Support grape producers with digital tools to develop their precision farming approach

Learning materials

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GRAPE PRODIGI

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Table of contents

Module 1 – Project Introduction

Objective of the project

Agriculture and as a partial sector grape-wine production is a critical sector at European Union level, with the creation of the Common Agricultural Policy (CAP) where economic and cultural benefits are well focused. Digitalisation of the agri- food sector is mandatory, to reach a higher level of sustainability with fit-for-purpose skills for farmers. Today's conventional grape production models are based on highly educated and experienced professionals who spend working hours to collect several sets of data for decision making processes such as climate, hand-work processes, machine working progress, vineyard health and plant protection, soil nutrition etc... The coherence of those measurements and treatments combined with the at least 25 years production length of a vineyard as it is a stationary plantation causes an overcritical mass of data which have to be concerned to achieve better economy and higher climate resilience.

1. Figure The logo of the GrapePRODIGI project

One of the objectives of the project is to create a well-developed digital grapevine management portal using GIS based geoinformatics framework complemented by GNSS, remote sensing, microclimate, and precision farming databases, integrated with data from proximal sensors in pilot vineyards. The portal contains education and information content about usage, economic benefits and environmental aspects of agricultural digitalisation from the point of view of grapevine productions. The portal is created in English, Italian and Hungarian language and demonstrating best practices to give easy to implement knowledge for the target group. In addition, the project would give digital tools for grapevine producers to get up-to-date knowledge about vineyard management implementations, data processing and utilization to help decision making processes. By creating educational materials about geoinformatic applications in field management, self-learning opportunities and blended learning roadshows will be developed to give digital knowledge for farmers. Using digital maps for vineyard management help producers to farm more economically, in a sustainable and climate resilient way by optimizing worker shifts, plant protection treatments, nutrition supply, as well as through a map based dataset that will be available for help decision making.

By assessing an easy-to-use information compilation, fundamentals of a geoinformatics and precision farming knowledge center can be funded, which aggregates up-to-date information, demonstrate pilot projects of vineyards digitalization benefits and present best practices for practical learning.

The target groups of the project

Producers often lack fit-for-purpose training opportunities and access to information on how to set-up these innovative farming applications (ex: how to deploy them, how to set up a digital farming system for a certain estate, how to collect and utilize digital data etc.) which stifle the uptake of more sustainable and effective production. More specifically, the GrapePRODIGI project will target EU grape producers lacking knowledge/training to take full advantage of the digital farm management, especially from small and mid-size farms and regional initiatives. The project's consortium will be a balanced cooperation of research and innovation centers, private companies and stakeholders interested in digitalization and precision farming. By their wide network of grapevine producers, local and multinational initiatives, agricultural innovators and leading sectoral stakeholders' numerous actors can be involved in the project.

The primary target group is grapevine and table grape producers in Hungary and Italy especially in historical wine regions where the added value of the final product is high enough to have good market share demanding innovation and digitalization in field management. By the two non-institutional partners of the project, it is ensured to reach higher impact. Beside the primary target group, fruit, vegetable, or crop producers are also targeted as the field management platform is not specialized only to grape growing, but other cultures can be implemented, especially stationary plantations. As alternative users of geoinformatic databases, regional initiatives and farmer communities are also targeted. Assessing the registered digital data at regional level beneficial information can be created for regional strategies, policy makers and governing actors. In line with the identified pillars of the post-2020 CAP draft, the project has identified a unique opportunity to address key challenges of the EU agri-food sector by providing tailored training opportunities to support the producers to get involved in and deploy new sustainable farm management thus allowing a better revenue for producers, give economic benefits and gain climate and environmental resilience.

Introduction of the partners

Eszterházy Károly Catholic University

Eszterházy Károly Catholic University is a state-recognised institution of higher education, which is mainly significant in the North-Eastern region of Hungary but is also known and recognised at national level. The University operates on 2 campuses, in Eger and Jászberény. Approximately 6,500 students are enrolled in the education provided by approximately 350 teaching and research staff. The main activities of the institution are education, scientific research and artistic creation according to the National Higher Education Act 2 (1). The Institute offers bachelor's, master's, diploma, postgraduate and diploma courses in specific fields and at specific levels. It also provides higher education vocational training and doctoral training and awards doctoral degrees. It also provides adult education. It also carries out basic research, applied and experimental research, scientific organisation, technological innovation and other research in support of education.

2. Figure The logo of Eszterházy Károly Catholic University

The Research and Development Centre is a part of the Eszterházy Károly Catholic University, Eger, Hungary. The research centre was established in 2006. Since then, it is a dominant professional institute in the fields of food sciences, food- safety technologies and bioanalytics in Hungary. The Centre for Research and Development (CRD) has relevant experiments in building cognitive knowledge in connection with education, research and dissemination of outcomes. The viticulture and oenological researches in the knowledge centre was strengthened during the last years, defer to the demands of the wine region with optimisation and reorganization the local research potential of the sector. The sub organisations of CRD Agricultural Consulting Center licensing by Oenological Consulting Center give a good opportunity to keep contact and a good relationship with professional viticultural and oenological organisations of the government, trade associations, clusters and individual farmers as well.

Although Eszterházy Károly Catholic University is primarily a higher education institution, we believe it is important to provide lifelong professional development opportunities for our former students and professional partners.

The website of the institute: https://uni-eszterhazy.hu/en

Universita degli studi di Padova

The university is one of Europe’s oldest and most prestigious HEI that aims to provide high quality education, to foster research, to nurture international relations and to promote strong links with the local territory. This project will be carried out at the DAFNAE Dept. which carries out research and teaching activities in the fields of crop and animal production, defense of agricultural crops, agricultural biotechnology and genetic improvement of plants and animals, food technologies, biodiversity, conservation and protection of the environment and sustainable management of the rural territory. DAFNAE mission is to promote the competitiveness of the agri-food sector and the sustainable use of natural resources, through the production and dissemination of knowledge on the management and improvement of plants, animals, soil and microorganisms for obtaining quality food, ensuring the preservation of ecological systems and the enhancement of the cultivated environment and biodiversity.

3. Figure Logo of the DAFNAE

DAFNAE carries out research activities in the field of Precision Viticulture and Digital Farming at the CIRVE research center, the Italian acronym for Interdepartmental Centre for Research in Viticulture and Enology of Padua University. Teaching activity is carried out by DAFNAE at the School of Agricultural Sciences of University of Padova with a B.Sc. in Viticulture and Enology and a M.Sc. in Viticulture, Oenology and Wine Markets associated to the Vinifera EuroMaster. Dr. Franco Meggio has a strong research and teaching experience in linking remote sensing methods to vine physiology to promote precision viticulture approaches through the deployment of remote and proximal sensors. He is teaching responsible for the course:" Monitoring of water and carbon balance in agricultural crops using advanced remote sensing techniques and ground truth" within the 2nd level Master in GIS Science of the University of Padua.

DAFNAE Dept. carries out higher education teaching to university students which range from 20 to 25 years old through B.Sc. and M.Sc. degree courses on Viticulture and Enology but their formation further continues with a doctorate school in Crop Science up to 30 years old on average. At the same time, DAFNAE exert dissemination activities to wine growers, viticultural technicians, agronomic professionals and ordinary citizens and high school students as well, with ages that could range from 15 to 60 years old.

CET Electronics

Development and production of electronic systems and software in the industrial automation sector and in the agricultural sector, with special focus on innovative sensors, computer vision systems, disease forecasting models and robotics applied to precision farming.

4. Figure Logo of CET Electronics

We managed several projects for the development of innovative tools for viticulture, with the role of technical manager and in the outreach of the projects as well. The main ones are: PV-sensing (www.pvsensing.it): development of a new forecasting model for grapevine downy mildew, based on the input of novel sensors for soil moisture and leaf wetness, together with a computer vision system for measuring the canopy growth through image analysis. ROVITIS 4.0 (www.rovitisveneto.it): development of an autonomous spraying robot for the vineyard, for which we developed the control of the robot, a part of the autonomous guide based on stereo cameras and the whole precision spraying apparatus, with variable rate and an automatic mixing and injecting system of the PPPs. IRRIVISION (www.irrivision.it): development of a new model for irrigation based on sensors and computer vision for detecting water stress status of the plants.

Our customers or, in general, the public who usually follows our seminars or demo activities, is characterized mainly by farmers and winegrowers of an age between 30 and 50, with high expertise in winegrowing (as it is typical in the Prosecco region) and already a bit familiar with the use of technology in general, even if not applied to agriculture yet.

EGER Borműhely Association

The implementation of a unified communication and professional marketing activity for the Egri wine region and the further development of a culture of quality wine and grape production, based on scientific principles, overriding quantitative aspects. The association organises events to promote the quality grape and wine production of the Eger region as widely as possible. It promotes the culture of quality wine and grape production among winegrowers and wine and grape producers through the production of professional materials, studies, the organisation of professional events and conferences. It maintains contacts with other organisations pursuing similar objectives.

5. Figure Logo of EGER Borműhely Association

The Association regularly communicates the latest exploitable results - both in terms of scientific research and training in the sector - to its members and to representatives of the Eger wineries who are open to the subject. The Association helps to disseminate the relevant professional results among the Eger wineries by organising professional days, during which theoretical presentations provide the basis for a precise follow-up of practical demonstrations. It is also the BAE's mission to make the Síkhegy, which is also involved in the project, better known to the professional public; the specialised press, sommeliers and wine experts.

The profile of the Eger Borműhely Association is primarily made up of winemakers from Eger. Most of them also involved in viticulture and winemaking. They are partly members of the Wine Workshop, but there is also close cooperation with non-member winemakers in Eger, so we can also count on reaching them. The age of the target group varies widely, with participants aged between 20 and 65. The results developed in the planned project could be of particular benefit to them. Their age range is estimated to be between 30 and 50 years.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

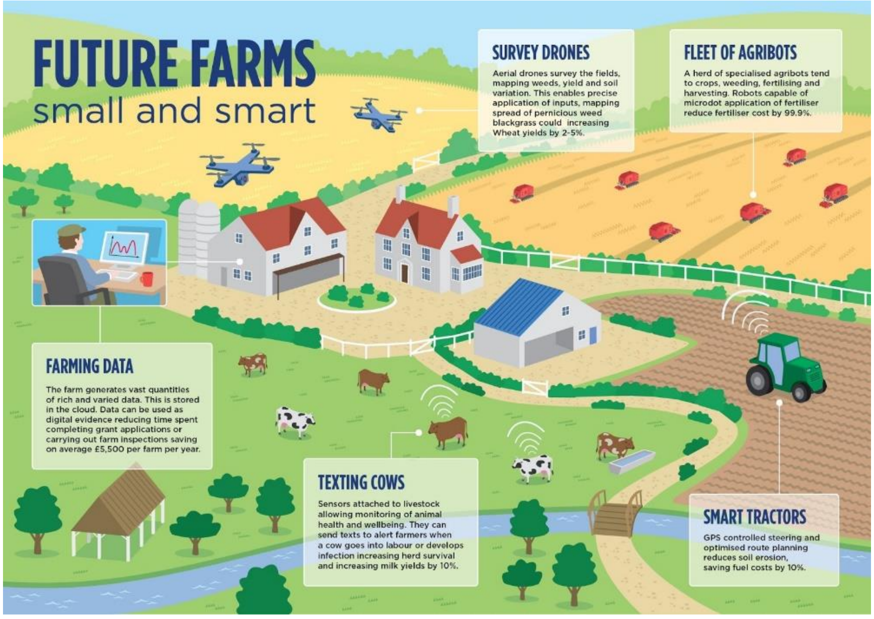
Lesson 2.1: The Digital Transformation Era

The present century is characterized by the development of new technologies from analogue, mechanical, and electronic to digital devices and the spread-off of the Internet. All these contributed to a new socio-economic and business context, the Digital Revolution. This Era started in the 1980s and was recognized as one of the major trends that will reshape societies and the global economy in the future.

Digital transformation uses digital technologies to create new business, culture, and customer experiences to meet the changes in market needs. It is a cultural change that promotes organizations' evolution to act and react to mutating conditions and strategies to evolve and further succeed.

Current trends in digitalization are promoting big changes such as finding new business models, opportunities and making existing ones more efficient and resilient. In other words, digitalization is not only about digitalizing new activities, but also about reshaping current ones thanks to new digital technologies.

Over the last decade, agricultural technologies have seen a dramatic rise in investment. Today's agriculture is looking to the common use of sophisticated technologies such as satellite imagery, GPS technology, robots, and temperature, moisture, and other sensors. All these technologies can revolutionize agriculture and help growers to work more precisely, efficiently, sustainably, and eco-friendly. Digital technologies also have the potential to offer consumers greater transparency throughout the production chain.



Schematic plant of a future precision managed farm

Figure 2.1

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: Goals of digitalization

Sub-Lesson 2.2.1: Introduction

The main idea of Digital Agriculture is "*Producing the more with fewer inputs and preserving higher quality standards*".

This approach allows multiple advantages to enterprises and the environment.

- **The wineries** can optimize resources use, reduce consumption and waste, and boost field productivity. Modern agricultural equipment and new devices embedded with sensors have enabled automatic data collection. All the processes become more profitable since they are managed more quickly and effectively and lead to hourly costs reduction which finally decreases human labour need.
- **The environment** can be preserved thanks to waste reduction, such as fertilizers and herbicides, emissions, and soil compaction with a more rational use of resources. The Internet of Things, cloud computing and machine learning algorithms have provided means for real or real-time data analytics to extract insights relevant for input use optimization and better management of natural resources at farm level.

The vine and wine sector can benefit from these technological advances. Nonetheless, these require great investments in time, money, and new capabilities and this is often the main reason behind its slow uptake. Main objectives of digitalization are the increase of:

- efficiency
- transparency
- productivity
- sustainability

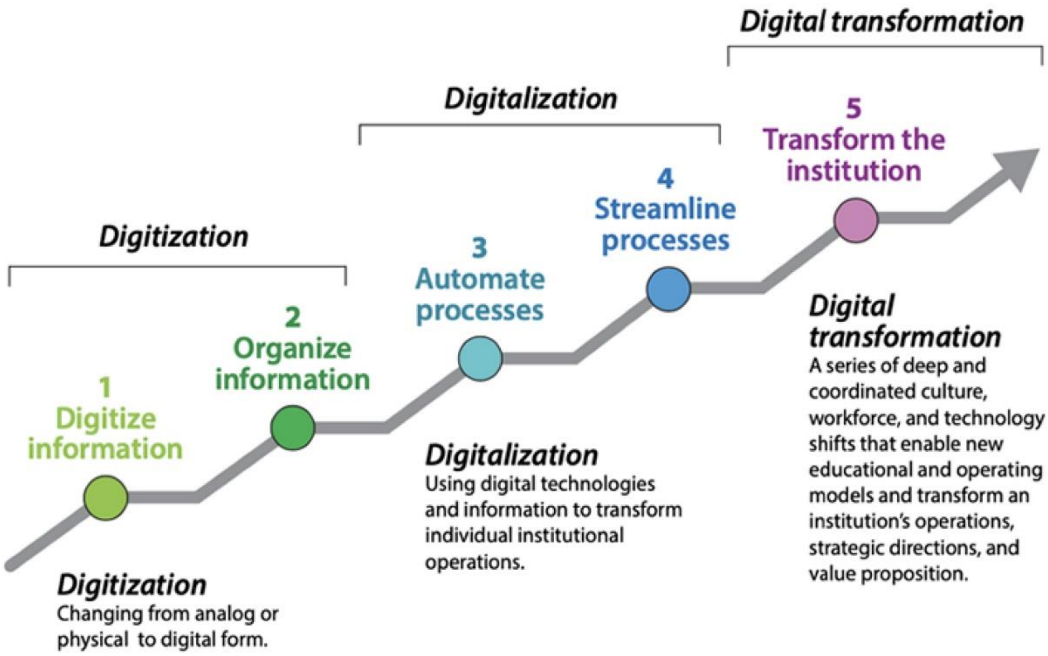


Figure 2.2

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: **Goals of digitalization**

Sub-Lesson 2.2.2: Efficiency

Increased efficiency of the production chain has clear benefits, such as using only the resources that are really needed, reducing the use of pollutants products, as well as improving the enterprise's ability to communicate in a more effective way. So far digitalizing manual processes has become a key issue for the development and survival of small-to-big organizations. Today, **artificial intelligence** and **robotics** may better perform repetitive tasks thus lessening hand labour and favouring employees to more adding-value or responsible activities.

For the vine and wine sector, this concept would allow an improvement at various stages of the productive chain, such as gaining data in the vineyard on the physiological state of the vines and quality of the grapes and better planning and executing the enological practices in the cellar as well as improving storage management.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: **Goals of digitalization**

Sub-Lesson 2.2.3: Productivity

One of the main goals of any productive sector is to increase annual production with the same number of resources and today the achievement of this goal can be strongly favoured by digitalization. Digitalization can provide high capacity to collect data for further exploitation leading growers make better decisions, optimize their operations, and increase productivity, leading to higher profits and a more sustainable agricultural sector. This allows the vine and wine sector to improve productivity in the winery by reducing costs and, thanks to the automatic monitoring using sensors deployed in the vineyard, to make better decisions on deciding if and how much to irrigate, perform most appropriate at the best timing canopy management practices and harvest the grapes at the most appropriate ripening stage for the next winemaking process in the winery.

By automating tasks and optimizing operations, digital technologies can help reduce the physical and mental workload of farmers, leading to better working conditions

Despite the costs of the technologies, the real economic benefits of this type of farming and tools are well established. Greater control over activities leads to optimization of resources and consequently to less wastage of water and fertilizer. All this translates into savings for the wine grower.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: **Goals of digitalization**

Sub-Lesson 2.2.4: Transparency

Transparency is a major concern for enterprises and consumers. In this frame, digitalization can contribute greatly through technologies that improve transparency by making information more accessible to a wider audience. Digitalization can help improve traceability of agricultural products, enabling consumers to make more informed choices.

A constant and precise monitoring of each stage of the production chain can be translated into a higher quality of the end-product, which is undoubtedly beneficial to health. It is estimated that products in a high-tech supply chain retain their properties and are therefore healthier.

One example of increased transparency for consumers in the vine and wine sector is the e-label, which allows a greater inclusion on a QR coder of information on the winery, the territory up to the specific vineyard from which the grapes were produced that traditional labels allow.

Recent years have seen a dramatic increase in the amount of data collected on farms. Agricultural technology providers, high-tech corporations and data companies start to play an increasingly important role in the processes of collecting, storing, processing, and analysing agricultural data. It is estimated that the amount of data generated per day by average farm exceeded 250,000 data points in 2015. A further increase in agricultural data generation is forecast from about 500,000 data points per day in 2020 to more than 2,000,000 data points per day in 2030 (Thompson et. al. 2021).

Potential limitations of digitalization diffusion may include the unclear ownership and residual decision rights to agricultural data and privacy concerns related to the use of both personal and non-personal data collected on farms. Growers may be primarily concerned with potential misuses of any agricultural data collected on their farms. The same datasets that may inform and provide guidance in farming decisions may also be used by agricultural technology providers and data companies to improve their businesses and market position at the expense of farmers and rural communities.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: **Goals of digitalization**

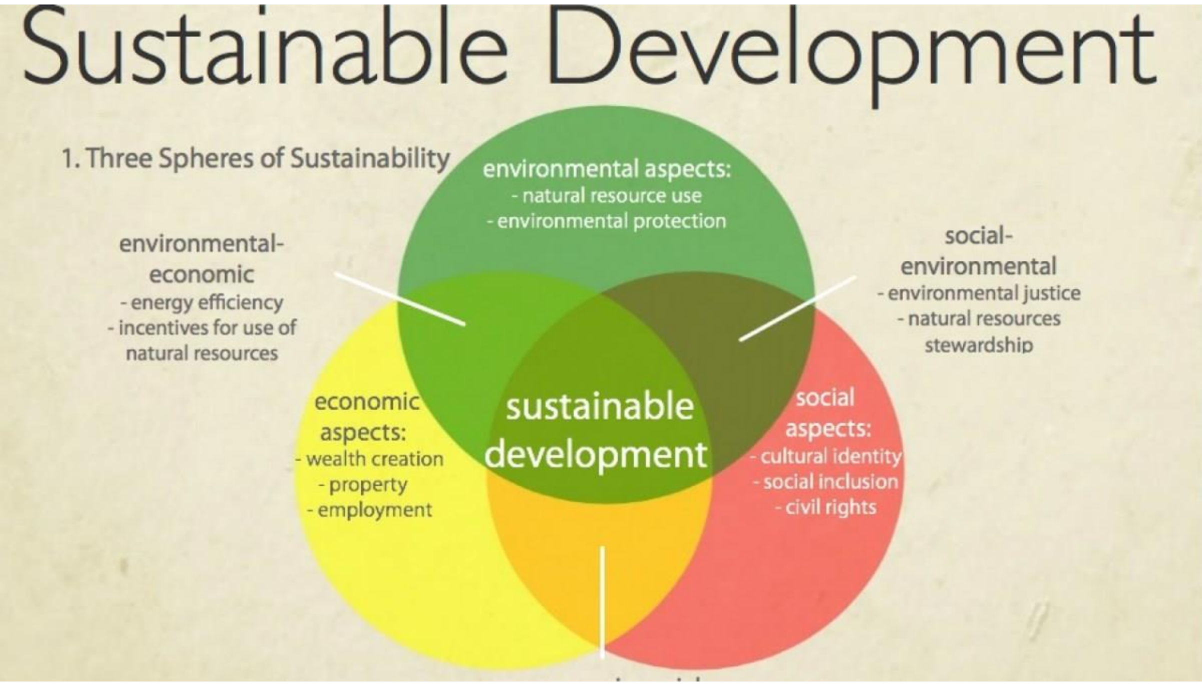
Sub-Lesson 2.2.5: Sustainability

Sustainability is another goal of digitalization to improve the vine and wine sector. Viticulture 4.0 is specifically designed to improve the sustainability of agricultural activity and reduce the environmental impact of the entire productive chain from the vine to wine.

By sustainable agriculture, we mean a type of agriculture that prioritizes respect for natural resources alongside human and economic resources. Sustainable agriculture can ensure the well-being of the actual world's population without harming the future generations that will inherit the world we live in.

Sustainable agriculture is based on an ethical economic model that is binding on all stakeholders and whose principles are to:

- improve working and living conditions for producers. This supports the most disadvantaged through greater development opportunities.
- raise consumer awareness of the mechanisms used for exploitation of land resources.



Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.2: **Goals of digitalization**

Sub-Lesson 2.2.6: Challenges for the sector regarding sustainability

The FAO – Food and Agriculture Organization of the United Nations defined the 5 principles of sustainable agriculture that can help understanding the importance of this change within our society.

1. **Increase productivity, employment and added value in food systems** with the aim of fostering a change in agricultural practices and processes to ensure global food supplies and reduce water and energy consumption.
2. **Protect and enhance natural resources** by promoting environmental conservation and reducing pollution of water sources and destruction of ecosystems.
3. **Improve livelihood and promote inclusive economic growth.**
4. **Improve the resilience of people, communities, and ecosystems** with a view to minimizing the impact of weather events due to climate change or market price variability.
5. **Adapt governance to new challenges** to ensure fairness and transparency at all levels (public and private)

The Circular Economy, an economic model that is regenerative, offers many new opportunities to help wine companies shift their business model towards sustainability applying three clear principles:

- avoid using limited resources and creating waste and other forms of pollution;
- keep products and materials in use for as long as possible and at their maximum possible value;
- and regenerate natural systems.

In the case of the vine and wine sector, the major challenges regarding sustainability are the follow:

- contributing to create economic value in rural areas by fixing population to the territory;
- guaranteeing rights and good conditions for employees in the value chain;
- investing in different forms of sustainable mobility in the distribution process;
- promoting sustainable and efficient production without pesticides and with the minimum use of water;
- promoting regenerative agriculture: improving soil quality and contributing to climate change mitigation;
- guaranteeing health and value in biodiversity and terrestrial ecosystems;
- new forms of sustainable energy as biofuels;
- reducing waste throughout the value chain;
- considering the climate risk and the impact of rising temperatures in the production process;
- maximum use of biological production: winery as a biorefinery;
- product eco-design and marketing model: new packaging formats (reusable, returnable, compostable, recyclable) and new product access formats that promote circularity;
- optimizing the life cycle of facilities, infrastructure, machinery, and equipment;
- water cycle: collection, use and regeneration of water;
- minimizing energy consumption and renewable supply.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.3: Main digital trends in the vine & wine sector

Sub-Lesson 2.3.1: Internet of Things (IoT) /Sensorisation

The Internet of Things (IoT) defines a network of physical objects (things) that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet. In recent years, IoT has become one of the most important technologies of the 21st century. Data collected on farms and aggregated into larger datasets (*big data*) can be further considered as having some public good characteristics. Specifically, the availability of these data can allow informed food production decisions, global food security, the environment, public health, and climate change policies.

At the farm level, monitoring the health status of crops requires a huge effort. Production in fields is hardly heterogeneous mainly due to different quality of soil, the presence of parasites and fungi or irrigation problems, especially when they extend over very large areas. Thus, it is vital to be able to promptly identify these causes, to remedy all and any situations that reduce productivity.

The development of sensor technology offers the possibility to many devices to coexist and work together exchanging information (e.g., soil and water conditions for efficient use of water, irrigation management). Today, the concept of **digital vineyards** refers to new measurement tools based on the collection of a multitude of data by using wireless sensors (eventually combined with satellite or drone images and powered by Artificial Intelligence). Regarding vineyards and wineries, they can be implemented directly in the soil, embedded in vine trunks, or placed among leaves, depending on the data to measure, to help improve productivity, monitor stress conditions and climate prediction.

The IoT applications can be classified according to their place in the value chain:

a. Vineyard

One of the main reasons for using technological solutions in vineyards is to reduce risks during harvesting. Most of the sensors and satellite imagery currently used in vineyards focus on vine quality control and environmental aspects: monitoring soil and water conditions for efficient water use, irrigation management and weather forecasting. It also allows monitoring key parameters such as air temperature, wind speed, relative humidity, leaf wetness, soil moisture and rainfall. There are also many applications thanks to the combination of technologies such as drones and infrared and multispectral images for pest control in the vineyard. For example, many wineries already combine sensor data (humidity, temperature, soil conductivity and vine quality) and satellite imagery to monitor key environmental factors for the harvest in real time. Another application of the Internet of Things is to make the sector more sustainable and regenerative by optimizing water use, eliminating pesticides, and measuring soil quality.

b. Winery and Distribution

The main objective of using sensors in the winery is to monitor most relevant parameters for a correct winemaking process and for quality guarantee. Climate change is fostering inter-seasonal variability. Under this scenario due to changing weather conditions, each year the product, even though it is made in the same way, has certain and even great differences. Sensorisation enables monitoring the winemaking process in real time. Small modifications can be made to achieve a product that is as close as possible to what is desired.
What winemakers are demanding nowadays are sensor-based online systems to carry out the evaluation of the fermentation process without needing laboratory facilities. Sensors can be used in wine cellars to monitor the ageing of wine, including the key factors of temperature, light, and humidity. Temperature is particularly important as even the slightest fluctuations can alter the oxidation of the wine and therefore significantly affect the quality.

In the distribution phase, IoT also has considerable advantages when it comes to improving logistics to boost efficiency and reduce costs. Examples include transport management systems to control and optimize all the company's logistics flows or computer vision solutions to control the incoming flows and in-plant movements of raw material and finished product transporters.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.3: Main digital trends in the vine & wine Sector

Sub-Lesson 2.3.2: Artificial Intelligence

Artificial Intelligence (AI) is a branch of computer science interested on developing smart devices able of performing tasks that typically require human intelligence. AI is an interdisciplinary science with a wide range of applications that make use of machine learning and deep learning techniques. Like human brains, AI learns from experience by using advanced algorithms and software to identify common or repeated patterns or single features contained within large amounts of data. AI is strongly dependent on sensor technology as the information used to identify patterns and make predictions.

Artificial Intelligence (AI) plays a central role in the digital transformation of society and is now a priority. Its future applications are expected to involve major changes, but AI is already used for several tasks on vineyards, in wineries and for distribution.

a. Vineyard

As far as the application of AI in vineyards is concerned, AI software provides valuable insights into quantitative aspects (e.g., size, yield) and other conditions (e.g., physiological, and nutritional status) in vineyards. AI integrates with data received from proximal sensors and satellite imagery enabling winegrowers to improve many aspects involved in vineyard management. For example classifying vineyards according to grape variety (distinguishing the grape variety by observing the characteristics of the leaf, the size, shape and colour of the grape, the type of skin, the taste, etc...); the management and optimization of crops through sensors and images that can provide supporting information to growers for most appropriate decision making to control yield and ripening stage better estimating the optimum time to harvest grapes and guarantee quality.

This technology, if properly merged with other technologies such as sensorisation, can bring many benefits. It can gather, interpret, and learn from collected data, helping farmers to make data-based decisions and predictions.

Complete crop monitoring and management application to optimize production and consumption of resources for wine growing, using various techniques (computer vision, predictive models) and data from various sources for: control of the ripening cycle and harvest planning, pest control, adequacy of actions and minimization of their consumption (irrigation, fertilization) with the following functionalities:

- Crop management: crop sensing for monitoring with machine vision (pest detection, nutrient deficiencies, fruit ripening, etc.) traceability of materials and objects.
- Predictive models: results of actions according to action history and previous context, prediction of harvest date, prediction of pest spread, etc. to make decisions on crop care.
- Dashboard: control interface with graphics and alerts, interactive and fully customizable.
- Data collection: based on IoT (sensor system in the crop).

b. Winery and Distribution

In wineries, AI collects data received from sensors and uses it to improve production chain efficiency. Having real-time control of inventory and barrel conditions allows for optimal production scheduling based on the analysis performed. This can help wineries to maximize their productivity and can contribute to more sustainable production.

In the last stage of the value chain, wine marketers use AI to reach the end customer, changing the way consumers buy wine, understanding product preferences and generating disintermediated direct channels to the end customer that will ultimately benefit productivity.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.3: Main digital trends in the vine & wine Sector

Sub-Lesson 2.3.3: Robotics

A robot is defined as a "*machine controlled by a computer that is used to perform jobs automatically*". Robots can assist humans and/or replicate human actions. In the beginning, they were used to performing single and repeated tasks but have evolved to perform more complicated actions that ease different types of work. All robots have different levels of autonomy, from human-controlled bots that carry out routine tasks that a human has full control over, to fully autonomous bots that perform tasks without any external influences.

In the wine industry, high-tech robots equipped with artificial intelligence can minimize, for example, the impacts of drought, high temperatures and changes in harvest schedules. They are more precise and quicker than any human winegrower is.

When talking about the applications and benefits of robotics in the vine and wine sector, a series of applications can be developed according to its position in the value chain:

Vineyard

Robots can monitor factors such as grape yield, vegetative growth and grape composition in vineyards. By doing this, a prescription map showing the quality of the crop in specific homogeneous zones can be created and, when it comes to increasing yield, preventing disease or controlling excess growth, vines can be pruned, and crop protection products can be further applied efficiently using robotics. To perform these tasks, even *on-the-go*, a 3D image of the plant or row must be computed, allowing machines to move along the vines, pruning and fertilizing.

Just as planting, monitoring, pruning and fertilizing vines can be automated; the task of harvesting grapes can also be carried out by robotics, by shaking the vines and collecting the grapes as they fall from the vine.

Winery & Distribution

In the final stages of the value chain, the use of robots is common in many warehouses, and for some logistics centers, it is necessary to efficiently track inventory within many warehouses in different locations helping to increase the productivity of the distribution stage. Through smart storing—which refers to the automation of warehouses through robotics and AI, and smart shops—the final stage of the wine life cycle is considerably improved. As distribution and commercialization are more efficient due to time savings and automation of operational work making tasks run autonomously due to the integration with artificial intelligence, increased task security, control and optimize all the company's logistics flows, improved inventory control capability, etc.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.3: Main digital trends in the vine & wine Sector

Sub-Lesson 2.3.4: Satellite Imagery

Satellite crop monitoring is a tool that allows farmers to constantly monitor the health of their fields thanks to a multi-spectral imagery analysis of high-resolution satellite images and promptly trigger any alarm.

Images taken by satellites are used for a wide range of purposes such as cartography, geo-positioning, climate change impacts, geographic surveys, etc. In recent years, the use of different satellite imagery for the benefit of the agricultural sector has become increasingly widespread. This has been particularly boosted since the start of the European Union's Copernicus Earth observation project- a project where a series of Sentinel satellites have been launched into space tasked with generating a vast amount of information on growing conditions and plant health used to improve farm efficiency.

This is possible because satellites can detect certain wavelengths of electromagnetic emissions such as visible and near infrared bands to detect problems that cannot be detected by the naked eye. In practice, they can "capture" sunlight reflected by the plants and soil to produce a sort of field imagery, providing information on key aspects such as vegetative development, humidity, and temperature of the soil. Images obtained from these satellites can be displayed with combinations of bands or vegetation indices. The most widespread used is the NDVI (*Normalized Difference Vegetation Index*) which helps to identify plants that are photosynthetically active and therefore healthy. These indices can provide a lot of information about the state of the crops, how ripe the crops are, and what type of crops are being grown on each plot of land.

For producers, having accurate images of the field that are renewed in a short period of time represents a considerable advantage, as it allows them to know the state of their crops, diseases, water stress, or ripeness in real time. When combined with AI and IoT, these technologies can create predictive models or decision supporting systems (DSSs), which farmers can use to predict annual harvests, anticipate extreme weather events, quickly and accurately detect diseases or pests, and learn from the past to forecast or improve harvests.

Module 2 – Economic benefits and environmental aspects of agricultural digitalization

Lesson 2.3: Main digital trends in the vine & wine Sector

Sub-Lesson 2.3.5: LIDAR (Laser Imaging Detection And Ranging)

LiDAR is a non-invasive sensing technology that can be used to map the structure including height, density, and other characteristics of vegetation. This makes it the ideal tool to study the characteristics of a particular area in detail (e.g., terrain, vegetation, obstacles, slope, etc.)

LiDAR is an "active" remote sensing system, which means that the system itself generates energy (light beam) to measure objects on the ground. The system emits light in the form of a rapidly firing laser, which travels to the ground and reflects off objects such as buildings and tree branches. The reflected light energy then returns to the LiDAR sensor where it is recorded.

Where this technology is primarily being used in autonomous vehicles, as it can accurately map the vehicle's surroundings. In the world of vine and wine, this tool can be used in several applications:

- **Map the vineyard** in three dimensions, from the topography of the land to the fruit of each vine. The "*3D cloud points*" that are recorded provide an accurate 3D model of a representation of the vineyard. The light emitted by the technology is reflected on the objects it encounters in its path, returns to the sensor and creates the 3D map.
- **Harvesting Yield Assessment**: since the sensor moves through the vineyard, it analyses the areas where there is more fruit and identifies possible high or low productivity so to calibrate other tools, such as fertilizers, to control or stimulate growth. This way fertilizers and water are used more efficiently.
- **Site Specific Spraying**: to accurately map areas that have the lowest or highest foliage and fruit density. This information can be further used to improve precision in the use of pesticides and reduce pollution and costs for the producers.
- **Reduce accidents in the vineyard**: by having a detailed 3D map of the terrain, the safety of tractors and autonomous vehicles can be improved as the terrain is perfectly mapped with slopes, holes, and other kinds of hazards.

In the future, the main frontier of this technology is expected to be tractor and autonomous vehicle in the vineyards as it becomes more accessible in terms of cost and adaptability (drones and tractors). As autonomous vehicles continue to develop, the demand for LiDAR tools will rise, resulting in an increase in supply and more competitive prices.

Module 3 –Digitalization in Agriculture

Lesson 1: Introduction

Digitalisation is the defining technological transformation of this era, and, as in other sectors, it will have important impacts on agriculture. Digitalisation refers to the adoption of information communication technologies, including the Internet, mobile technologies, and devices, as well as data analytics, to improve the generation, collection, exchange, aggregation, combination, analysis, access, searchability and presentation of digital content, including for the development of services and applications.

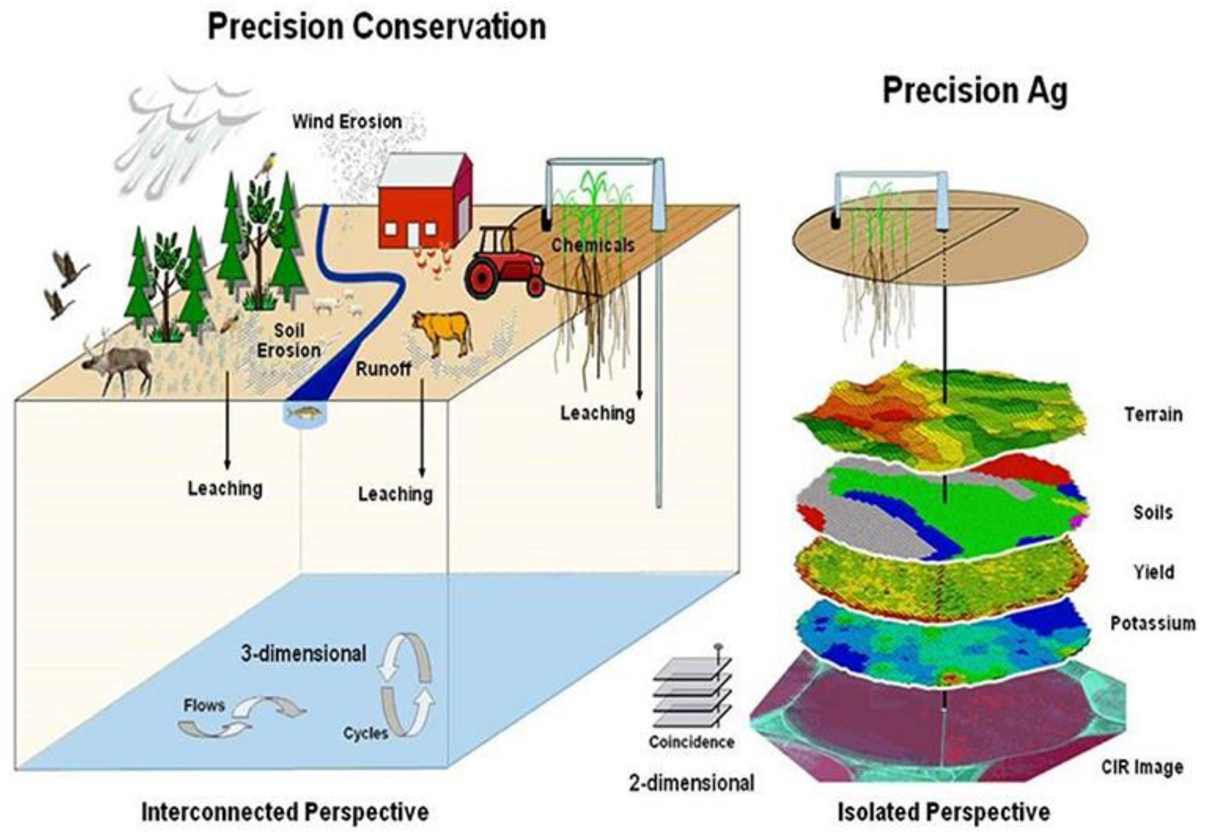
This process holds the potential to bring about a significant change in how agriculture functions, beyond discrete tools, technologies, or practices, and to offer a path for innovation and new ways of organising production and supply chains. In particular, the agricultural sector is seeing a set of transformative trends due to digitalisation, such as a greater focus on precision agriculture and the use of big data to drive production and business efficiencies.

6. Figure Digitalization in agriculture

Public and private actors in agri-food value chains and the wider agricultural innovation system (AIS) could benefit from the digital transformation of agriculture in multiple ways. For farmers, digital technologies and the insights that are generated from agricultural data could support better decision-making on farms, helping to boost innovation and improve agricultural productivity, sustainability, and resilience. Digital technologies could also offer opportunities for new sources of efficiency and value creation upstream and downstream of farms, supporting research and innovation, the creation of new services for the sector, and improved traceability and more efficient transactions in value chains (Jouanjean, 2019). In addition, policymakers could use digital technologies to improve how policies are designed, implemented, and monitored, and design new, better policies for the agriculture sector. Indeed, even if not all agricultural innovation relates to digital technologies, digital technologies can support most other types of innovation.

It is important to evaluate as much data of the filed as possible to get more precise picture of the actual condition of the vegetation.

Overlay *(Figure 7)* is a GIS operation that superimposes multiple data sets (representing different themes) together for the purpose of identifying relationships between them. An overlay creates a composite map by combining the geometry and attributes of the input data sets.



7. Figure The site-specific approach can be expanded to a three- dimensional scale approach that assesses inflows and outflows from fields to watershed and regional scales

The next video shows how digitalization and overlaying maps, assessing information works in agriculture practice.

https://www.youtube.com/watch?v=s7QDPwHiFAU

How Drones are Elevating Intelligence in Agriculture
The video below shows why are drones useful in modern agriculture, and how drones provide data for decision making.
https://www.youtube.com/watch?v=wagjFXb_uz4

Lesson 2: UAV measurements

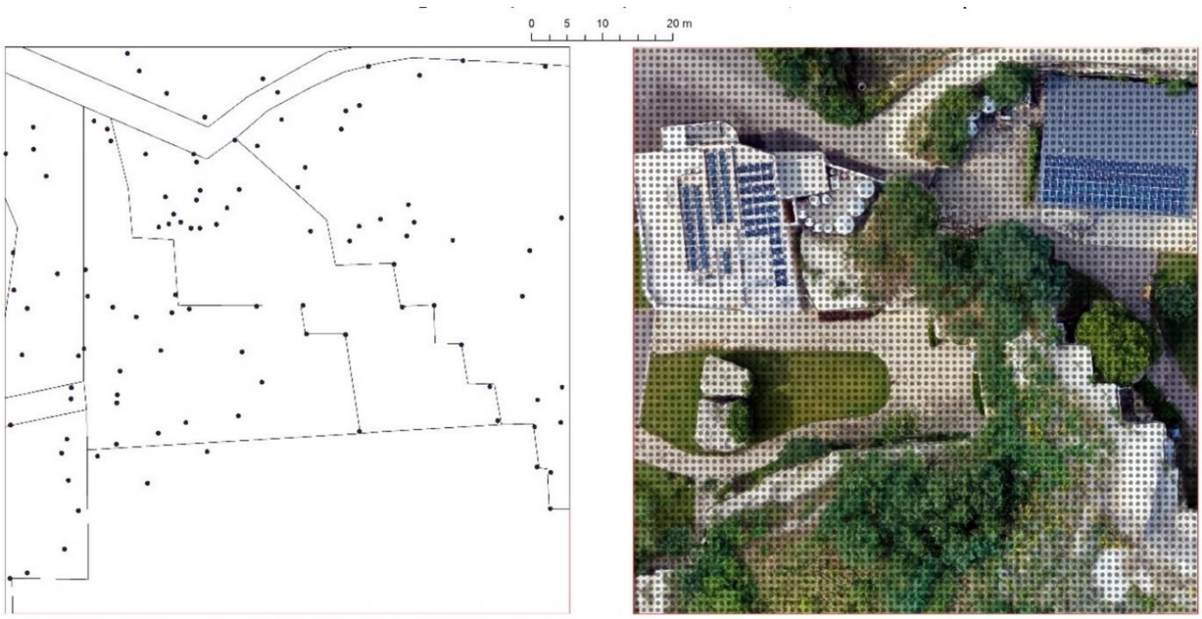
Remote sensing is defined, for our purposes, as the measurement of object properties on the earth's surface using data acquired from aircraft and satellites. It is therefore an attempt to measure something at a distance, rather than in situ. Since we are not in direct contact with the object of interest, we must rely on propagated signals of some sort, for example optical, acoustical, or microwave.

The unmanned aerial vehicle (UAV) sensors and platforms nowadays are being used in almost every application (e.g., agriculture, forestry, mining etc.) that needs observed information from the top views. While they intend to be a general remote sensing (RS) tool, the relevant RS data processing and analysis methods are still largely ad-hoc to applications. The main advantages of UAV data are their high spatial resolution and flexibility in acquisition and sensor integration, there is in general a lack of systematic analysis on how these characteristics alter solutions for typical RS tasks such as land-cover classification, change detection, and thematic mapping.
With the help of aerial photogrammetry, UAV technology is able to measure millions of points from the entire area, so there is no missed part or area to which you may have to go back.

8. Figure unmanned aerial vehicles (UAVs) are regularly used in agriculture for field surveys.

Airborne digital images of vineyards have potential for yielding valuable information for viticulturists and vineyard managers. Different cameras can be used for different measures, for example high resolution cameras and/or multispectral cameras.

Traditionally, points are measured with geodetic measuring devices and the outline drawing is made and the height points are plotted, which has the disadvantage that only a few points are recorded, measuring each point requires a lot of time, thus the costs are high. With the help of aerial photogrammetry, drone technology is able to measure millions of height points from the entire area in a fraction of the time (*Figure 9*), so there is no missed part or area to which you may have to go back. During the measurement, in addition to the 3D point cloud, an orthophoto is also taken, which helps the planning process and visualization. Based on the topography and height model, the location of earthworks and structures, their integration into the landscape, or the planning of plantations can be planned.



9. Figure Survey with traditional and UAV method

How Can You Use A Drone For Mapping?
This video below shows how drone mapping has changed the surveying industry. By the end of the video, you will not only have insights of the advantages of using drones to plan and execute a mapping mission but also, have a basic understanding of concepts such as drone mapping, photogrammetry, and 3D Modelling.

https://www.youtube.com/watch?v=rLOM82se6W8

Lesson 3: Digital models

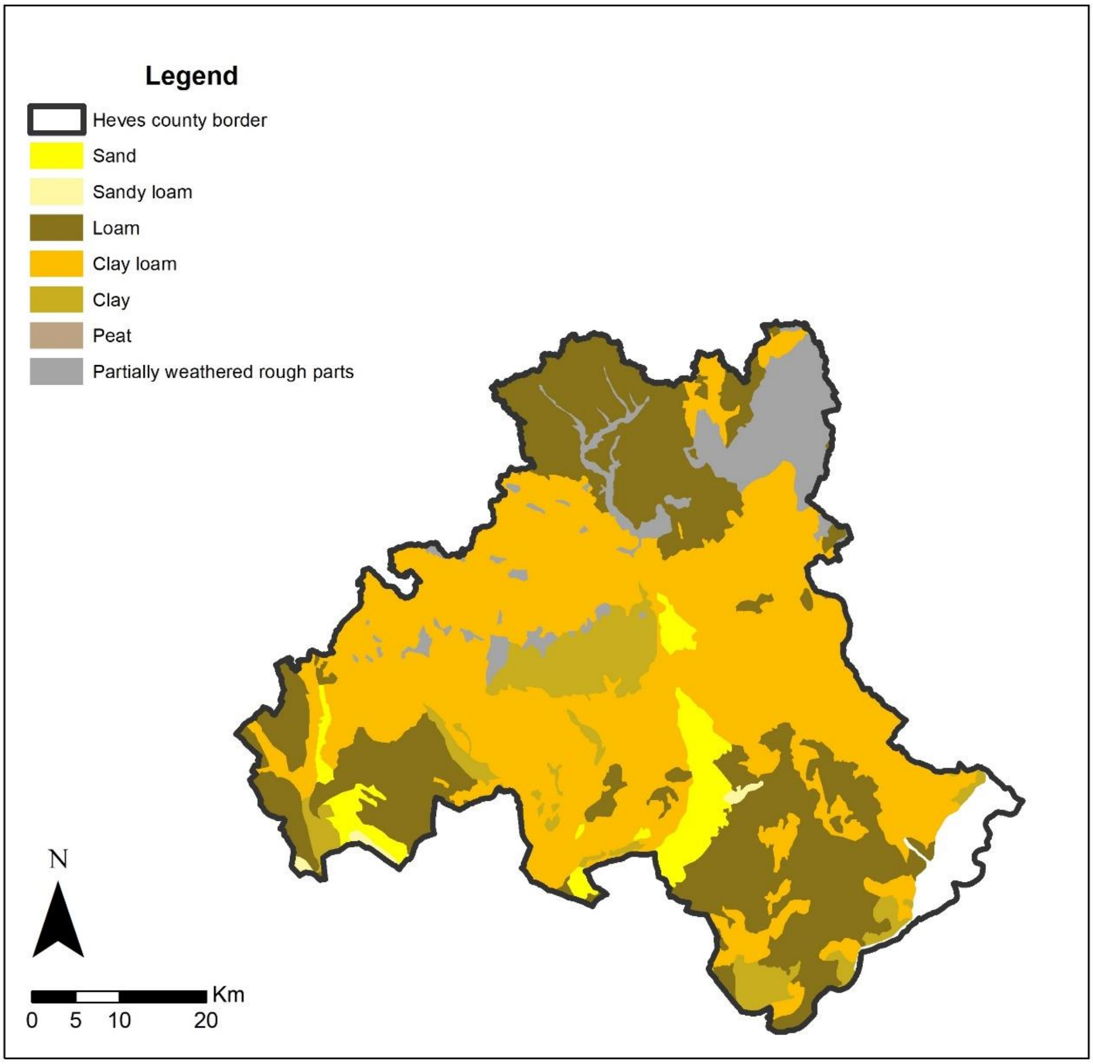
Digital mapping is performed through typically a computer. Whilst GUIs have been available for some time, it is worth stressing that image interpretation requires graphical display and the greater the size and number of pertinent displays, the easier interpretation potentially becomes. It is also essential for all work to be performed within a geographical information system (GIS) to ensure that input imagery and interpreted data sets maintain the same geographical coordinate system. This allows data export into other geographic products and facilitates accurate map production and quantitative analyses. Interpreters need to be familiar with the operation and use of a GIS, and familiarity with the principles of remote sensing is beneficial. Introductory texts describing GIS, remote sensing and image processing include Lillesand et al. (2008)

As described above in Lesson 1 Introduction, it is important to overlay maps and evaluate all the crucial components and aspects of the field. Therefore, below is a brief introduction of some possible maps that a precision farmer can take into account.

Firstly, the concept of a thematic map: A thematic map shows the spatial distribution of identifiable earth surface features; it provides an informational description over a given area, rather than a data description. Image classification is the process used to produce thematic maps from imagery. The themes can range, for example, from categories such as soil, vegetation, and surface water in a general description of a rural area, to different types of soil, vegetation, and water depth or clarity for a more detailed description. It is implied in the construction of a thematic map from remote-sensing imagery that the categories selected for the map are distinguishable in the image data.

For example, *Figure 10* is a thematic map, which shows the physical type of soils of Heves county, Hungary.

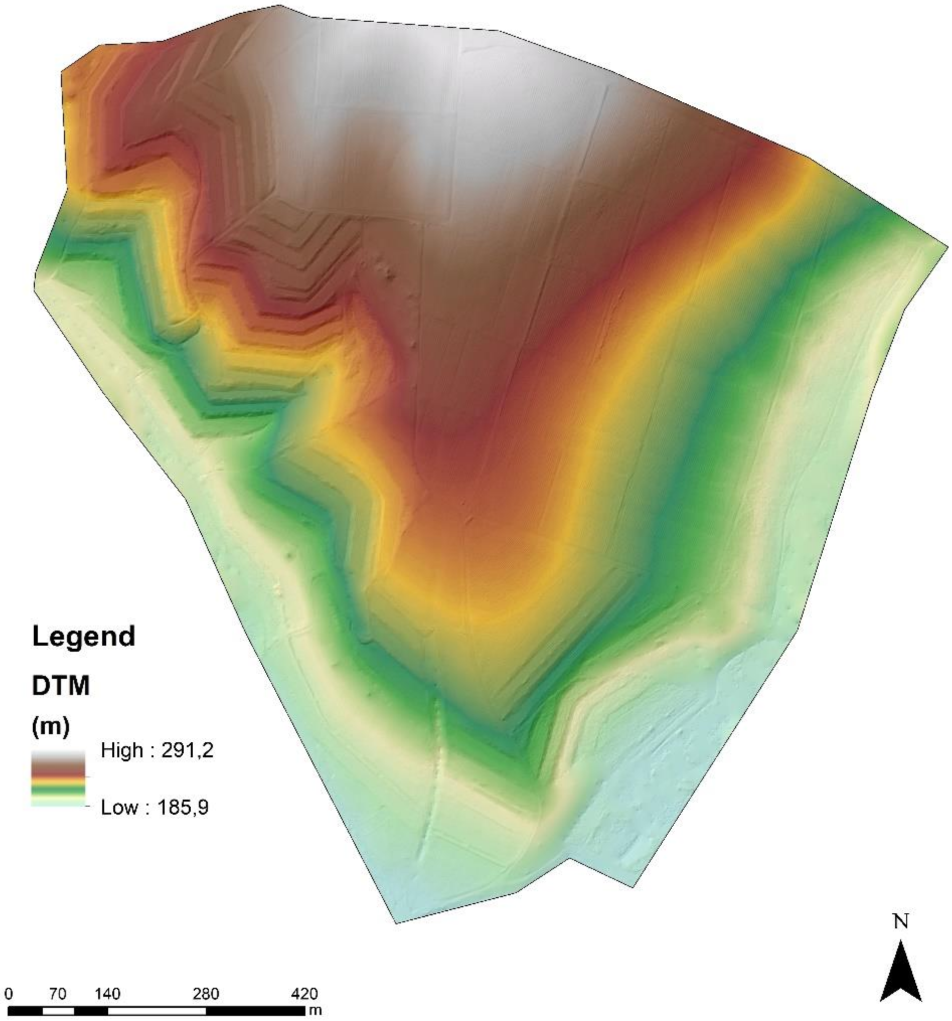
All soils were not created equally. Often, we think of soil variability on a large scale, between regions or counties, but soil properties can also differ within a field. The next video provides information of Digital Soil Mapping.
https://www.youtube.com/watch?v=nvgFiYEU25Q



10. Figure Physical type of soils in Heves County, Hungary

Land is an important component in farming. Therefore, much precise information about the land has significant impact on improvements. The geospatial products of the land provide useful information. The Digital Elevation Model (DEM) is an important geospatial product.

Digital Terrain Models (DTM) just like the one below on *Figure 11* is a topographic model of the bare Earth that can be manipulated by computer programs.



11. Figure DTM map of the Sík-hegy vineyard area

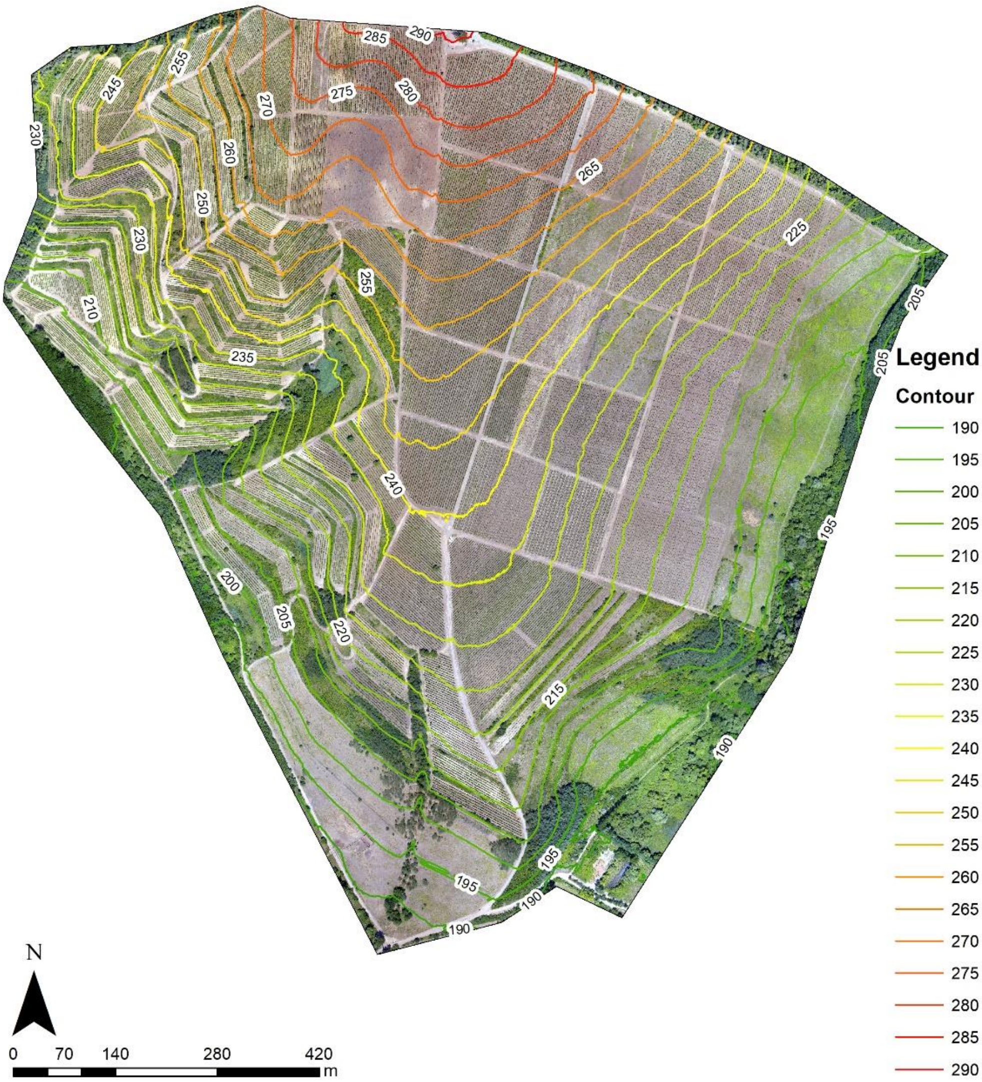
Link to the GIS portal: https://gis.uni-eszterhazy.hu/grapeProdigi/

The data files contain the elevation data of the terrain in a digital format which relates to a rectangular grid. Vegetation, buildings, and other cultural features are removed digitally - leaving just the underlying terrain.

The video below gives a brief introduction of Digital Elevation Model, or DEM:
https://www.youtube.com/watch?v=fvzNkdmoy48

The following video shows the difference between Digital Elevation Model (DEM), Digital Terrain Model (DTM) and Digital Surface Model (DSM).
https://www.youtube.com/watch?v=Ilu9j-q9Tvs

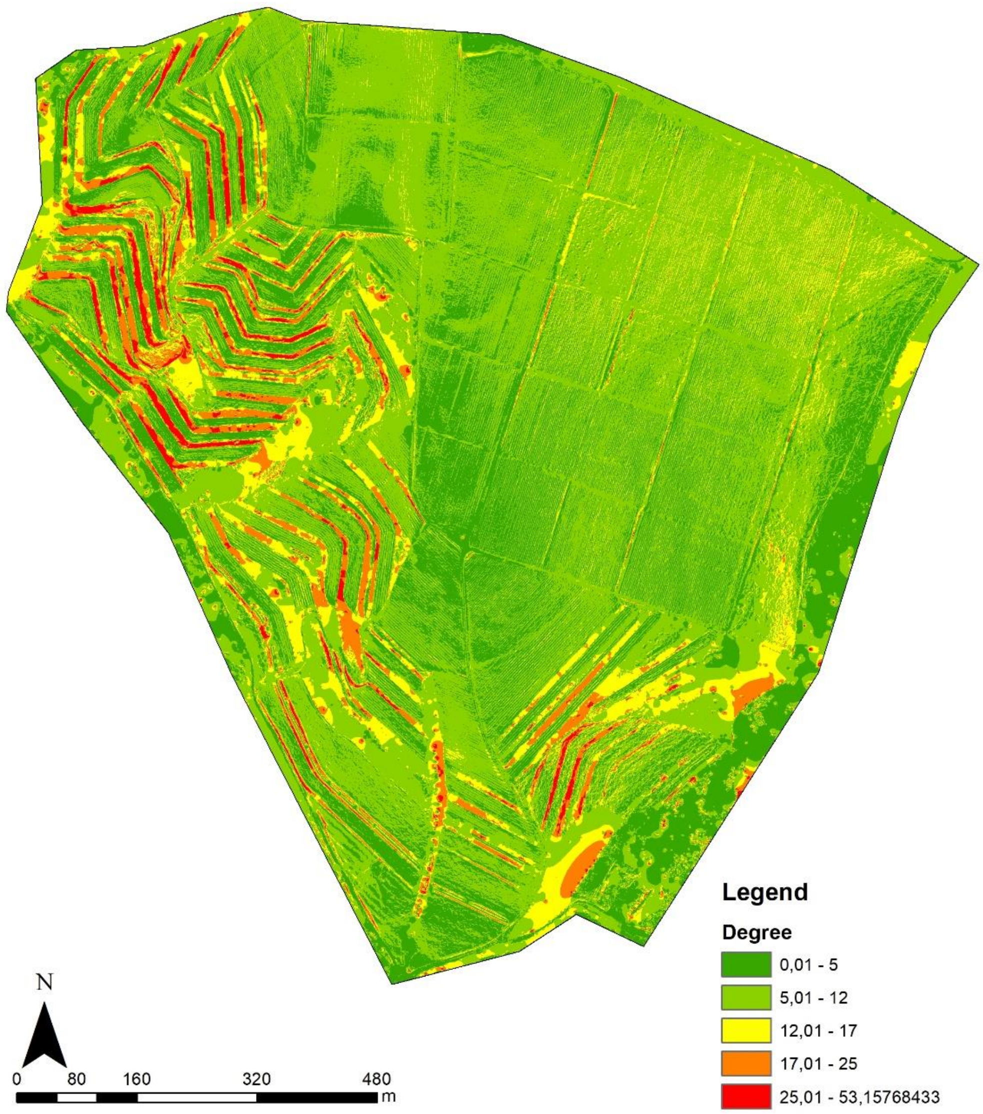
Contours are lines that connect locations of equal value in a raster dataset that represents continuous phenomena such as elevation, temperature, precipitation, pollution, or atmospheric pressure. The line features connect cells of a constant value in the input. *Figure 12* presents an elevation contour map. Topographic maps use elevation contours. Many people are familiar with topographic maps, commonly called topo maps, provided by several national geological survey agencies. These diagrams plot lines through points of constant elevation: the closer the lines on the map, the steeper the landform.



12. Figure Elevation contour map of Sík-hegy vineyard area

Link to the GIS portal: https://gis.uni-eszterhazy.hu/grapeProdigi/

A slope map *(Figure 13)* is a topographic map showing changes in elevation on a highly detailed level. Architects, landscape designers, and water control planners use a slope map to evaluate a particular site. Detailed data are required to generate one of these maps.



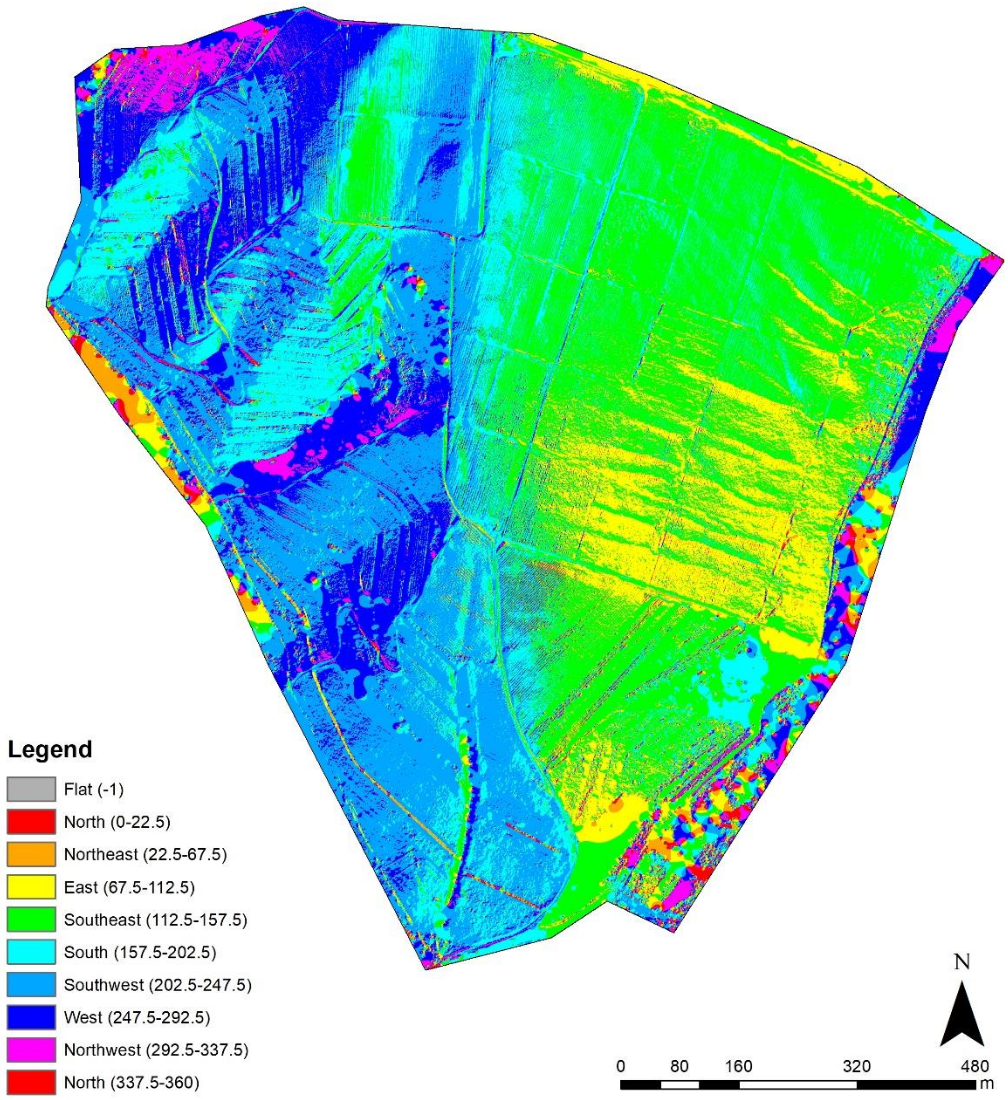
13. Figure Slope map of Sík-hegy vineyard area

Place of link to the education portal https://gis.uni-eszterhazy.hu/grapeProdigi/

When the terrain is flat, there is no slope. So, this also means that there is no aspect. But in the mountains, there are slopes in all directions. There are north-facing, west-facing, south-facing, and east-facing slopes. The compass direction that the slope faces is aspect *(Figure 14)* and there are some unique real-world applications of aspect:

- Farmers seed crops depending on the amount of incoming solar radiation and aspect data.
- Ecologists study microclimate for biodiversity.
- And even recreational planners study slope direction to prevent avalanches.

The concept of an aspect map is simple to understand. Aspect values indicate the directions the physical slopes face. We can classify aspect directions based on the slope angle with a descriptive direction. An output aspect raster will typically result in several slope direction classes.



14. Figure Aspect map of the Sík-hegy vineyard area

Place of link to the education portal https://gis.uni-eszterhazy.hu/grapeProdigi/

If no slope exists, then the cell value will be -1. These are the grey cells in the aspect map above. Where slope exists, aspect is measured clockwise starting north at 0°. It returns as 360° north again.
Here is how the Aspect tool classifies an aspect map:

- Flat (-1)
- North (0°to 22.5°)
- Northeast (22.5° to 67.5°)
- East (67.5° to 112.5°)
- Southeast (112.5° to 157.5°)
- South (157.5° to 202.5°)
- Southwest (202.5° to 247.5°)
- West (247.5° to 292.5°)
- Northwest (292.5° to 337.5°)
- North (337.5° to 360°)

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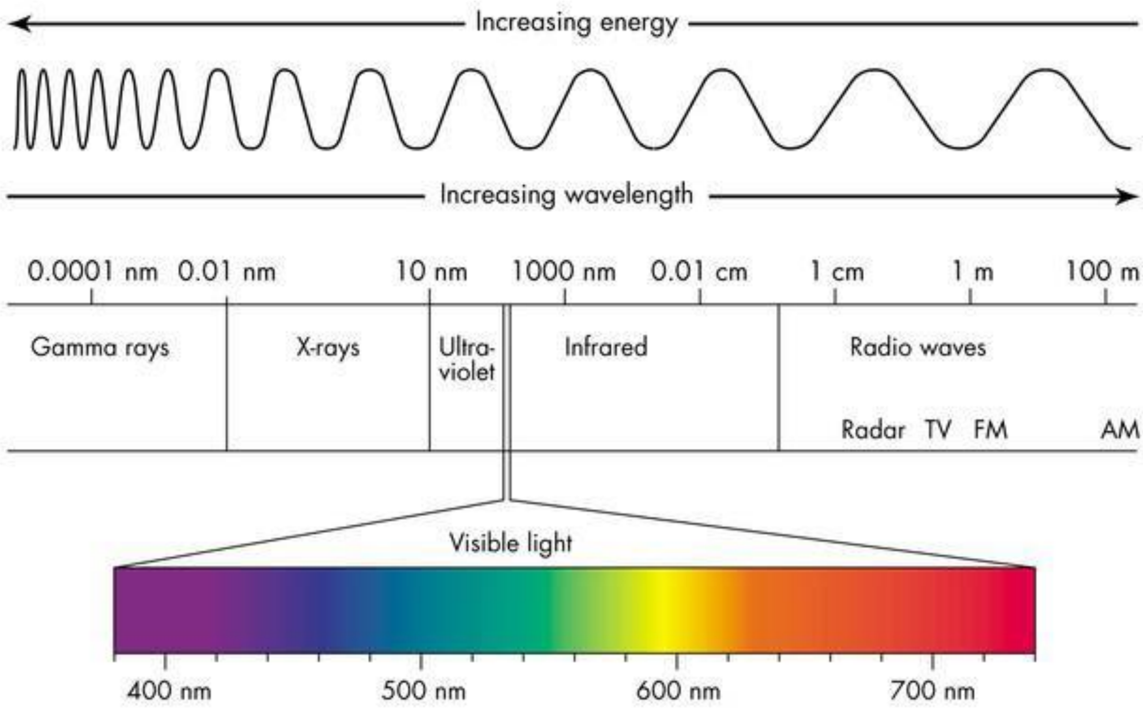
Lesson 4: Multispectral mapping and connecting indices

What Is Multispectral Imaging?
The next video shows how does multispectral imaging work and what kind of vision applications can benefit from this technology? Multispectral cameras can be used for a variety of applications. Although traditionally primarily used in labs, they are now also used in drones, for example, to check the health of plants in the field.
https://www.youtube.com/watch?v=b0webdvlySo

Electromagnetic spectrum *(Figure 15)*: Only a small portion of the electromagnetic spectrum (visible light) can be perceived by humans, but satellite sensors can use other types, like infrared light, ultraviolet light, or even microwaves. When satellite images are made, these invisible types of light are assigned a visible colour. Most active sensors operate in the microwave portion of the electromagnetic spectrum, which makes them able to penetrate the atmosphere under most conditions.

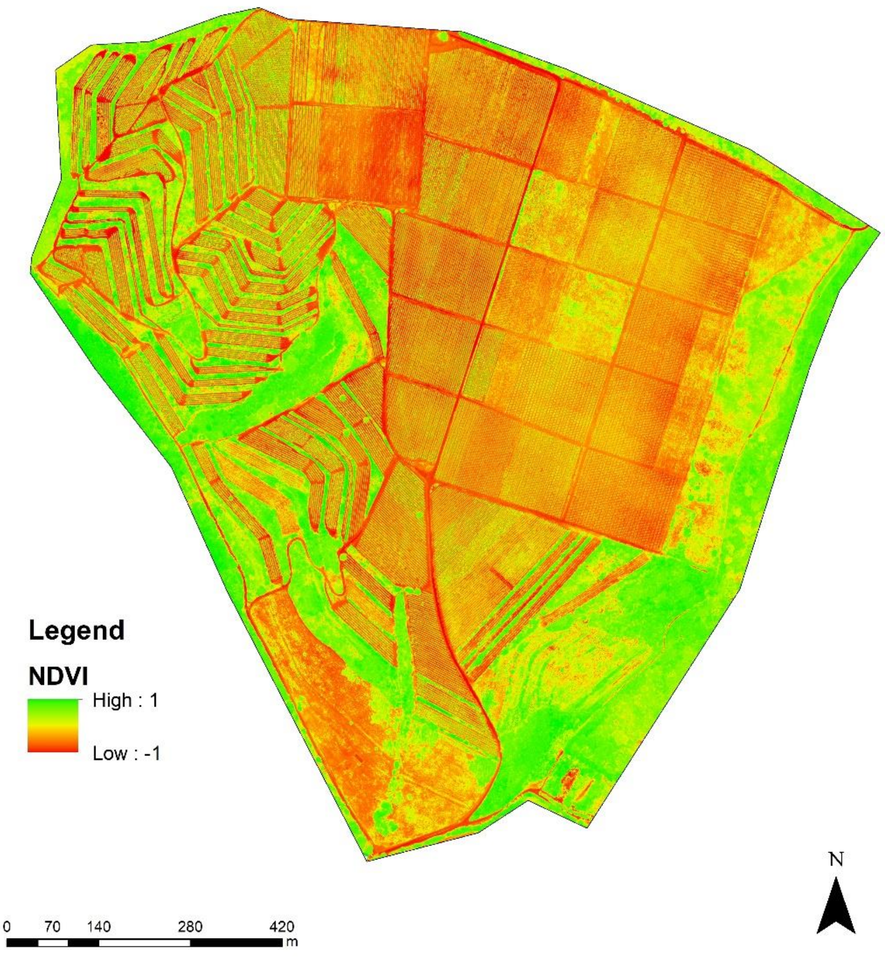


15. Figure The Electromagnetic Spectrum

To the human eye, a plant is green because the chlorophyll pigment in it reflects green waves and absorbs red waves. Cell structures in plants reflect the near-infrared (NIR) waves. So, when photosynthesis occurs, the plant develops and grows and contains more cell structures. This means that a healthy plant—one with a lot of chlorophyll and cell structures - actively absorbs red light and reflects NIR. An unhealthy plant will do the exact opposite. This relationship between light and chlorophyll is how we can use NDVI to tell apart a healthy plant from a diseased one. Healthy plants actively absorb red light and reflect near-infrared light. Satellite sensors in space measure wavelengths of light absorbed and reflected by green plants. They are an excellent source of spectral signature data for NDVI analysis. The NDVI index detects and quantifies the presence of live green vegetation using this reflected light in the visible and near-infrared bands.

An image of a vineyard block composes of pixels corresponding to vines themselves and the space between the vine rows (inter-row spacing). Depending on the exact composition of the image, other pixels may comprise additional features such as outbuildings, roads and tracks and trees.

Figure 16 is an NDVI image of a vineyard block calculated pixel by pixel using the near infrared and red bands of a multispectral image. In this coloured-scale, green pixels represent pixels with the highest NDVI value while red pixels represent pixels with the lowest NDVI values. Green pixels in this image include those corresponding to vines and other healthy vegetation.



16. Figure Coloured NDVI image calculated from multispectral image. Green pixels represent highest NDVI values and red pixels represent lowest NDVI values. Note that green pixels correspond to vigorous vegetative surfaces such as grapevines and trees.

Place of link to the education portal https://gis.uni-eszterhazy.hu/grapeProdigi/

The NDVI index detects and quantifies the presence of live green vegetation using this reflected light in the visible and near-infrared bands. Put simply, NDVI is an indicator of the vegetation greenness —the density and health—of each pixel in a satellite or airborne image.

Module 4 – Climate monitoring and computer vision in agriculture

Lesson 1: Sensors in the field

The application of sensors in the field allows to monitor variables of interest in agriculture such as temperature, humidity, rainfall, leaf wetness and others, with measurements provided constantly in time.

Through localised sensors the farmer can perceive in every moment the status of the vineyard/orchard and detect critical conditions for the development of pathologies or other problems. One can thus plan prompt and targeted activities, according to the actual needs of the cultivation.

17. Figure Weather station with multiple sensors in the field

Different sensors can be assembled in a weather station and located in one or several points of the field. All the sensors are powered by solar panel, and they must be developed to withstand the bad weather and chemical treatments.

The data collected by the sensors can be transmitted via internet or via radio and can be viewed by the users on a Web portal. An automatic elaboration of the data is performed by algorithms providing decision support notifications, as for example alerts in case of risk of infection or when critical thresholds are reached.

RAIN GAUGE:

The electronic rain gauge measures the rain amount (mm/day, or persistent accumulated rain) and rain intensity (mm/h) with a tilting sensor that has typically a resolution of 0,2 mm.

The aerodynamic cone design is devised to ensure higher accuracy even in strong wind conditions, allowing the wind to circulate around the cone, decreasing turbulence and friction at the opening of the rain gauge, that could divert part of the inlet rain.

18. Figure Rain gauge

ANEMOMETER:

The anemometer measures the wind direction, the instantaneous wind speed (km/h) and can also furnish the average speed or the peak speed in the hour.

The usual bi-dimensional model is equipped with three cups placed around a rotating vertical axis: the rotation is proportional to the wind speed; the average speed is calculated from the number of rotations in each period of time.

The weathervane follows the direction of the wind, and it is equipped with a brass tip for an optimized precision.

Knowing the wind speed is fundamental to schedule crop spraying, to ensure uniform coverage and to minimize the drift. The wind enters also in the empirical computation of the water evapotranspiration.

19. Figure Anemometer

AIR TEMPERATURE, HUMIDITY AND PRESSURE

Digital probes for air temperature, humidity and atmospheric pressure, are suitable for many applications. On the weather station the probe is usually embedded in a solar shading attached under the rain gauge, to avoid perturbations in the measurements by the direct solar radiation. It enters in the empirical computation of the water evapotranspiration.

20. Figure Air temperature, humidity and air pressure

SOLAR RADIATION:

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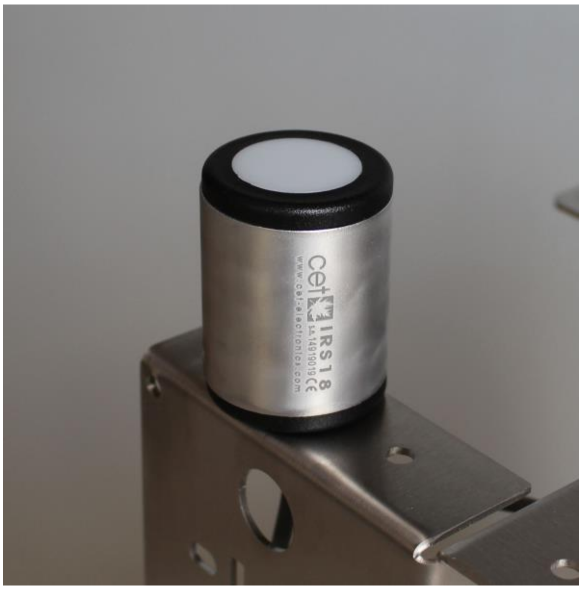
A sensor for solar radiation usually measures the radiation power per unit area (W/m^2) in certain spectrum bands. It should have high sensitivity and fast response, being sensitive at least to the visible spectrum and the near infrared, covering the region of interest for the photosynthesis. The sensor can be used to estimate photosynthetic activity, or it can relate to an automation system for artificial lighting, if the cultivation requires it (e.g., Greenhouses). It enters in the empirical computation of the water evapotranspiration.



21. Figure Solar radiation

AIR TEMPERATURE AND HUMIDITY INTRACANOPY

Air temperature and relative humidity probe to monitor the climate inside the canopy is an additional sensor that can be tied in a central position in the canopy, and it is usually not completely shielded. The mechanics should be resistant for the exposure to pesticide spraying. The intra-canopy climate is far more representative of the plant conditions, with respect to the external climate: its measurement allows higher precision in monitoring the conditions of infection development.

22. Figure Air temperature and humidity intracanopy sensor

LEAF WETNESS AND WATER DRIP

Capacitive sensor can measure the leaf wetness in terms of % of surface covered by a thin water layer. A new patented version of this sensor also allows the measurement of the foliage temperature and of the dew drip. Leaf wetness is a critical factor for the development of fungal infections, and it is of utmost importance to monitor its duration. The dew drip consists in water fall from one leaf to another, even in absence of rain, which can be responsible of infections transmission, favouring a possible epidemic explosion.

The sensor can be supplied together with the weather station to measure the external wetting of the canopy, however the use of an additional sensor inside the canopy is recommended, to measure the specific microclimate. The sensor should be resistant to pesticide spraying.

23. FigureLeaf wetness and water drip sensor

SOIL MOISTURE

A reliable volumetric moisture sensor measures the % of water in the volume unit should work at high frequency and be suitable for all types of soils and growing substrates. This kind of sensors measure the dielectric characteristics of the medium in which the stainless electrodes are inserted, to obtain the material's humidity and conductivity. Some particular measuring systems "FFVA" – Fixed Frequency Vector Analysis, are based on a high-frequency generator and a neural network based computational algorithm, which allows to obtain high precision on every substratum. Unlike the common resistive or low-frequency sensors, this kind of sensors provides a moisture measurement which is not affected by the salinity of the soil.

The sensor can be connected to a weather station or to secondary micro-stations to measure more points of the field. The sensor must be completely buried in the soil to the depth of interest and it's necessary to wholly insert the tips into the soil without producing air spaces. An extension tube that protrudes from the ground is attached to the sensor can protect the connecting wire from eventual mechanical damages.

The sensor is used to monitor the water supply in the ground, and it can be connected to an automation system controlling the irrigation facility. Installing more sensors at different depths can be very useful. The sensor can also measure the soil temperature and the water conductivity, which is related to saline components provided for example using fertilizers.

Lesson 2: Computer Vision applied to the canopy

24. Figure Computer Vision applied tot he canopy

WCAM2 is an innovative stereo vision device for monitoring the vegetative development of the crops by means of a 3-dimensional reconstruction, that allows specific and innovative measurements on the foliage.

This camera is permanently installed in front of the crop, acquiring daily pictures of sample plants in the field. The hardware is specifically designed for outdoor use, enduring bad weather conditions and the exposure to plant protection products: a patented mechanism for automatic lens protection always ensures the acquisition of "clean" and high-quality images, notwithstanding a dirty environment.

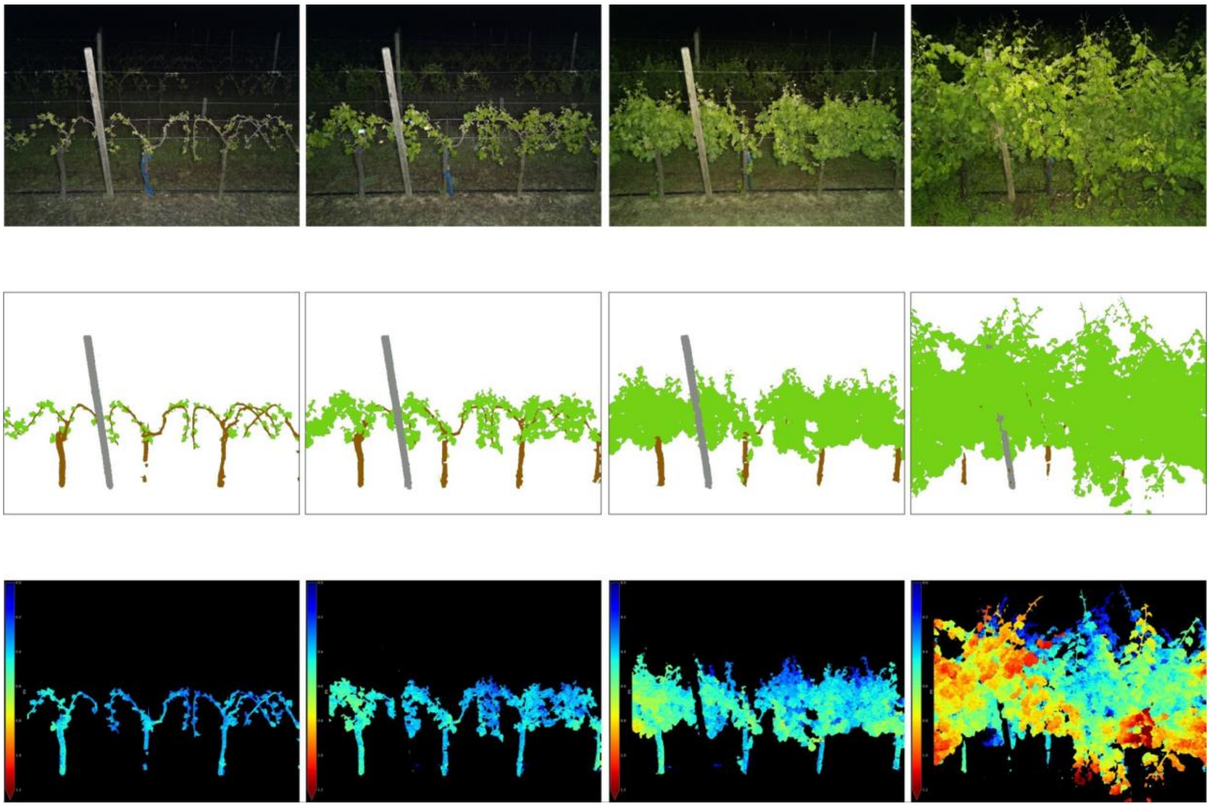
WCAM-2, powered by solar panel, can be installed independently or it can be combined with climatic sensors, becoming a complete weather station.

The camera is integrated with a thermal IR sensor for low-resolution measurements of the canopy temperature.

The daily images are sent via internet (SIM or Wi-Fi) and are then automatically elaborated by an image analysis software, extracting various features of the canopy status that are otherwise very difficult to be provided by manual observations on the vegetation.

The software automatically provides:

- detection of the complete canopy foliage in the picture (with distinction from the background and other elements);
- measurement of the canopy volume and estimation of the total leaf area inside the volume (daily growth of the plant);
- measurement of height and width of the canopy (average, percentiles);
- detection of single leaf samples and computation of their leaf angle (average, percentiles);
- detection of fruits (if visible and if of interest)
- detection of phenological stage (under trial development);
- detection of occlusions and other relevant conditions affecting the measurements (heavy rain or fog, etc.)
- computation of the average leaf temperature from central pixel band of the IR thermal sensor;



25. Figure Pictures provided by the softver

The image analysis is nowadays well developed for vineyards with espalier structure, while other vineyard structures as well as other tree crops are currently undergoing trial development. The system can be adapted to any kind of crop by a proper software training.

The extracted data are extremely useful for agronomic management:

for phytosanitary management: new green tissue is associated to the risk of infection (if uncovered with PPPs) and total leaf area permits to compute precise PPPs doses.

for the water management: total canopy, leaf inclination and temperature are associated to the water status and can be analysed together with other data from the soil.

for the canopy management: deciding when cutting/pruning operations are necessary according to the plant development and phenology.

26. Figure Weather station equipped with stereo camera

Lesson 3: Computer Vision applied to the insects

WTrap is an innovative insect trap equipped with an 8 Megapixel high-resolution camera, that allows the remote monitoring of captures. The trap attracts insects on a plate smeared with

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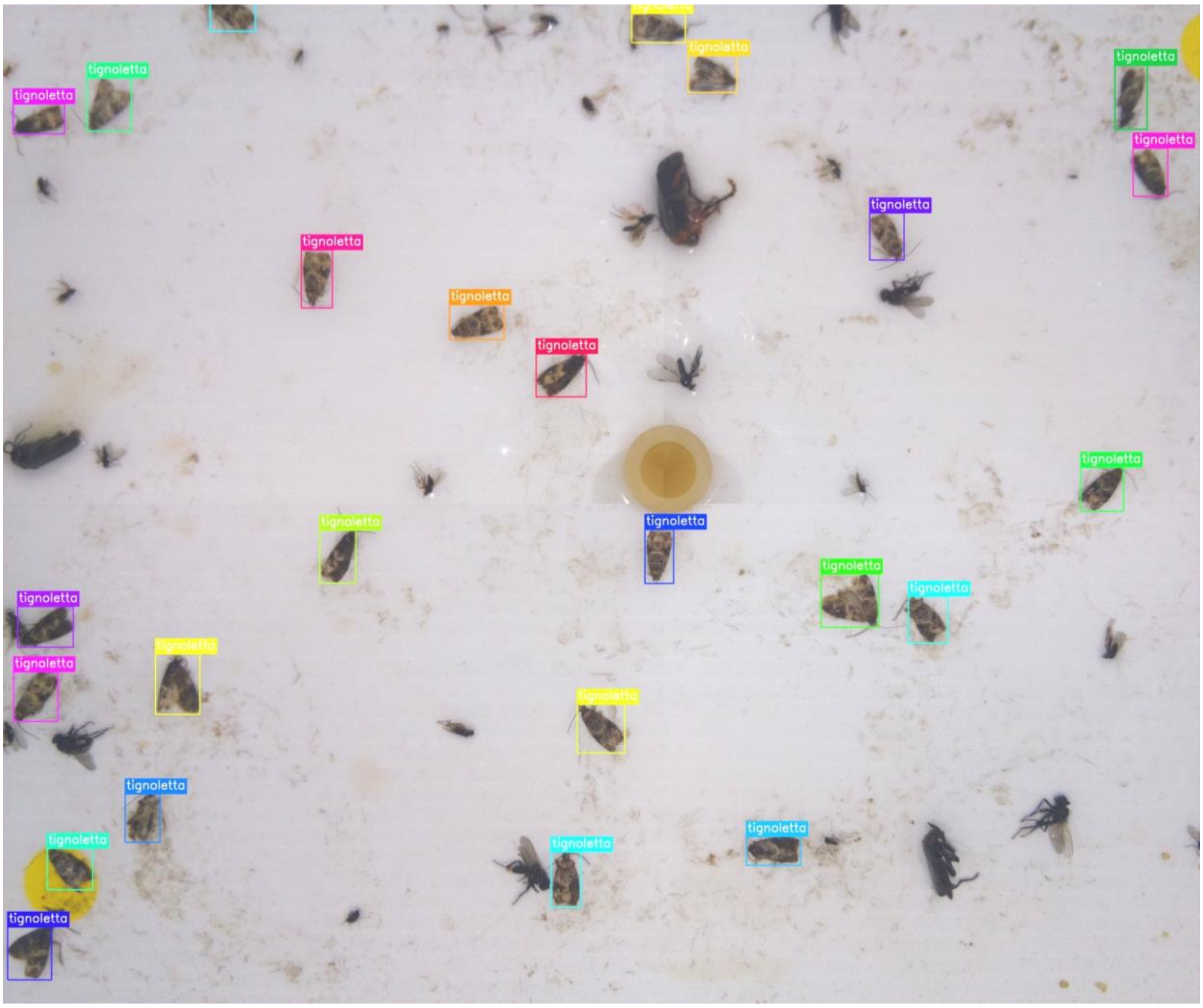
entomological glue with selective pheromones. The camera targets the plate from above, taking daily pictures which are sent through an internet connection and can be viewed on the “Aurora WEB” monitoring portal. The quality of the pictures is such to allow the identification of most insects of interest, which can be integrated by automatic software recognition.

WTrap has an integrated data communication system via SIM card. With the use of a solar panel power supply, it can be positioned everywhere as an independent monitoring station.
WTrap brings great benefits where it is necessary to monitor insects in large-scale or distant plots: the survey of insects catches becomes more frequent without the need of an operator, and the data can be automatically stored together with the weather conditions.

The software for the automatic detection of the insects captured with WTrap is able to recognise some insects of interest which are detrimental for the vineyard or the orchard (e.g., vine moth, European grapevine moth, chestnut tortrix), while the detection of other insects of interest is under trial development and will be released in the next future. The system memorizes the previously detected catches, providing the number of daily catches or the cumulative catches of a given insect. Automatic detection of the dirt level of the plate suggests when changing it is required.
The software allows a complete and instantaneous tracking of the catches, enormously simplifying and speeding up the work of the agricultural operator. Insecticide treatments can be therefore applied in the most appropriate moment, according to the real trend of the insect's populations.

27. Figure WTrap, an innovative insect trap in the field



28. Figure Automatic detection of insects

Lesson 4: Disease forecasting models

PVsensing is a system composed of hardware and software elements, representing an innovative forecasting model for grapevine downy mildew infections. New variables are measured in the field and considered as an input, with the aim of making more accurate simulations of the life cycle of the pathogen and thus the forecast of infections. Such variables are measured by a novel set of sensors, as listed below.

A precise measurement of canopy volume and leaf surface is carried out by the "WCAM" device, a particular camera suitable for permanent installation in the field, which uses automatic image analysis techniques for the recognition of the foliage and its three-dimensional reconstruction. P. viticola is an obliged parasite of the vine vegetation tissues, which is more or less susceptible to infection depending on the quantity of open stomata leaf surface being present and unprotected. The measurement of this aspect is thus of fundamental importance for a greater precision in the prediction of infections, adapting the forecast model to the specific vegetation conditions of the vineyard, which depends on several local variables and on the specific vine management. The measurements provided by the system are also useful for optimizing the dosages of plant protection products, adapting them to the vegetation growth.

The superficial soil moisture and temperature are fundamental variables for assess in a good model of maturation and germination of the P. viticola oospores, wintering on the soil surface. Normally in other models such variables are not measured but simulated by temperature and RH data collected at 2 m above the soil from a weather station, with the inconvenience that such data may not be representative of the real climate at the soil level (depending on factors as soil composition, structure, covering). Direct measurements of superficial soil moisture and temperature are obtained by a set of newly developed sensors, characterized by an electronic mechanism (patented) that only involves the first millimetres of the soil surface, i.e., where the oospores actually overwinter and germinate. The correlation of primary infections with the direct soil surface moisture is investigated for the first time in this project.

To determine the risk of infection by P. viticola, it is very important to know the temperature, air humidity and leaf wetness status by placing sensors inside the canopy. The "dripping" is an innovative measurement taken by the "LWS-PLUS" sensor, capable of detecting when the overnight accumulation of dew on leaves is such to cause the water drip from one leaf to another. In presence of infection, the dripping water holds the pathogen spores and drags them from leaf to leaf and on clusters, causing possible new infections. Dripping also affects the wash off of plant protection products, even in the absence of rain. Monitoring this phenomenon allows a more precise and reliable definition of the infection risk.

A forecast model is an important tool for the winegrower as a support in making decisions about the vineyard's management. The user can indeed know, from objective data, when there are favourable conditions for an infection and the actual necessity to perform a phytosanitary treatment. Such a system should allow a rationalization of the pesticides use, avoiding the waste of resources in unnecessary treatments, that are sometimes performed on the basis of an uncertain knowledge of the infection risk.

Module 5 – Best practices

Lesson 5.1: Digital vineyards

The "Viticulture 4.0" emphasizes that digitization is more than a technical innovation regarding the processes in the vineyard, the cellar and in marketing. It calls for a completely new way of thinking and operating when it comes to operational and corporate management in the organization, controlling, and finally in the way we approach customers.

A **digital vineyard** considers environmental protection, the consequences of climate change, the aim of producing high-quality wines and cost pressure to be the key drivers behind the digitization of wine production, especially in areas with steep slopes. The demands of soil, water and plant protection management are getting more and more stringent, and the amount of documentation required is getting more and more onerous. The digital vineyard sees innovative application techniques, resource-efficient procedures, electronic operating systems, drones, and robotics as an opportunity to meet these increasing requirements.

Digital vineyards are an agronomic concept that defines the management of agricultural fields based on **observation, measurement,** and **action** under situations of 'natural' environmental variability. This methodology requires a set of technologies that include global navigation satellite systems (GNSS), drones, sensors, satellite, and airborne imagery integrated with geographic information systems (GIS) and machine learning techniques to estimate or evaluate and understand these variations. The collected information can be further used to estimate the right amount of fertilizer, water or other inputs needed and more accurately predict crop yields and production. This information can also be used by variable-rate technologies (VRT) to optimize the fertilizers distribution, water supply, crop protection products and segmented harvest.

Smart vineyard is a type of crop management strategy in which decisions can be made dynamically thanks to the vast amounts of information obtained directly from the field through technologies such as sensor technology or aerial imagery. Farmers can improve their decision-making and act proactively on crops by receiving first-hand information directly and in real-time. These systems provide highly accurate knowledge of the needs and status of crops for a more efficient management of resources and production that can save operational costs and aid producer profitability if applied correctly.

By knowing the amount of water, the plant needs and receives, optimal irrigation can be planned, saving not only water, but also maximizing the productivity of each plant to obtain a higher yield or more commonly improved quality.

Smart vineyards bring many benefits such as:

- support decision making;
- establish early warning / detection systems;
- provide tools for climate change adaptation management strategies adoption;
- improve sustainable and profitable crop production.

Table. Current and future application of digital technologies in viticulture including their main opportunities and limitations.

Viticultural application	Opportunities	Limitations
Soil properties and soil quality assessment	- Soil quality preservation and limit soil contamination - Precise soil variability identification and mapping - Monitoring changes of soil organic carbon	- Spatial resolution - Time frequency of observations - Accurate prediction of spatial distribution - Average high cost of digital soil mapping technologies
Vegetative growth, nutritional status, and canopy architecture	- Input costs reduction (e.g., fertilizer, fungicides, water) - Canopy microclimate improvement - Development of physiological diagnostic tools	- High variability within the vineyard development - Dense canopies - Segmentation of the canopy - Limitations in artificial intelligence
Pest and disease detection and management	- Improvement of pests and diseases management - Early detection about pest and disease issues - Reduction of fungicides and pesticides use	- Similar symptoms across different pathogens and disorders
Vine water status	- Accurate water stress symptoms identification - Improvement of water use efficiency - Resources preservation	- Definition of thresholds for various levels of stress - Time frequency of observations
Yield components and crop forecasting	- Improvement of winery logistics and reduction of wine production risks and costs	- High variability - Occlusion problems for accurate clusters detection
Fruit composition and quality attributes	- More accurate fruit composition estimation prior to harvest	- Information mainly derived from skin and not from pulp - Fruit must be visible - Feasible for few berry compounds

Vineyard sampling	- Improvement of vineyard sampling activities (e.g. maturity, yield, nutrition)	- Still requires field sampling and large databases
Targeted management	- More efficient resources use through VRT applications - Data collection for sustainability indicators monitoring	- Accounting for environmental impacts of single activities
Selective harvesting	- Wine quality and winery end use products improvement - Production towards targeted wine profiles	- Average high costs - No selective picking machinery

Lesson 5.2: Digital wine cellars and consumers

Digital wine cellar

The Digitalization concept is convinced that international competition and the changes in customer preferences are constantly changing the requirements placed on wine production. The digitization of harvest technology, processing, analytics, and cellar technology as well as filling and packaging technology offers new opportunities in terms of controlling and monitoring production processes.

Digital methods of measuring and assessing quality, as well as the use of analytical apps can help to produce higher quality wines. Smart winery technology is an opportunity to use less resources and save on costs.

Digital companies and consumers

Digitalization sees new opportunities in terms of marketing. This includes new ways of speaking to customers through social media. Digitalization offers new marketing opportunities through projecting information from the vineyard and the cellar to the sales room, thus creating a new sales tool as well as creating added value and verifying the authenticity.

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