	30 people
Teachers:	László Zsolt Túrós, Katalin Molnár, Béla Biró-Janka, Sándor Papp, Artúr Csorba, Imre-István Nyárádi
Duration of the project (weeks):	1 semester
Project work (number of hours):	56 lessons

Acknowledgments

I would like to thank both the staff involved in the Horticulture 4.0 project and the external colleagues who selflessly contributed to the realization of the project's goals with their knowledge and experience.

Aim of the project

The aim of the project is to raise awareness of the importance of precision irrigation among specialized university students, and to present the theoretical and practical background of its implementation.

At the same time, the project also plays the role of a trial training, at the end of which the curriculum created within the framework of the Horticulture 4.0 project can be perfected based on the feedback formulated.

Learning Objectives

By the end of the project, students will:

- understand the role of water in the functioning of the plant organism;
- they acquire the basic concepts of irrigation theory;
- learn about the benefits of precision nutrient irrigation;
- get to know the components of the precision fertilizing irrigation system and their role;
- they will be able to design and build a precision fertilizing irrigation system;
- they can operate the precision nutrient irrigation system designed and designed by them.

Preparation of the project

- purchase of basic supplies for the irrigation system;
- the acquisition and commissioning of the appropriate meteorological station and specific soil moisture sensor sensors in the area of the university's Experimental and Training Farm;
- acquisition and commissioning of appropriate data loggers and irrigation system controllers;
- selecting and installing the appropriate software backend for the user interfaces, as well as selecting the appropriate mobile devices and checking compatibility issues;
- the creation of the necessary plant stands in greenhouse and field conditions.

Implementation of the project

In the main topic, fertilizer precision irrigation, in the spring semester we implemented the project in the framework of the Irrigation Theory subject with a total of 28 hours of lectures + 28 hours of practice. The lectures were carried out in large groups, and the practical sessions were carried out in the form of small group activities. The data sheet of the course and the completed work plan of the project contain the content and pace of the project in detail, and it places the project steps in space and time. Our first task is to present the project in a classroom setting, as well as the basic concepts related to irrigation, fertilization, sensing, control, design and construction. After that, the applicative part of the project will be implemented with the construction and operation of a specific nutrient irrigation system in greenhouse and field conditions.

We perform a complex comparative analysis of conventional and precision irrigation, focusing on the technological efficiency of fertilizing irrigation, the saving of water use, and the time and cost of the process.

Evaluation of the project

During the project, we created small groups that work independently within the framework of the grades, who complete a predetermined and agreed task during the semester. The tasks include regular data collection, mainly regarding the water consumption, time and labor requirements of irrigation. The data collected will be processed and benchmarked at the end of the semester, in the framework of which the following will be highlighted:

- the relationship between the amount of water used and soil moisture and the supply of plant water;
- irrigation requires time and manpower;
- economic analysis of the irrigation process.

Each small group presents its own activities and processed data collection through a written report and a projected presentation. Subsequently, the complex lifting/evaluation of the project's small group activities was carried out together.

Success stories, failures, risks, impact

Through the small group activities, the implementation of the project was largely based on experiential pedagogy through the *learning by doing* method, so it captured the students' attention and ensured their active participation. Due to the low rainfall weather conditions, the irrigation-related project supported the positive effect of precisely executed irrigation both in greenhouse and field conditions.

Through the project, students have acquired lasting knowledge and skills in the subject, which they can use in their everyday professional practice.

Project information

Acronym:	Horticulture 4.0
Title:	Vocational Education for Digital Transformation in Horticulture
Project number:	2021-2-HU01-KA220-VET-000050665
Key action:	Erasmus + KA220-VET
Project Type:	Cooperation partnerships in vocational education and training
Duration:	36 months
Start date:	01-03-2022
End date:	01-03-2025
Target group:	VET teachers and trainers in the agricultural sector
Beneficiaries:	VET students learning for horticultural qualifications (IVET/CVET) VET providers and horticultural enterprises
Partner countries:	Hungary, Romania, Serbia
Project coordinator:	Alföldi ASZC Galamb József Mezőgazdasági Technikum és Szakképző Iskola
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CONTEXT

When people think of agriculture, not computer science, data analytics, networking, automated devices, the Internet of Things (IoT) or robotics are the first things that come to mind, although e-agriculture is already present today.

Farmers have always been aware that yields depend on many factors such as soil quality or climatic conditions. However, until now they have not had the tools with which they can measure, influence, control and optimize these parameters to obtain the most favourable yields.

In the era of digital transformation, horticulture plays a key role in providing fresh and nutritious vegetables and fruits to an ever-growing population. The use of smart technologies in greenhouses reduces uncertainty and increases productivity, which is why automated greenhouses are becoming increasingly popular. The demand for automation and remote control of greenhouses worldwide, in many countries, is growing, but there are few farmers and skilled workers who can use these tools with certainty and professionalism. Unfortunately, vocational training can only respond to current challenges with a delay of several years, not to mention the fact that technological changes are developing continuously and at an exponential pace.

In the project partner countries, teaching materials on greenhouse automation and remote control are still lacking in vocational training, even at higher education level. As this field is quite new, the related technologies and services in many cases do not have an adequate standard system, making it difficult for growers and entrepreneurs to decide which system is worth implementing and using.

RESULTS

The project implementation included five working packages with the results as follows:

1. Identifying and inventorying the digital skills of users operating in smart green houses

- DATABASE OF DIGITAL TECHNOLOGIES IN THE GREENHOUSE

An online database was created including technologies used by smart greenhouses in Europe and in the partner countries.

- DIGITAL COMPETENCE MAP

The Competence Map describes the digital skills necessary for working with new technologies in smart greenhouses.

2. Curriculum on the use of smart greenhouses

- NEEDS ASSESSMENT SURVEY & ANALYSIS

Before developing the learning content and the online course the partners implemented and run an online survey in the partner countries to identify the teachers' level of digital skills, knowledge about green houses, and their use of 21st century innovative teaching methods and finally the availability of teaching materials. The conclusions of the survey were used for next steps of the developments. The curriculum were elaborated in line with the EU directives EQF, NQF, EQAVET, DigComp and DigCompEdu.

3. Development of learning content on smart green houses

Based on the curriculum, the partnership's university lecturers and vocational instructors developed the learning content in three major chapters in four European languages:

4. **IT basics of operating smart greenhouses**
5. **Smart technologies in greenhouses**
6. **Innovative teaching methods**

The first topic discusses the essential IT fundamentals required for operating intelligent greenhouses in a clear and accessible manner. The second topic describes the advanced technologies of smart greenhouses across eight chapters, adapting to the physiological stages of plants, with a practice-oriented approach and a special focus on artificial intelligence solutions. The third topic is a methodological guide for teachers of horticultural subjects who want to teach the latest technologies to their students using innovative methods of the 21st century.

4. E-learning platform and online course for educators teaching horticulture in the partner countries

E-LEARNING PLATFORM

The online courses were implemented in four languages in the multilingual Moodle Learning Management System (LMS). In addition to the learning materials of the three modules, the e-learning interface also contains additional course components in four languages supporting online learning and collaboration, such as learning guides, forums, assignments with templates for submission, knowledge tests and questionnaires evaluating the course, etc.

E-LEARNING COURSE – PILOT TRAININGS

The online course was tested by involving 150 horticultural trainers from the partner countries. The course participants were asked to select a topic and develop with their students (by applying project method) in a collaboration with an external horticultural company they learni in the 3rd module. After the course we selected one project from each country and published the experiences in the handbook for teachers.

5. Smart technologies in green houses – a digital handbook for horticultural trainers

In the final phase of the project, the partnership produced the e-book "Horticulture 4.0 - Intelligent Greenhouse Technologies" in English and in the languages of the partner countries: Hungarian, Romanian and Serbian. In addition to the specialized content, the book includs the experiences of teachers who participated in the pilot online course and tried the digital tools and methods with their students/learners, as well as the recommendations received from the horticultural farms involved in the implementation of the project.

SUSTAINABILITY

The project will result in a flexible, future-oriented digital vocational training programme for horticultural educators in the agricultural sector. The products are widely recyclable in European vocational education and training because, in addition to the knowledge on state-of-the-art technologies used in smart greenhouses, the training themes, methods and e-learning solution are in line with key European education frameworks, including EQF, ECT, EQAVET, DigComp and DigCompEdu..

Key features and multi-purpose applications:

- **Modular learning content and online course:** The online course can be downloaded in four languages with the course material and other course elements (learning guide, assignments, tests, etc.) and can be reused in any other standard Moodle environment.
- **Smart technologies in green houses – Digital Handbook for teachers:** Based on the learning content, a digital teacher's manual was prepared in four languages. The downloadable manual can be a valuable addition to teaching, with knowledge that is not yet included in current textbooks due to rapid technological development.
- **Microlearning resources:** The content can be divided into independently understandable chapters, and continuously released as digital microlearning materials. These are freely

accessible in four languages on professional and educational content-sharing platforms as Open Educational Resources (OERs)

We recommend the results of the project to all those teachers of horticulture subjects in vocational schools, vocational secondary schools and higher education who would like their students to succeed in agricultural workplaces equipped with the latest technology.

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