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WATERAGRI

D2.2: Farm Models and Interoperability Mechanism

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Abstract:	Deliverable D2.2 “Farm Models and Interoperability Mechanism” report the activities of Tasks T2.2 (Farm Management System) and T2.3 (Farm Model Predictions). The Deliverables describes the Interoperability tools to manage WATERAGRI farm and sensor data and a set of models and practices to support the water and nutrient resources management at the farm-scale.

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ALS	Airborne Laser Scanning
API	Application Programming Interface
BBCH	Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie
DSM	Digital Surface Model
DTM	Digital Terrain Model
DSLR	Digital Single Lens Reflex
DSS	Decision Support System
ECMWF	European Centre for Medium-Range Weather Forecasts
ET_0	Reference Evapotranspiration
ET_c	Crop Evapotranspiration
FC	Field Capacity
FMIS	Farm Management Information System
GCP	Ground Control Point
GNDVI	Green-NDVI
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSM	Global System for Mobile Communications
LAI	Leaf Area Index
NDMI	Normalized Difference Moisture Index

NDVI	Normalized Difference Vegetation Index
NMDI	Normalized Multiband Drought Index
OGC	Open Geospatial Consortium
OSAVI	Optimized Soil-Adjusted Vegetation Index
RAW	Readily Available Water
RMSE	Root Mean Square Error
SAVI	Soil-Adjusted Vegetation Index
SEASS	System 5 seasonal forecasts
SOS	Sensor Observation Service
TAW	Total Available Water
TCARI	Transformed chlorophyll Absorption Ratio Index
TIN	Triangulated Irregular Network
ULS	UAV-borne Laser Scanning
UAV	Unmanned Aerial Vehicle
VRI	Variable Rate Irrigation
WDRVI	Wide Dynamic Range Vegetation Index

1 Introduction

1.1 The purpose and objective of this deliverable

The purpose of this deliverable is to report the state of the activity of Tasks T2.2 (Farm Management System) and T2.3 (Farm Model Predictions) in developing a set of tools and methods to support the water and nutrient resources management at the farm-scale.

Aims of these tasks are:

- The implementation of a farm management information system (FMIS) to collect data at the farm/pilot level according to the requirements identified in WP1. The FMIS allows the management and the characterization of data related to i) field and crop traits, ii) geographic location, iii) input for the irrigation and fertilisation models, iv) agrometeorological data and remotely sensed indices;
- The setup of fertilisation and soil water balance models to support users in estimating the crop water and nutrient need budgets and to provide the access to easy-to-use irrigation and nutrition Decision Support System (DSS) to farmers;
- To deliver a set of solutions for the farm-scale management of irrigation and fertilisation practices using different water and nutrient sources:
    - guidelines with a concise overview of best practices required for variable rate irrigation and solutions for alternative water sources in irrigation practice;
    - catchment inventory digital surface model using airborne laser scanning data and local data cation based on photogrammetric or laser scanning data collected with an unmanned aerial vehicle;
    - hydrological predictions at the farm catchment scale, using locally adapted forecasting procedures from multi-modal medium range weather forecasts.

The document is structured in the following sections.

- Section 2 describes the **interoperability tools** which aim to support pilots and farmers in data collection and allow the declination of the input data needed by the WATERAGRI models and pipeline. In particular, the tools that allow the interoperability of the system are presented:
    - the Farm Management Information System, with functionality to manage the data at farm scale (section 2.1);
    - the procedures developed to acquire and harmonize the weather data, gathered from different sources and with different formats, allowing the integration of these data within the WATERAGRI framework.
- In section 3 a set of **best practices** developed in WATERAGRI to support the water and nutrient retention at farm scale are delineated:
    - an irrigation technology demonstration guideline for the farmers (section 3.1);
    - the methodology to produce a catchment inventory digital surface model to be used to produce a solid data input to the physical simulation models (section 3.2).
- Section 4 is dedicated to the farm-scale tools to support irrigation and fertilisation management:
    - the water balance model delineates the irrigation requirements of crops as well as the scheduling of the irrigation practises to optimize the use of water;

- the fertilisation DSS is based on the calculation of macro elements (N, P, K) balance model to properly determine the crop requirements. Both models enable the update with the irrigation and fertilisation logs.
- hydrological predictions at the farm catchment scale, applying locally adapted forecasting procedures from multi-modal medium range weather forecasts.

1.2 User requirements

In coordination with the Work Packages 5, the data availability at pilots' level has been assessed, as described in the previous deliverable (D2.1). All the case study sites have registered in the AGRICOLUS Farm Management Information Systems (FMIS) and all the users have been associated to the WATERAGRI group; the Simple Farm Model modules have been activated the. On December 11th, 2020 an online webinar has been organized by AGRICOLUS and a help desk was activated to support WATERAGRI pilot's managers in using the platform and the tools developed. A total amount of 9 subscriptions has been activated with a farm surface up to 10 000 hectares for each subscription. For each account the following dedicated tools are available:

- Functions for crops and fields management
- Access to irrigation/phenology/fertilisation models
- Sentinel2 satellite imagery indices
- Tools for crop scouting and crop planning.

During the 1st and 2nd WATERAGRI workshop (see Deliverable D1.4 and D1.5, respectively) the stakeholders have been informed about the solutions developed in WP2 in order to collect feedbacks about the developed functionalities.

In the 2nd online WATERAGRI Workshop the WATERAGRI conceptual framework has been evaluated and it was defined how the tools developed in WP2 should be integrated in the WATERAGRI framework.

Stakeholders' ownership feeling is crucial to let them feel confident and trust tools they cannot fully understand. Stakeholders indicated that whatever tool must prove its value for money, where also the time spent to use has to be monetized.

It must be duly taken into account that farm data collection could be a time consuming and costly activity for farmers. In most cases, data collection requires installing sensors or implementing monitoring schemas, that are investments which positive impact must be clearly proved.

Therefore, one of the main issues is the definition of a set of procedures to facilitate the farm data management and the integration of different sensors and data sources:

- **farm data**: farm data collection user interface is described in section 3.1;
- **weather**: a set of "Extract, transform, load" tools (ETL) to manage and harmonize weather data are presented in section 3.2;
- **remote sensing**: the remote sensing pipeline will be further discussed in the next deliverables; however, a common data model structure and the main flows of information have been already defined.

2 Interoperability

2.1 Farm Management System

Farm data is the most important source of data to guarantee the running of the WATERAGRI models and solutions; the data collected has to be integrated in a complete Farm Management Information System (FMIS) to ensure the ease of use of the platform.

The FMIS developed by AGRICOLUS has been designed to support farmers in data collection, the system enables the provision of farm data required as model input.

AGRICOLUS provided a cloud-based FMIS with tools for data collection. The FMIS allows users to manage agronomic data (e.g., cropping system, crop cycle length, date of sowing/transplanting and harvest) as well as climate and hydrological data (e.g., weather forecast, soil moisture) and it is complemented by tools to handle soil analysis and the irrigation-fertilisation log. Spatial data and environmental variables may be manually entered or imported.

The FMIS has a hierarchical structure with all the features accessible from a side menu where data can be handled.

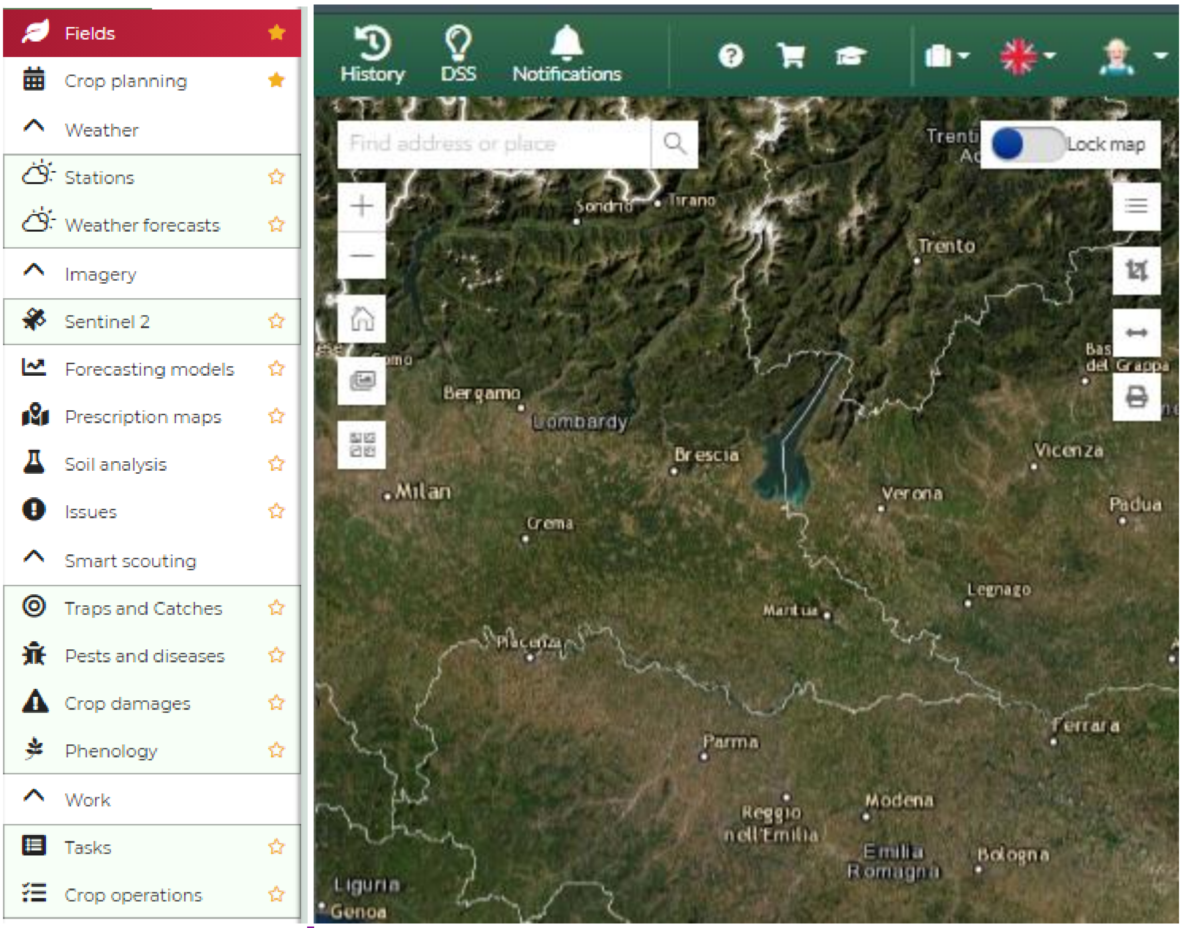

Figure 1: The AGRICOLUS platform interface showing the features available in the tool side-bar. The map shows the dedicated geographic tools with DSS and history navigation buttons in the top-left corner.

The **user interface** is optimized to help farmer's in easily access, manage and visualize all the data available. A base map allows the user (Figure 1) to navigate fields and visualize spatial data, and specific tools to manage these types of data are available (e.g., measurement, layer upload). A summary of the farm situation is also integrated, as well as a method to filter/aggregate/visualize data.

Moreover, to complete the experience, a dedicated feature to visualize historical data and old fields is integrated in the platform. A video tutorial for general platform usability and for specific sections is provided inside each feature.

2.1.1 Field and crops

Field is the basic entity of the AGRICOLUS platform, where primary attributes are stored and managed (e.g., cardinal dates, polygons). Crop cycle and timing can be planned, updated and registered.

Fields can be manually drawn in the map (given a geographic location) or they can be uploaded in the system as a shape-file (or kmz file), in a field-by-field or in a bulk-upload process. Fields' information is the input both for irrigation and fertilisation model and can be easily edited during the life of the field itself.

Field-related data are divided into 4 groups:

- **basic attributes**:
  - name of the field
  - crop (selection of the crop from a drop-down menu)
  - crop use (selection of the main use of the crop product)
  - field work start date (the date when work on field starts)
  - soil management (e.g., tilled, cover crop, green manure)
  - geometry (manually defined in the map or uploaded);
- **optional attributes**:
  - crop varieties
  - crop variety level of earliness (e.g., medium, late);
- **crop details**:
  - year of plantation
  - sowing or transplanting type
  - seed/plants per hectare
  - expected yield
  - expected date of harvest;
- **field details**:
  - type of irrigation system
  - flow rate of irrigation system
  - soil texture (selection of the soil textural class)
  - type of drainage (e.g., surface, sub-surface)
  - management type (e.g., organic)
  - slope (e.g., plain, steep)
  - weather station (selection of the closest weather station connected to the farm centre).

An overview of the fields with basic details in card-view is available with a useful geo positioning tool in an integrated base-map. Moreover, each field can be linked to a group of sensors (weather station) which is representative of the environmental conditions of the field. The weather data visualization is available in a separate interface along with the possibility to download data (.xlsx or .csv format) for daily or longer time-interval.

Overall, the field creation is a guided process made up of different sequential steps (Figure 2) and data can be edited anytime in the crop-field lifecycle.

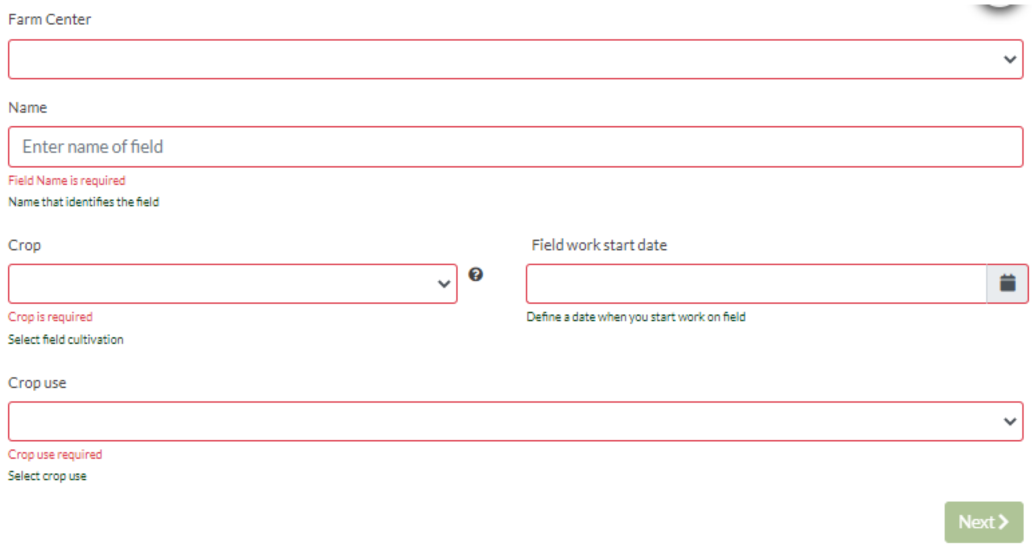

Figure 2: The AGRICOLUS platform interface of the field creation tool, user can define the crop name, the crop use destination and the field work start date.

2.1.2 Soil data

Soil data in AGRICOLUS are managed as georeferenced field features, allowing the user to enter soil data for different sample points within the same field.

The soil data have been designed to focus on the main parameters needed to run the water and nutrient balance models. The following parameters related to soil analysis can be delineated in the system (Figure 3):

- soil texture (percentage of sand, clay and silt)
- bulk density (g cm^{-3})
- skeleton (%)
- pH
- organic matter (%)
- total nitrogen (g kg^{-1})
- assimilable phosphorus (mg kg^{-1})
- total organic carbon (g kg^{-1}) (calculated)
- carbon/nitrogen ratio (calculated)
- exchangeable potassium (mmol dm^{-3})
- cation exchange capacity (mEq g^{-1})
- depth of the sample (cm).

When these data are missing, standard soil type attributes are assigned to the field. This is related to the need to make the models work with a minimum of input data. The logic consists in having different levels of approximation depending on the users' inputs. The higher system reliability is obtained through a precise management of all data.

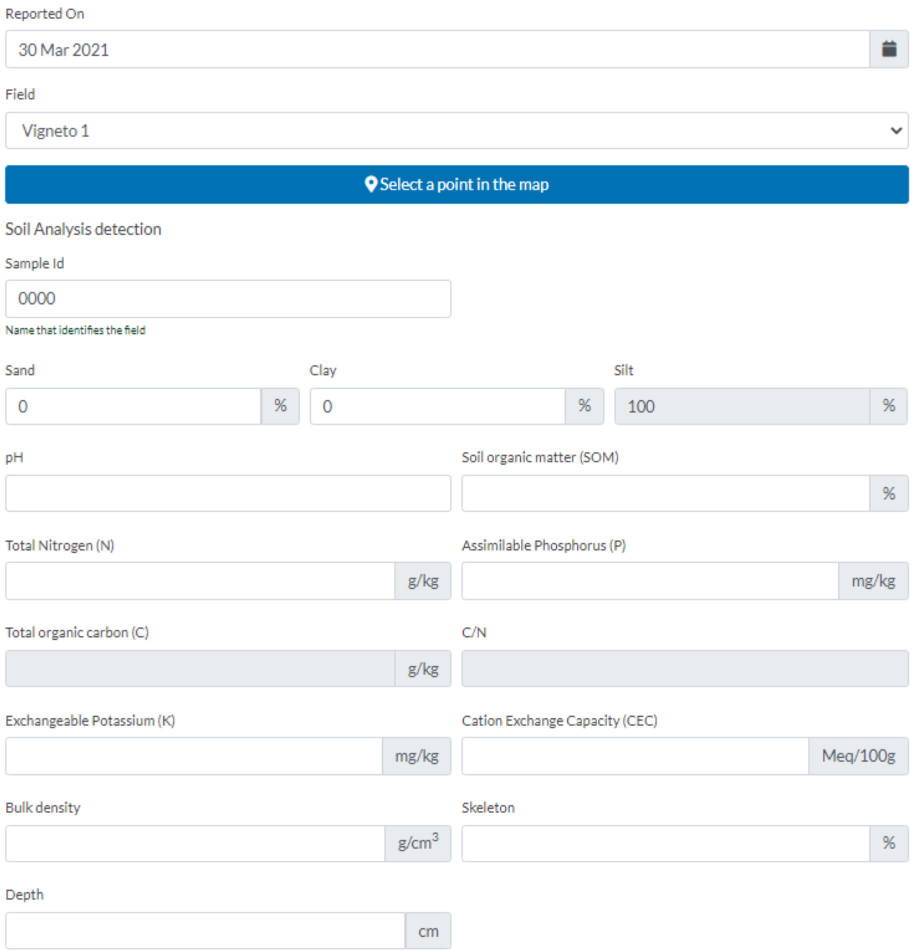

Figure 3: The AGRICOLUS platform interface for entering the soil analysis data.

2.1.3 Weather data

The platform uses two sources of weather data:

- a set of weather stations and soil sensors may be associated to each farm and field;
- an external weather forecast system providing for each field five-day weather forecast of the main variables (temperature, rain, relative humidity etc...).

The user can visualize the sensor and the forecast data at different time intervals (Figure 4); there is a function to download the sensors' data. These data will be then used as input of the crop models (e.g., irrigation, nutrition, phenology).

The platform can be connected with different data sources, in the 2.2 section the weather harmonisation and import protocols are described in detail.

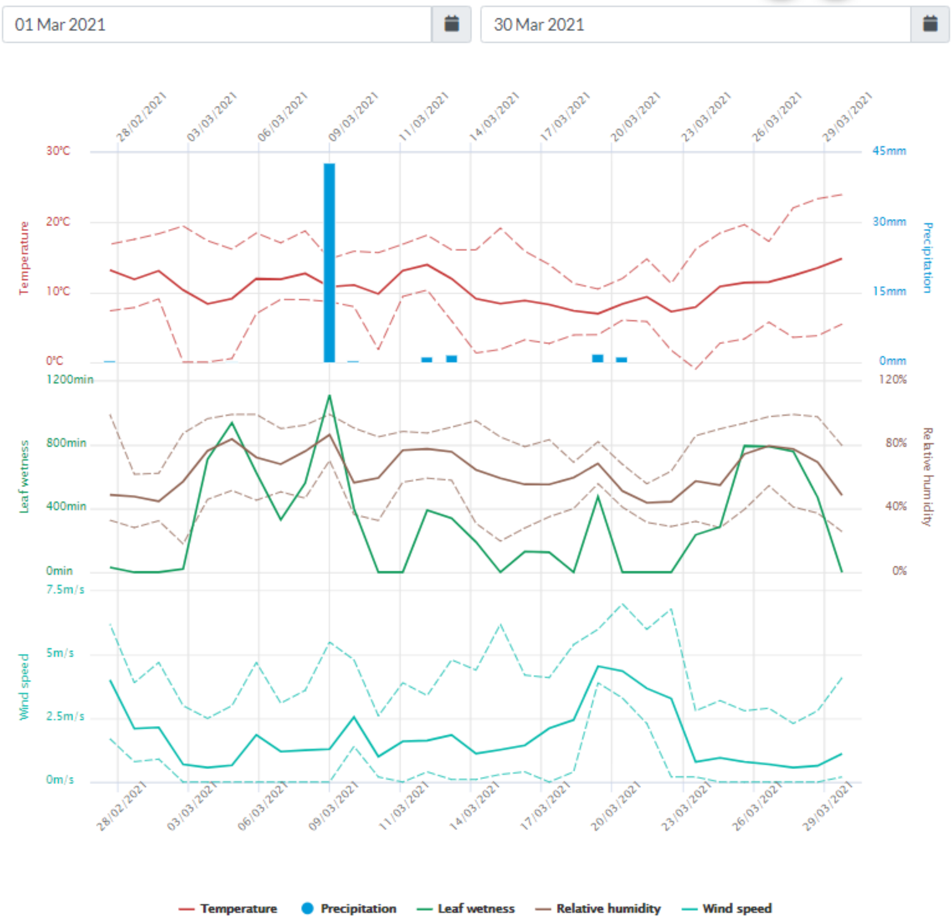

Figure 4: The AGRICOLUS platform interface to visualize data from a weather station connected to a farm/field.

2.1.4 Irrigation and fertilisation log

AGRICOLUS system allows user to track the crop operations and connected details, carried out in the field. For a better user experience, crop operations can be edited field per field or multiple fields having the same operations can be grouped. Moreover, fields can be visualized in a map using the crop operation as a visualization criterion. Finally, all these logs can be downloaded as electronic sheets (.csv or .xlsx).

Irrigation water log (Figure 5) is denoted in mm to have consistency with the output of the water balance model but data can be also entered as:

- irrigation duration in time (h)
- total water quantity (m^3)
- water quantity per hectare (m^3 ha^{-1}).

The different options for data entering enhance the usability of the system.

Figure 5: The AGRICOLUS platform interface to enter field irrigations.

For fertilisation (Figure 6) the user must select the amount of the product delivered and the type of fertilizer which is assigned to a specific nitrogen, phosphorous and potassium concentration or, *vice versa* the user can assign a specific nutrient percentage. The output is then calculated in kg per hectare to meet the fertilisation (simple model) units.

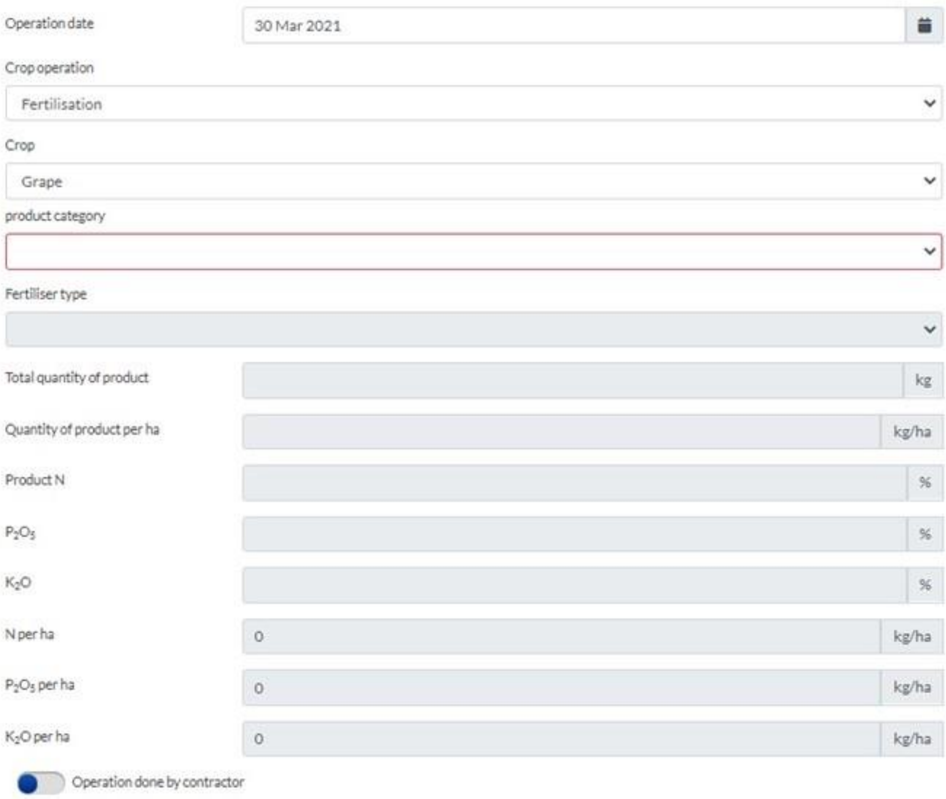

Figure 6: The AGRICOLUS platform interface to enter a field fertilisation.

2.1.5 Imagery Section

The **imagery** is implemented through Sentinel2 Satellite data and is one of the technological pillars of the platform. These data have a spatial resolution of 10m and a temporal resolution of 3-5 days, depending on the area where the field is located (Figure 7a). Data are subjected to cloudiness. Different agronomical indices are elaborated, which can be grouped in three categories:

- **Vigour**
  - NDVI (Normalized Difference Vegetation Index)
  - GNDVI (Green-NDVI)
  - SAVI (Soil-Adjusted Vegetation Index - applies a correction to the bare soil)
  - WDRVI (Wide Dynamic Range Vegetation Index)
  - LAI (Leaf Area Index);
- **Chlorophyll**
  - TCARI/OSAVI (Transformed chlorophyll Absorption Ratio Index/Optimized Soil-Adjusted Vegetation Index - high index values indicate chlorosis, while low values indicate high chlorophyll content);
- W**ater stress indices**
  - NDMI (Normalized Difference Moisture Index)
  - NMDI (Normalized Multiband Drought Index).

The temporal trend (figure 7b) of each index is shown for the field and an aggregated view in map is available.

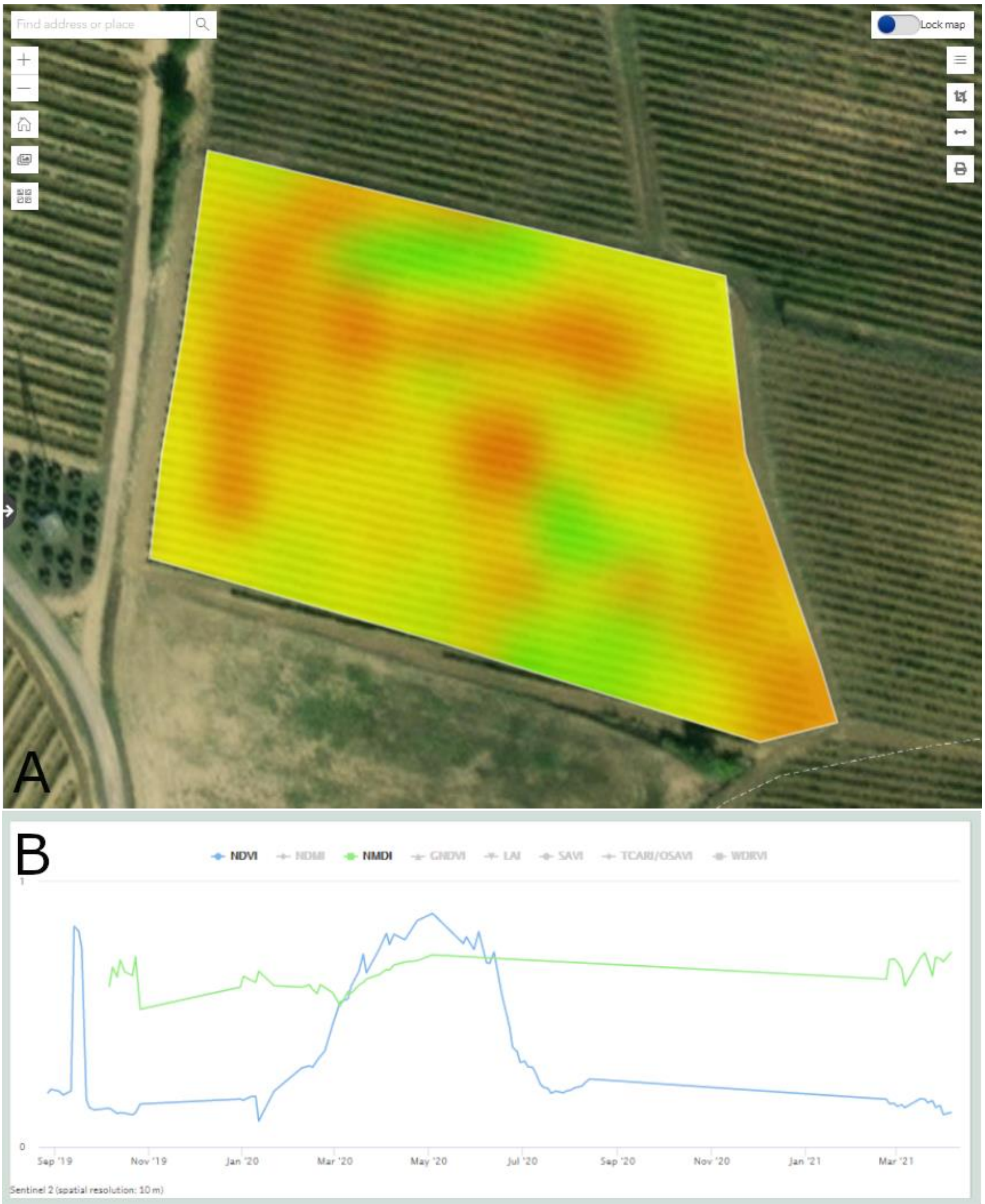

Figure 7: a) map visualization of Chlorophyll index in AGRICOLUS; b) temporal trend of NDVI and NDMI indices for a selected time interval.

2.1.6 Modelling Section

A specific section of the platform focuses on the **forecasting models** which work at the field level using as input crop/field traits and data of the connected weather station. The following models are available for all the crops managed in the AGRICOLUS platform (~130) with specific model parameters for each crop:

- crop phenology (temperature-based prediction of the main BBCH phase)
- irrigation (water balance model to support irrigation management)
- fertilisation (nitrogen, phosphorous and potassium balance models to support fertilisation management).

Whereas crop protection models are specific for crop-disease or crop-pest combinations.

The Irrigation and fertilisation DSS are described in section 4.

2.2 Sensor Interoperability

The principal data of the project are the weather and soil data collected in real time from the pilots. Data come from different data sources that require harmonisation, to allow all the WATERAGRI pipeline accessing weather data in a standard format.

The weather data sources have been gathered for the pilots since they need to provide data in real time. In the following Table 1, the data for weather data sources are listed.

Table 1: List of data source for each pilot and format used to gather data.

Site	Data access	Data format	Data
Sweden	Web API	JSON	Weather
Poland	FTP	CSV	Weather, Piezo, Soil Sensors
Hungary	Web API	JSON	Weather
Germany	Web API	XML (SOS)	Weather, Soil Sensors
Finland	Web API	JSON	Weather
Switzerland	Web API	JSON	Weather
Italy	FTP	CSV	Weather

The WATERAGRI weather connector is a set of Python procedures to harmonize the sensor data; the scripts are available on the project github repository at the following address: https://github.com/AGRICOLUS /WaterAgri.GeoDB/tree/master/weather.

Data acquisition - the first step is the acquisition of the data from the following type of data sources:

- FTP: file repository (can be FTP or FSTP) containing the files
- Web services:
  - the Sensor Observation Service (SOS) is a standard defined by the Open Geospatial Consortium (OGC); SOS allows a web service to query real-time sensor data and sensor data time series, the standard is a part of the Sensor Web, the actual measured values are available using the Observations and Measurements (O & M) encoding format; to acquire the data it has been used an SOS library developed by the Institute for Bio- and Geosciences (IBG-3) of Forschungszentrum Jülich GmbH via standardized OGC Sensor Observation Services (SOS) (available at https://ddp.tereno.net/ddp/prov.jsp)
  - custom web services: several other data sources are available using a set of different web services, available in different formats.

Data format management - the acquired data are available in CSV, JSON and XML data format, using the Python panda library (https://pandas.pydata.org/); Panda is an open-source library widely adopted for data manipulation and analysis, with a specific focus on time series analysis; all the data are converted first in a CSV-like data format and then transformed in a Panda data frame for further manipulation.

Data merging - data can be available across different files divided by station, time and types of variables; all data are merged defining for each data row the weather station and the time reference; variables are stored in column; only the relevant variables are collected (Table 2) and stored in a raw table.

Time harmonization - all time references are transferred in UTC; all sensors' data are grouped at 1hour time; all data are grouped at the end of the hours (i.e., all data sensed from 02:00:01 to 03:00:00 are referred to 03:00:00).

Aggregate data - the raw data are aggregated on hourly basis; different aggregate functions have been implemented: average, minimum, maximum, sum; the type of aggregation for each variable is described in Table 2; if needed data are converted in the required unit of measure.

The final results are a set of data files containing observations with: reference to the observing station, a time reference of the hourly observation and a set of variables collected and aggregates. Data files are loaded in the WATERAGRI geodatabase and can be accessed by all the authorized users and pipeline.

In the following Table 2, the list of the currently acquired data is given. Starting from the data collected at pilots and described in D2.1, a set of variables needed as input for the WATERAGRI digital solutions has been selected:

- Water balance model
- Simplified Nutrient balance model
- Hydrological predictions solution at farm catchment scale
- Physically based hydrological model
- Data assimilation pipelines
- WATERAGRI framework.

Table 2: List of WATERAGRI main sensor variables.

Sector	Variable	Unit of measure	Hourly Aggregation	Variable code
Weather data	air temperature	°C	Minimum	tmin
			Maximum	tmax
			Average	tavg
	relative humidity	%	Minimum	tmin
			Maximum	tmax
			Average	tavg
	precipitation	mm	Sum	psum
	total solar radiation	kW/m^2	Average	ravg
	wind speed	m/s	Average	wavg
Soil data	soil temperature	°C	Average	stavg
	soil humidity / moisture	%	Average	smavg

Ground water	level	m	Average	lavg

3 Best practices

3.1 Irrigation technology demonstration guideline

The European Commission (EC) presented an EU strategy for adapting to climate change in 2013, (COM/2013/216 final) with the overall aim of contributing to a more climate-resilient Europe. Specifically, water management adaptation involves investing in the development of irrigation infrastructure, which provides greater security of water availability for irrigation, which in turn reduces dependence on rain cycles, while allowing evapotranspiration to be reduced and thus providing greater productivity with less water consumption.

In the case of irrigation, sustainable water supply is one of the most important requirements. Due to population growth, concerns about irrigation water reliability are becoming more common due to increasing water demand. This increases the pressure on water resources, making areas more vulnerable to drought. In arid areas, water scarcity and soil salinization have become a critical problem and severely limited the development of sustainable agriculture and directly affected food security. Precision irrigation can boost the economy and reduce water use as efficiency increases by optimizing inputs, aligning with the area.

Precision irrigation consists of several parts, and operating conditions of irrigation are considered as a complex system concept. Irrigation technology has an impact on irrigation costs and workload management, on biological efficiency of water used for irrigation, and also closely related to production standards and the certain crop structure. Certainly, similarly to other agro-technical processes, irrigation works properly only if all the necessary production inputs are provided in sufficient proportions and quantities.

Nowadays, "Variable rate irrigation" (VRI) offers options to integrate up to date plant related data, soil characteristics, and topographical maps in irrigation. Machines with VRI technology require a complete set of computer and monitoring tools as well as automated real-time data collection and evaluation systems on the observed crop sites. Irrigation is monitored and controlled by real-time data transmission via radio, Internet or GSM, with GPS positioning accuracy of 2-3 cm. VRI offers many benefits to farmers, and an opportunity to increase farming results and profits.

This guideline is highly related to integrated water management from agricultural aspects, both at local and sub-regional scales. It summarizes measurement and engineering tools both for farmers and experts in order to support the design and operation of water saving precision irrigation systems. The topics discussed in the guideline are the followings:

- Data and Monitoring for irrigation
    - Available drought indices
    - Topographic data
    - Monitoring for Irrigation
        - Agrometeorological monitoring
        - Soil moisture monitoring
        - Vegetation monitoring
        - Groundwater monitoring
        - Surface water monitoring;

- Alternative Water Resources and Irrigation Systems
  - Alternative Water Resources as Water Supply for Irrigation
    - Alternative water resources from natural sources
    - Reclaimed water resources
  - Precision irrigation system at Hungarian case study.

Therefore, the guideline (Annex 1) provides a concise overview of best practices required for VRI, and discuss a set of solutions for alternative water resources in irrigation, and offer a special solution for irrigating from alternative water resources with a unique pivoting lateral moving irrigation machine to properly irrigate long fields.

3.2 Catchment inventory digital surface model

3.2.1 Technologies used to collect data for terrain surface modelling

Airborne Laser Scanning (ALS) is currently the main technique used to collect data for creating digital models of terrain surface. The result of an ALS acquisition is a set of points (point cloud) which are the reflection of the laser beam from the ground and off-ground (e.g., tree, roofs) objects. The advantage of ALS technique is that it allows mapping terrain surfaces even in areas covered by vegetation. This is possible thanks to the divergence of the laser beam, that allows it to penetrate the vegetation and reach the ground. The disadvantage of this technique is the high cost even in the case of considering only data acquisition by 3rd parties who have necessary equipment and offer such services. This makes this technique suitable for mapping large areas, because unit cost per area typically decreases if the mapped area is larger. However, very often ALS data collected earlier for other projects is available and can be purchased at a much lower price than the costs of acquisition or even for free, though the access procedure may be restricted or require complicated authorisation. Many countries run projects on collecting ALS data for the entire country (e.g., Denmark, Estonia, Finland, Poland, Spain) and some of them give open access to the data (https://www.researchgate.net/post/Which-EU-Countries-provide-free-access-to-LIDAR-data-files-in-2017).

The alternative for ALS may be laser scanning performed with Unmanned Aerial Vehicles (UAVs). These platforms allow flying over smaller areas but, on the other hand, usually the density of the collected point clouds is much higher than for a regular ALS. The UAV-borne Laser Scanning (ULS) is cheaper than ALS in all aspects (platform, equipment, acquisition costs), but it is still an emerging technology and may suffer from data accuracy or quality due to the lower performance of the sensors, especially in vegetated areas.

The algorithmic development in the last decade in image processing resulted in many dense image matching algorithms that allow to create point clouds directly from images, without the need, for some applications, of investing in an ALS acquisition. Usually, such point clouds have very high density that is practically impossible to achieve with laser scanning. This causes that UAV photogrammetry is very often used for mapping purposes because its products are not only orthomosaics, but also point clouds that can be used for surface modelling. In comparison to laser scanning, the drawback of UAV photogrammetry is that it cannot be used for modelling terrain surface in vegetated areas, due to the inability of penetrating the canopy. On the other hand, the costs of equipment used in UAV photogrammetry is much lower than for ULS. The mapping sensor used in UAV photogrammetry is an RGB camera that may be any kind of off-the-shelf camera used for taking pictures, though the highest quality UAV images can be collected using Digital Single Lens Reflex (DSLR) or mirrorless cameras.

The use of different types of source data to build a digital terrain model may have a positive effect on the improvement of the quality of the catchment inventory. In this project, it is planned to use two types of source data for this purpose, i.e., ALS and photogrammetric point clouds. The ALS data should be collected from available resources (databases). The UAV photogrammetric data can be collected for non-vegetated areas that are important for further modelling. The need of collecting UAV photogrammetric may be caused by changes of terrain shape, height, roughness, etc. Point clouds collected with the ALS technique and created from UAV images are the basis for the modelling of the terrain surface. The proposed idea was tested in this project for the Polish case study and is described below.

3.2.2 Digital Terrain Model *vs*. Digital Surface Model

Typically, two digital models are created from the point cloud: Digital Terrain Model (DTM) and Digital Surface Model (DSM) (Figure 8). The DSM shows the elevation of the terrain surface or objects connected with terrain (e.g., vegetation, buildings) whichever is higher. In contrast, DTM shows the elevation of the terrain height only related to ground points. The elevation of terrain height in places without ground points, e.g., under off-ground objects such as buildings, is interpolated based on neighbouring ground points. From the perspective of further simulations and modelling for the purpose of this project, the model not affected by the vegetation or other off-ground objects, i.e., DTM, is the appropriate choice.

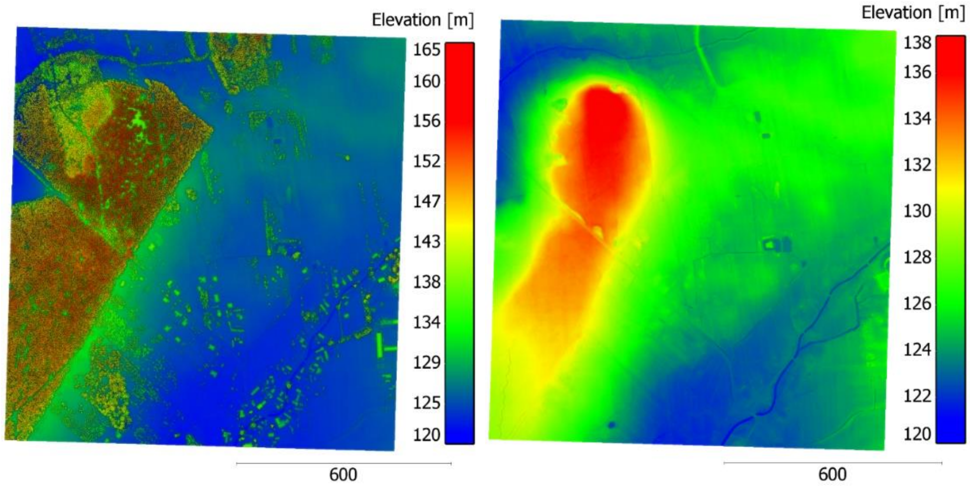

Figure 8: Visualization of DSM (left) and DTM (right).

3.2.3 Data collected

The data collected to test the proposed solution are:

- ALS point cloud collected in the scope of the ISOK project (isok.gov.pl/index.html) (Figure 9)
- UAV photogrammetric data collected for one field with an area of about 35 ha
- Shapes of borders of 3 neighbouring catchments which include parcels of the Polish case study (Figure 9).

The ALS data were collected for this area in 2012 or 2014 depending on the region. The nominal point cloud density is at least 4 points/m^2. This density means that the average point spacing is 0.5 m which can be the minimal size of the cell during DTM creation. Any higher resolution DTM will cause a larger size of the model without bringing any additional useful information. The ALS point cloud was classified, i.e., each point got the number of the class to which it belongs. Types of recognised classes are specified in the LAS file format (www.asprs.org/a/society/committees/standards/asprs_las_format_v12.pdf) and include, among others, the "ground" class which contains all points representing the reflection from the terrain surface. Such classification simplifies processing of ALS data in terms of DTM creation. The ALS data was obtained from the administration office that keeps surveying products of the ISOK project (www.gugik.gov.pl/projekty/isok/produkty) in its database. The total number of points collected from the database is about $1.13 \cdot 10^9$ points.

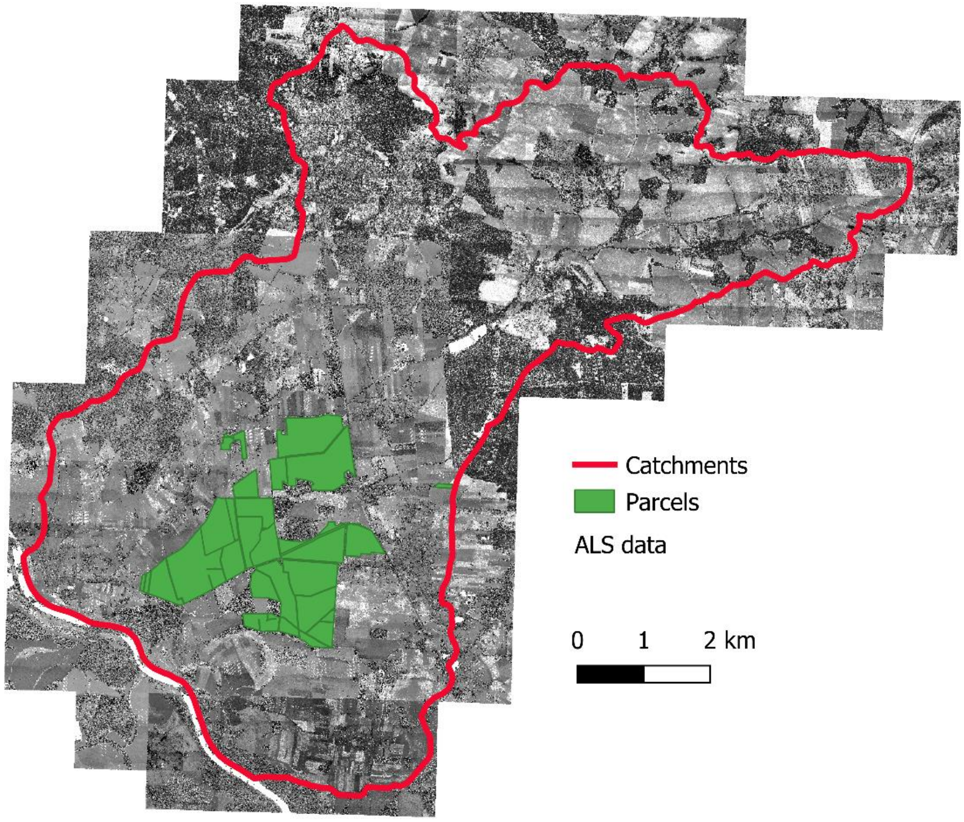

Figure 9: Coverage of ALS data with respect to parcel and catchment location.

The UAV data were collected for selected fields, in which soil sensors were installed (after flights). The acquisition of UAV data were executed using Aibot X6 V2 hexacopter (Figure 10) equipped with 36 Mpix Nikon D800 DSLR camera with 24 mm focal length lens. The areal extent selected for the UAV acquisition campaign is based on system performance (e.g., flight duration, speed), legal limitations (e.g., maximal flying height), and assumptions of data processing (e.g., minimal image overlap). The results from these assumptions were 6 separate flights along parallel lines (Figure 11) executed at flying height equal to 100 m above ground level. The planned size of a single pixel in the field was equal to 2 cm that is sufficient to create a very detailed DTM. In addition to flights, 20 cardboard markers of Ground Control Points (GCPs) were placed on the surface (Figure 11). GCPs were measured using a surveying-grade Global Navigation Satellite System (GNSS) receiver to determine coordinates of these points necessary in photogrammetric processing. The accuracy of measured GCPs was equal to 3 and 5 cm in the horizontal and vertical direction, respectively. Note that this accuracy, especially in the horizontal plane is better than the accuracy of ALS points. In total, 770 images were collected (Figure 11).

Figure 10: UAV data acquisition.

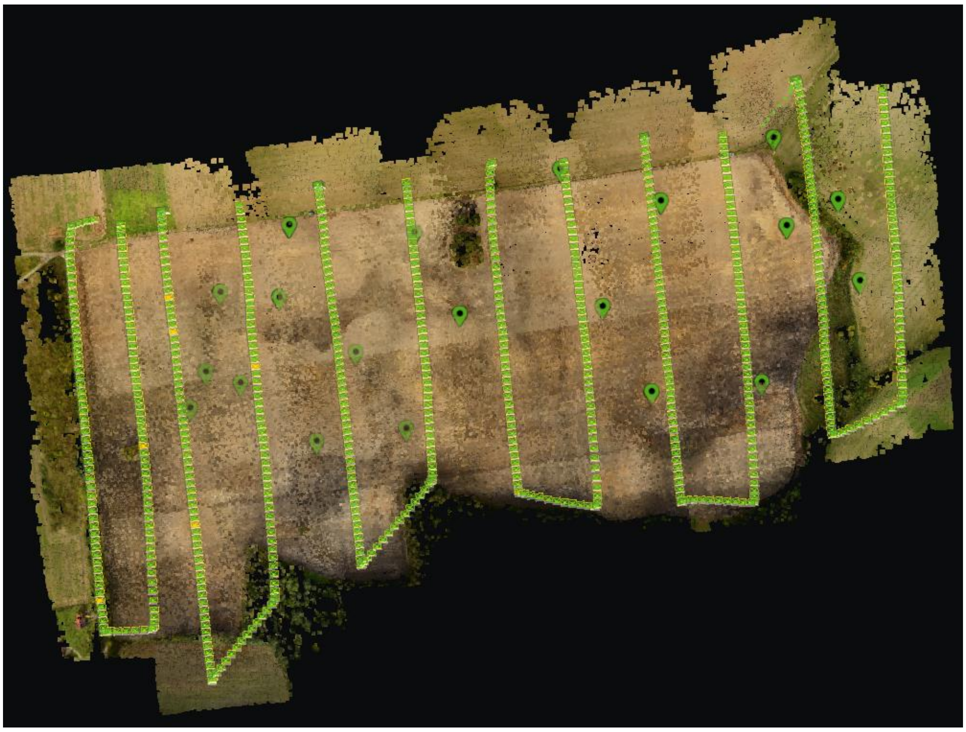

Figure 11: Images collected along lines and location of GCPs.

3.2.4 UAV data processing

Collected UAV data were processed according to a typical UAV data processing workflow that consists in (1) image block adjustment by aerotriangulation with GCPs, (2) image dens matching that results in the dense point cloud, and further processing of (3) DSM and orthomosaic which were created, though not used during development of the final DTM. The accuracy of the image block adjustment determined as the Root Mean Square Error (RMSE) of residuals measured in the field, and determined from photogrammetric model coordinates of GCPs, was equal to 7 cm. This parameter describes internal accuracy: how the photogrammetric model fits GCPs measured in the field. The absolute accuracy (accuracy of absolute terrain heights) will be worse since terrain heights in DTM are also affected by mentioned above errors of GCPs measurement using GNSS receiver. However, it should be emphasized that the error obtained during aerotriangulation has minor impact on the absolute accuracy of UAV photogrammetry products. The second stage of image processing is the point cloud creation by means of image dense matching. The point cloud created from collected images contains almost 2.4 billion points that gives average point cloud density of more than 4000 points/m^2 and average point spacing equal to 1.5 cm. Figure 12 presents the visualisation of the created point cloud. It clearly shows that the UAV photogrammetry does not allow to create ground points in vegetated areas. Very high point cloud density allows to create high resolution DTM that shows trails after agricultural machines and soil ridges (Figure 13); however, it is extremely large (>2 GPix for single tested area), thus difficult to use in practice.

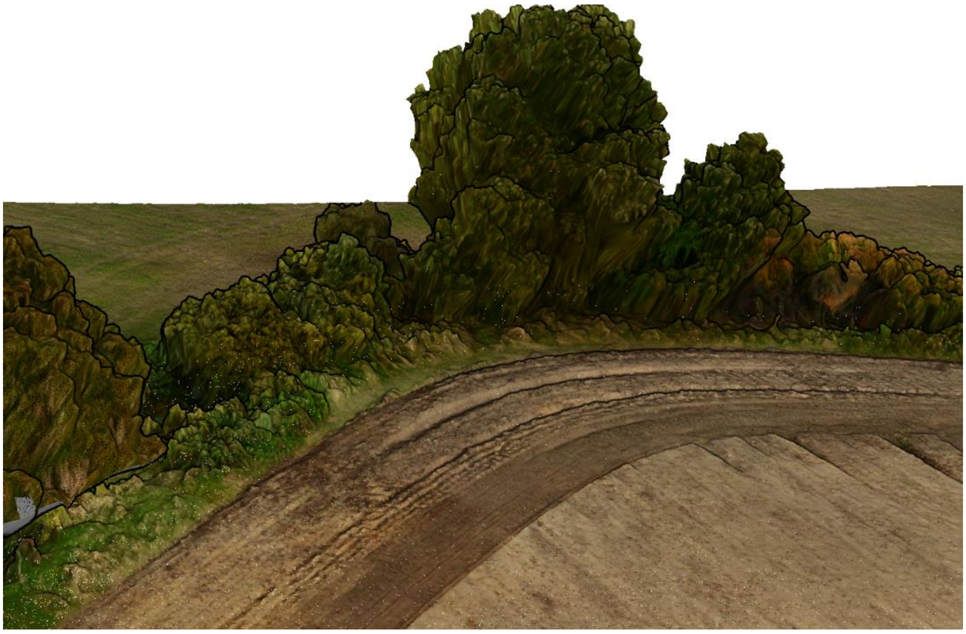

Figure 12: Created dense point cloud

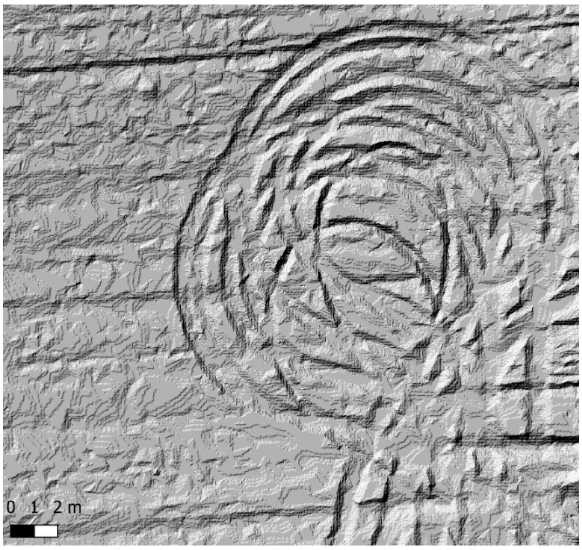

Figure 13: 2 cm DTM created from dense point cloud.

3.2.5 Comparison of DTMs created from ALS and UAV photogrammetric data

The comparison between two DTMs created for the same area but using different techniques might show strong and weak points of the ALS and UAV data. The visualisation of two DTMs created from point clouds of similar density, but collected using different techniques is shown in Figure 14. The DTM created from ALS data is rougher than the model created from UAV data. The reason for this is probably the presence of some low vegetation during ALS data acquisition and insufficient accuracy of point cloud classification. The ALS data was collected on 11.03.2012, thus plants could start to grow on this field. Such plants (small height, low density) pose a big challenge in an automatic point cloud classification or filtering to extract ground points. In addition, such points are very difficult to find and remove manually. However, they did not negatively impact the DTM, thus such points may be classified as ground points in archive databases. In contrast, UAV flights were performed over the field without any vegetation resulting in a much smoother DTM, though the surface of the field was rougher.

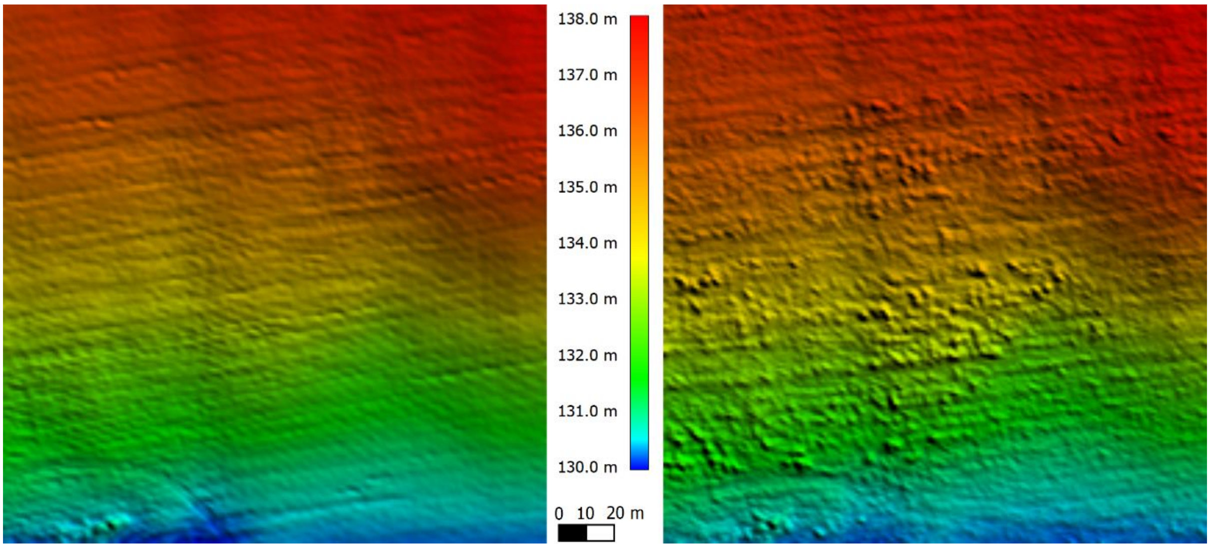

Figure 14: 1 m DTM created from dense point cloud (left) and ALS point cloud (right).

Beside differences in the noise, also differences in geometry (height) between these DTMs may occur. These differences were calculated as the height difference between points created from UAV data and DTM created from ALS data, but in the form of Triangulated Irregular Network (TIN) model. This method was selected in order to avoid interpolation of photogrammetric data DTM in areas without points (vegetated areas) and to avoid interpolating ALS data DTM during its conversion from TIN to GRID format. The visualisation of calculated height differences including the histogram is shown in Figure 15. The distribution of height differences shows that in some places DTM created from UAV data is higher than DTM created from ALS data (red colour in Figure 15) and in some areas it is opposite – DTM created from ALS data is higher than DTM created from UAV data (blue colour in Figure 15). The reason for these differences may include tillage, terrain levelling after removal of trees (see central part in the North in Figure 15), local errors of photogrammetric model, inaccuracy of ALS points, errors of GCPs, and others. Negative values of height differences (UAV model below ALS model) can be explained by the mentioned above low vegetation in ALS data (north-west part of the field). This explains also the mean height difference between both models that is equal to – 6.1 cm. This means that the UAV model is slightly lower than the ALS model. Considering the impact of vegetation and the accuracy of the GCP measurement, the changes are insignificant. The standard deviation of the height differences is equal to 10.1 cm.

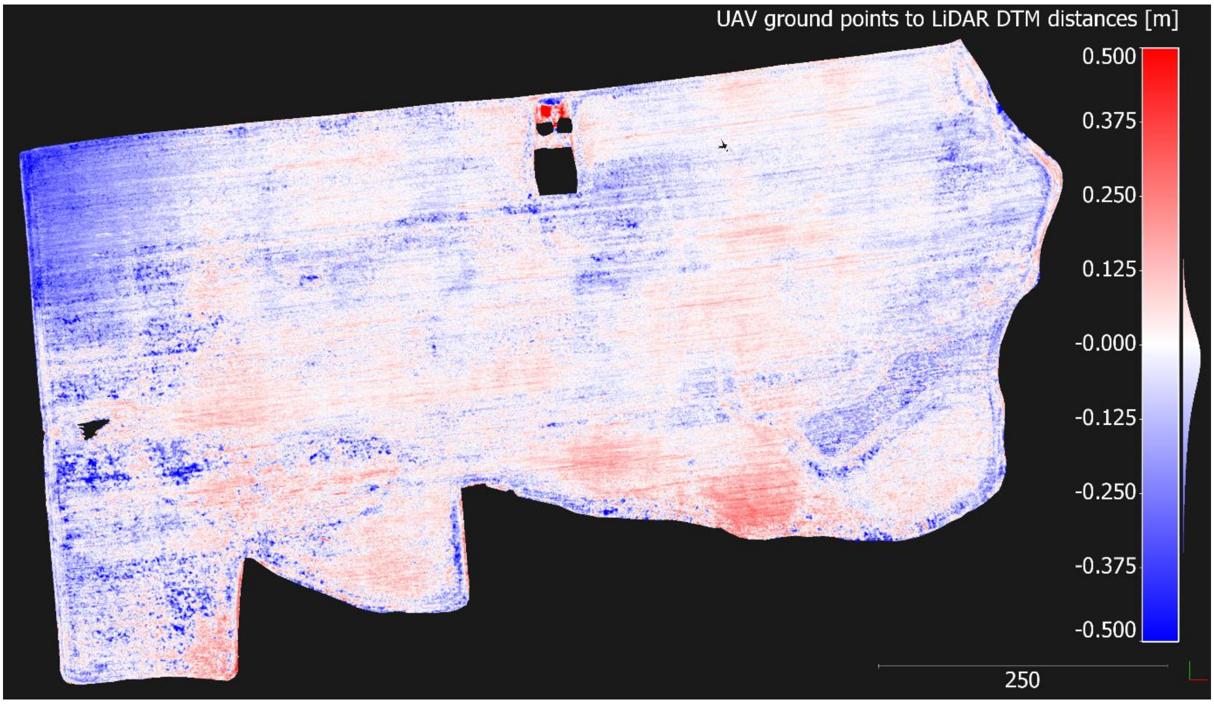

Figure 15: Height differences between terrain models created from UAV photogrammetric dense point cloud and ALS point cloud.

3.2.6 Point cloud integration and refinement

The DTM for the catchment using both types of data may be created in two manners – by integrating the two DTMs or by building one DTM but from integrated point clouds. The second method was selected since additional smoothing of seemliness is not needed and is executed during the process of DTM interpolation from the point cloud. The integration of two point clouds was executed by extracting from the UAV point cloud only ground points for the field surface. This was executed by manually cutting the point cloud along natural edges (e.g., bound next to road, trees or ditch). The same lines were used to cut ALS ground point cloud, but all points in the area of the field were removed. Such selection of the seamlines between point clouds caused that the seamlines will not be visible in the integrated point cloud, and final DTM.

Before the creation of the final DTM, the integrated point cloud containing only ground points was visually examined. It was observed that decks of bridges were classified as ground points in the ALS point clouds (cyan circle in Figure 16a), causing that water flow in the stream was not preserved in the DTM (cyan circle in Figure 16 b). A similar issue was observed in cases where dense vegetation grows next to the stream causing lack of ground points in that place (purple circle in Figure 16 a), and consequently wrong interpolation of DTM (purple circle in Figure 16 b). These issues were fixed by manual removal of points on the bridge deck and adding artificial points on lines connecting lowest points in the middle of the stream next to areas without points (Figure 16c). These points added to the ground points allowed to interpolate a DTM that keeps the water flow in the streams (Figure 16d).

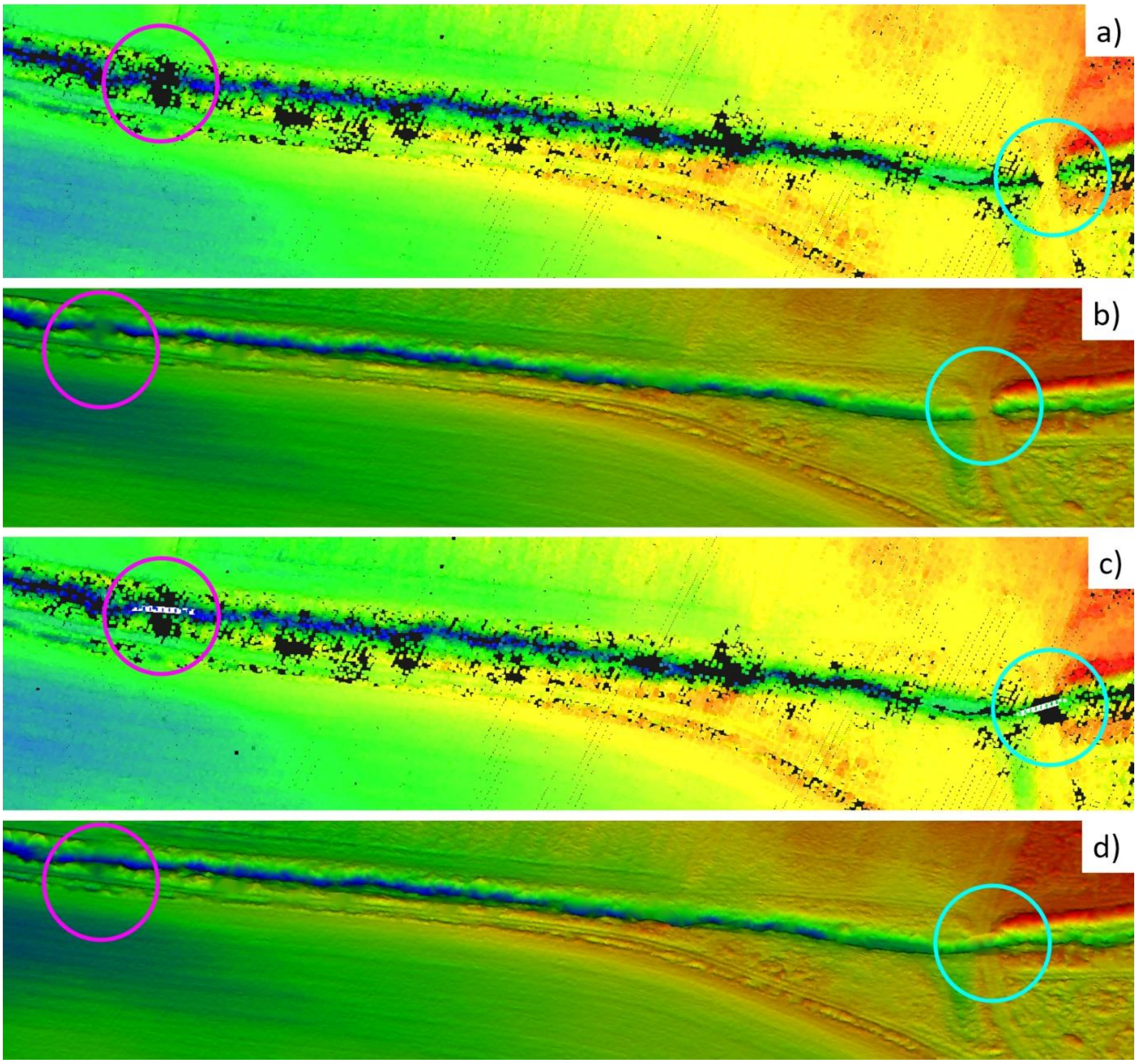

Figure 16: ALS ground points obtained from archive data, b) DTM created from ALS ground points, c) Refinements of ALS ground points, d) DTM created from refined ALS ground points. Purple circles indicate part of stream without ground points. Cyan circles indicate place with bridge.

3.2.7 Creation of final DTM

After integration of point clouds and its refinement, the point cloud was cut along the shape of the catchment extended by 50 m. Although the size of the GRID in the final DTM was selected as 0.5 m, a much bigger buffer was selected to avoid an edge effect in the DTM even if the original 0.5 m DTM will be up-sampled to lower resolution (bigger GRID size). The density of the ALS point cloud allows it to create 0.5 m GRID or larger. The smallest size was selected since it keeps the most detailed shape of the terrain and shows even small ditches. If the GRID size will be larger than the width of streams, then such streams may not be indicated in the DTM. The GRID DTM was interpolated from the point cloud using linear interpolation. It means that first the TIN model was created and then heights of points in GRID nodes were interpolated on TIN facets. Since none of the techniques used (ALS and UAV photogrammetry) allows to collect points of the ground surface covered by water (e.g., bottom of the pond), the proper interpolation of DTM in such places is practically impossible. Two solutions to this issue are used. The first solution excludes such areas from the DTM; however, it is executed usually manually because it is practically impossible to distinguish automatically in the ALS point cloud areas covered by water – points may exist on the water surface (laser beam can be reflected from e.g., duckweed), and ground points may be missing in the dense forest. The second solution is to interpolate the DTM in such areas, though in these areas it shows the terrain surface incorrectly. This solution is also automatic and it was selected to build the final DTM (Figure 17). However, small modifications were applied to exclude from the DTM larger areas covered by water (e.g., ponds). It was achieved by removing long edges from the TIN model before interpolation of the GRID. Long edges in the TIN model are created if points are missing. However, ground points are missing in the point cloud also in areas below buildings, though the DTM should be interpolated in such areas. To interpolate the DTM even below large buildings, the maximal allowed length of the edge in the TIN model was set to 50 m. The resulting DTM for the whole catchment covers an area of about 66.3 km^2.

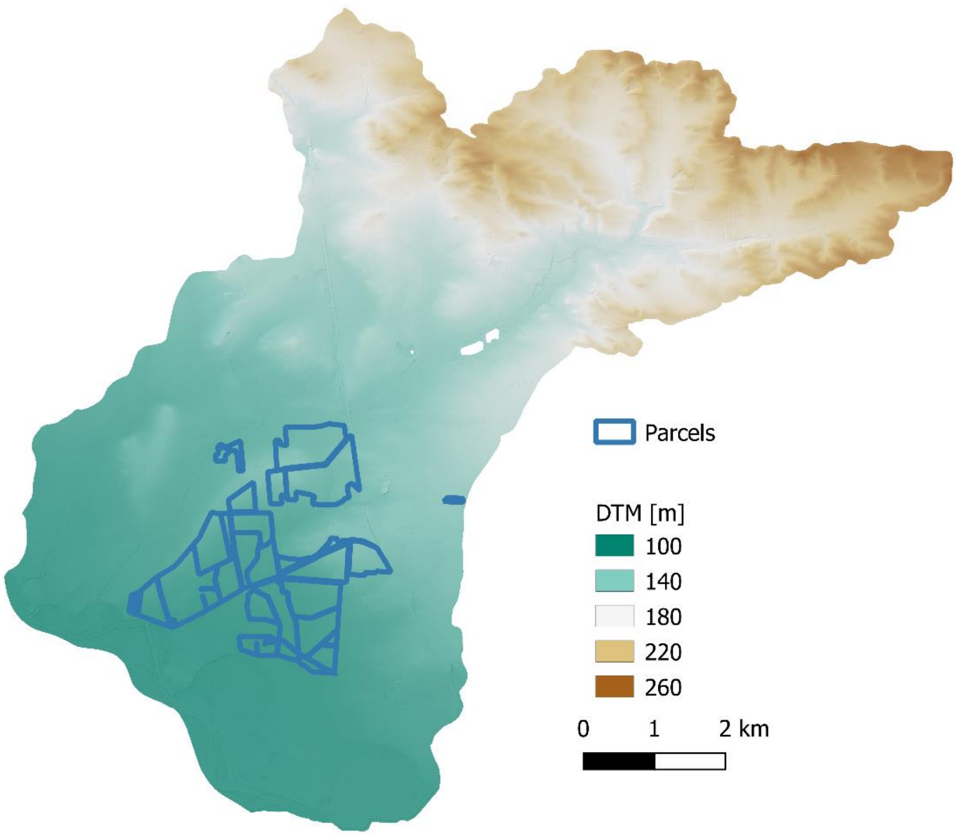

Figure 17: DTM created for catchments covering Polish case study.

The work described above showed how the catchment inventory in a form of detailed DTM can be created. The presented approach is relatively cheap and, in some cases, may be executed almost for free. This can happen if the archive ALS data is free of charge and there is no need to perform UAV flights to collect additional data. The condition to build detailed and accurate DTM for the catchment is the ALS data, since this technology allows to map larger areas and collect some information about the terrain surface even in vegetated areas. However, costs of performing such data acquisition are very high, thus the availability of ALS data collected for other purposes, even several years ago, seems to be mandatory. The best if available ALS point cloud is already classified because it simplifies the process of DTM creation. Performing flights with UAV for the entire area of the catchment is practically impossible from the technical point of view and also difficult from the legal point of view due to presence of areas with restriction to UAV flights. The DTM created from ALS data may be improved by collecting UAV data. Unmanned aerial systems collecting laser scanning or photogrammetric data can be used. Due to high costs of the equipment of the ULS system, the UAV photogrammetry is preferred. The limitation of the UAV photogrammetry is that it can be used only to build DTM in non-vegetated areas. In addition, other issues related to the restrictions in UAV flights may also occur. Currently EU states adapt their law to match Commission Implementing Regulation (EU) 2019/947. During this adoption some additional limitations may occur but in future performing UAV flights should be very similar in all EU member states.

4 Farm Model Predictions

4.1 Soil water balance model

The AGRICOLUS model for irrigation management, is a soil-water balance model which can support farmers and other professionals in assessing the water requirements from daily field to seasonal farm scale. The implemented model is a deterministic system in which different blocks concur in estimating the final crop needs and the support system on a daily basis.

The units of such model are:

1. Crop water demand
2. Soil water balance
3. Sensors
4. Irrigation log
5. Water quality
6. Decision support
7. User interface.

The proposed model is embedded in a DSS informing the user on the soil moisture content and the irrigation needed (in terms of timing and quantity).

4.1.1 Crop water demand

To assess crop irrigation demand we followed the approach proposed by FAO Irrigation and Drainage paper n. 56 (Allen et al., 1998). Crop requirements are estimated with an algorithm that simulates the reference crop evapotranspiration (ET_0) according to the Hargreaves and Samani equation (Hargreaves and Samani, 1985). Crop evapotranspiration (ET_c) is obtained multiplying ET_0 by the crop coefficient (kc) which is specific for each crop and for each crop phenological phase (Figure 18).

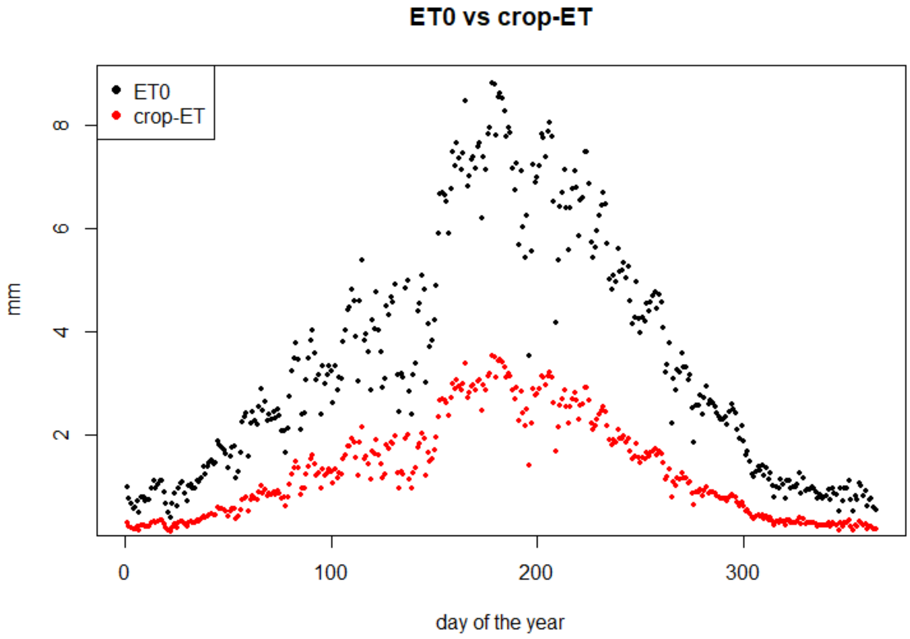

Figure 18: Daily comparison between reference evapotranspiration (ET0) and crop specific evapotranspiration for an olive orchard.

The first section of the module estimates the crop phenology using a degree-day accumulation model. For each species it has been defined the minimum and maximum temperature threshold and the degree-day requirements for the main phenological stages.

Results of these equations are presented as a BBCH value which is a specific scale for generic crop phenology classification. The BBCH derives from the cereal code system developed by Zadoks 1974, and it is based on a decimal code system, which is divided into principal and secondary growth stages (e.g., BBCH62 means <first digit> the plant is in flowering stage with <second digit> 20% of flowers open).

The crop coefficient (Kc) is a parameter used to calculate crop evapotranspiration (ET_C) and it express the ratio between the crop ET_C and a reference standard crop evapotranspiration (ET_0 – see section 4.1.3. Sensors). Kc varies during the growing season according with changes in vegetation and ground cover (Figure 19). Kc is further tuned according with the specific crop management situation (e.g., mulching) and crop use (e.g., fresh tomato, processing tomato). The Kc is estimated using as input the phenological stage and using a set of reference crop and stage specific parameters based on an extensive collection of literature data.

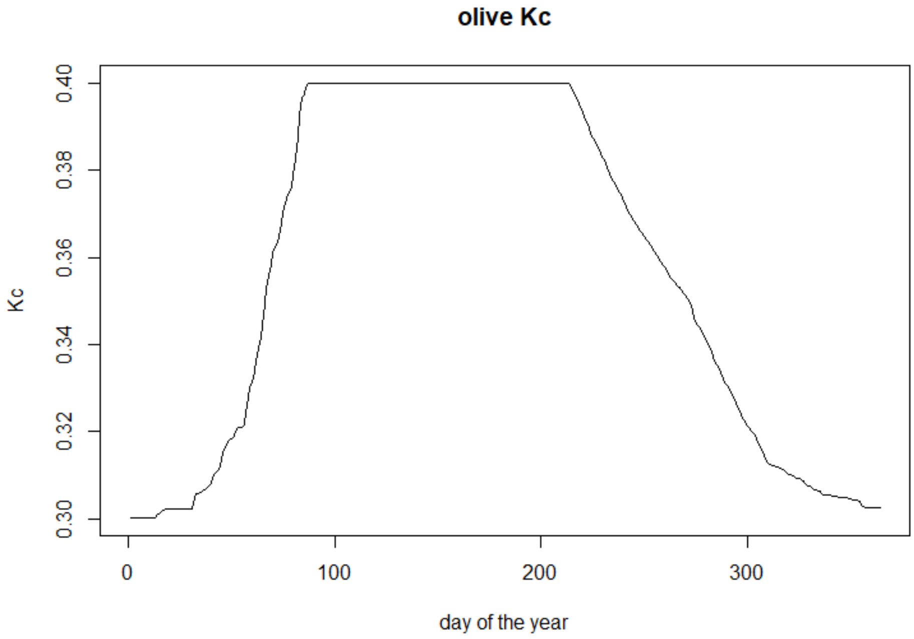

Figure 19: Temporal dynamics of the Olive Crop Coefficient (Kc).

Water balance model calculates a Crop Stress Coefficient (Ks) that depends on crop and actual water content. Ks is calculated using the method explained in the FAO56 The Ks estimates the effects of different levels of soil water stress on crop in reducing evapotranspiration.

Another crop sub-model estimates the root growth to define the soil depth explored by the plant based on crop phase, and degree-day accumulation.

4.1.2 Soil water balance

The soil at the root zone level is the second pillar of the model structure, being the container where the water content may fluctuate. Soil data to run the model may come both from soil analysis or from a classification of the field following the soil texture triangle scheme (see Section 2.1.2 - soil data). Data accuracy is critical for model efficiency. Starting from the soil data, different pedo-transfer functions are used to assess:

- Field Capacity (FC) that commonly refers to the water content that a soil is able to hold against gravitational forces
- Total available water (TAW) that is the water content which plant roots can extract
- Readily available water (RAW) represents the portion of the water that crops can easily assimilate without any stress.

For each crop two types of soil moisture thresholds based on the percentage of RAW have been defined:

- Optimal threshold is the optimal water content for the crop; usually this level is below the field capacity
- The critical threshold is the water content level that requires an irrigation by the farmer to avoid stress conditions to the crop; it depends on the crop and crop stage.

The most appropriate time to irrigate is when the deficit (the amount of water needed by the field to return the soil to the field capacity) exceeds a critical threshold (crop-specific). The volume of water that must be supplied to the soil is instead equal to the amount needed to restore the soil to the optimal threshold.

4.1.3 Sensors

Data coming from sensors, particularly weather data, are the engine of the system. The cardinal temperatures, rainfall and the geo-positioning of the sensors are the minimum input requirements for the model. Data are usually at hourly resolution but in case of daily data collection, the model may still perform with a good level of accuracy.

These data are first used in the degree-day model for phenology that is somehow the clock of the crop needs (see section 4.1.1. - water crop demand), and also to calculate reference evapotranspiration (ET_0) and the rain contribution to the soil water content. ET_0 can be defined as the amount of water lost due to evaporation and transpiration in a defined time interval from a surface covered by a standard meadow crop with standard parameters (uniform, low, fully vegetative activity, optimal irrigation and nutritive condition).

ET_0 can be calculated using two methods:

- Hargreaves and Samani equation (Hargreaves and Samani, 1985) requires as input the minimum and maximum daily air temperature, the latitude of the field and the day of the year; this equation shows a good trade-off between a discrete level of approximation and a low number of parameters needed to calculate it;
- Penman-Monteith equation (Allen et al., 1998) is typically referred as a standard method for the computation of ET_0; it requires air temperature, relative humidity, wind speed and solar radiations; the main limitation in the application of this equation is that all data must be measured with a good level of accuracy whereas in real farm conditions these parameters may not be collected or sensors may have issues resulting in not accurate estimation of ET_0.

We compared the two approaches with real data and the ET_0 calculated with Hargreaves-Samani equation shows an acceptable correlation with ET_0 calculated with the equation of Penman-Monteith, in selected fields (Figure 20 - Pearson's r =~0.8). These tests were necessary due to the impact of ET_0 on the whole model output. The model calculates by default the Hargreaves evapotranspiration, then if the data of relative humidity, solar radiation and wind are all available the estimation switch to the Penman-Monteith equation.

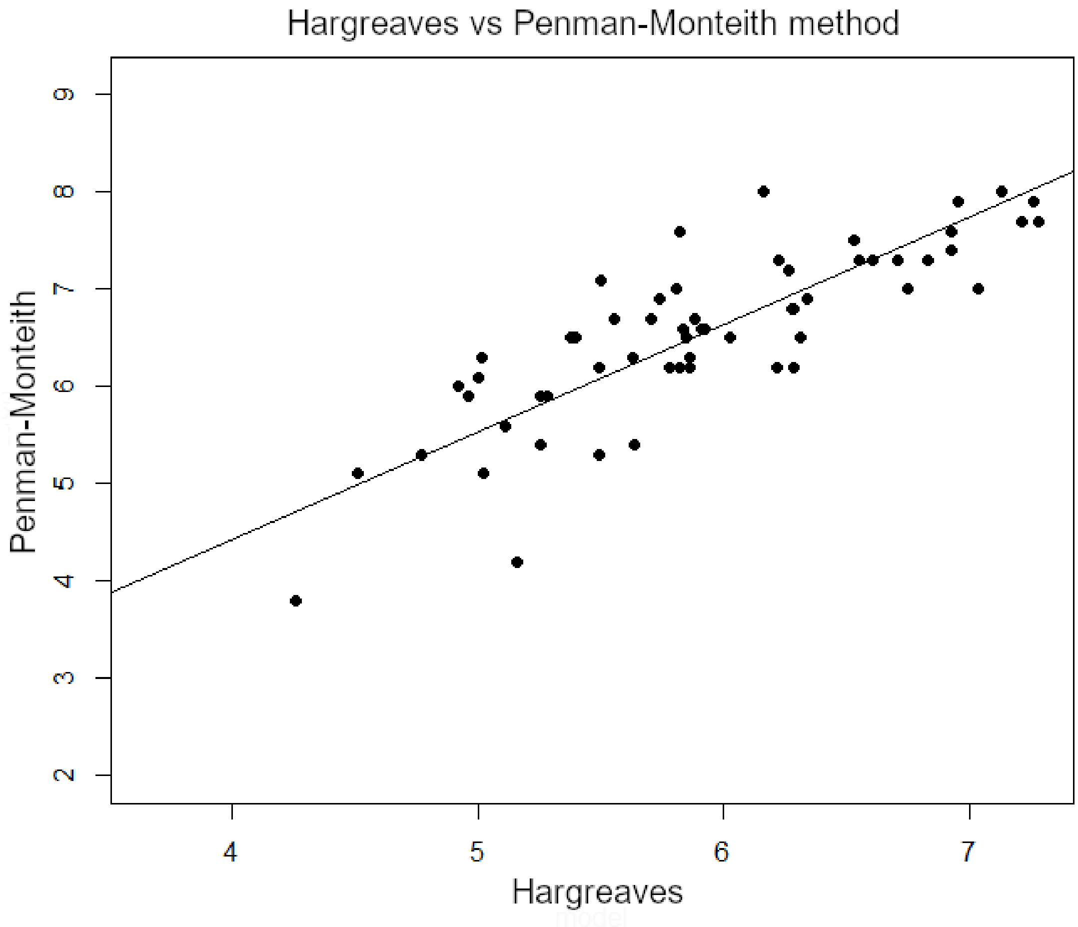

Figure 20: Comparison between Hargreaves-Samani and Penman-Monteith method for the same sensors station.

4.1.4 Decision support

The model is embedded into a decision support system (DSS) where the user can directly assess model data, trend, parameters and risk status.

The final output is the definition of the crop daily status and the irrigation needed in order to save water and maximize production (Figure 21). The irrigation is suggested when the deficit level (that is the amount of water which restores the soil at the field capacity level) overtook the critical threshold and plant starts to accumulate stress.

A rapid intervention here is needed. To avoid water wastage, the system is designed to restore the water level at the optimal threshold instead of field capacity. Irrigation needed is dependent on irrigation system efficiency which is a field parameter (see section 2.1.1. - fields and crops) and it may widely vary, deeply contributing to the final suggested irrigation value (Table 3). This parameter is implemented using a modified version according to Howel (2003). New irrigation systems can be added to the model configuration to adapt it with more types of technology. The average efficiency can be updated.

Table 3: Irrigation system efficiency (Howell, 2003).

Irrigation system	Average efficiency
furrow	0.6
sprinkler	0.75
drip	0.9
pivot	0.88
subsurface	0.9
microspray	0.85
side scrolling	0.87

The irrigation logs are fully integrated in the model (see section 2.1.3. - irrigation and fertilisation log). The model uses the irrigation logs to update the soil water content according with the water amount provided by irrigation and the system efficiency.

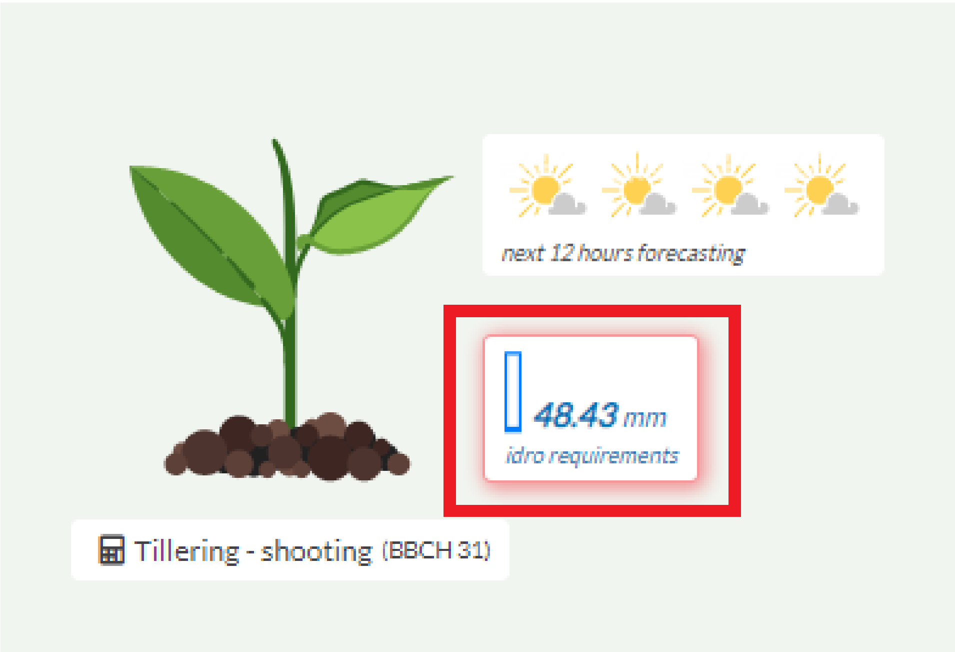

Figure 21: Example of DSS summary overview with the irrigation suggestion (highlighted).

4.1.5 User interface

The user interface is designed to help user in accessing and editing data in an intuitive and guided way. Data for phenology (Figure 22) and irrigation (Figure 23) are provided in the form of plots and tables and updated daily. Updates are also provided in case of user input (e.g., phenological observations, crop operations, irrigations).

A summary overview with alerts and risk status is delivered grouping all the fields within the farm centres. Moreover, the system allows the user to intuitively jump from models to sensors/soil data, fields, and irrigation log, thanks to a side tool-section and the possibility of filtering and grouping data per crop, field or farm centre.

A useful tool integrated in the DSS is the weather forecasts data, which are used as 7-additional days of forecasted data by the model. These can be used for fields management and planning. The forecast is highlighted in the chart with a different background colour and dotted lines (Figure 23).

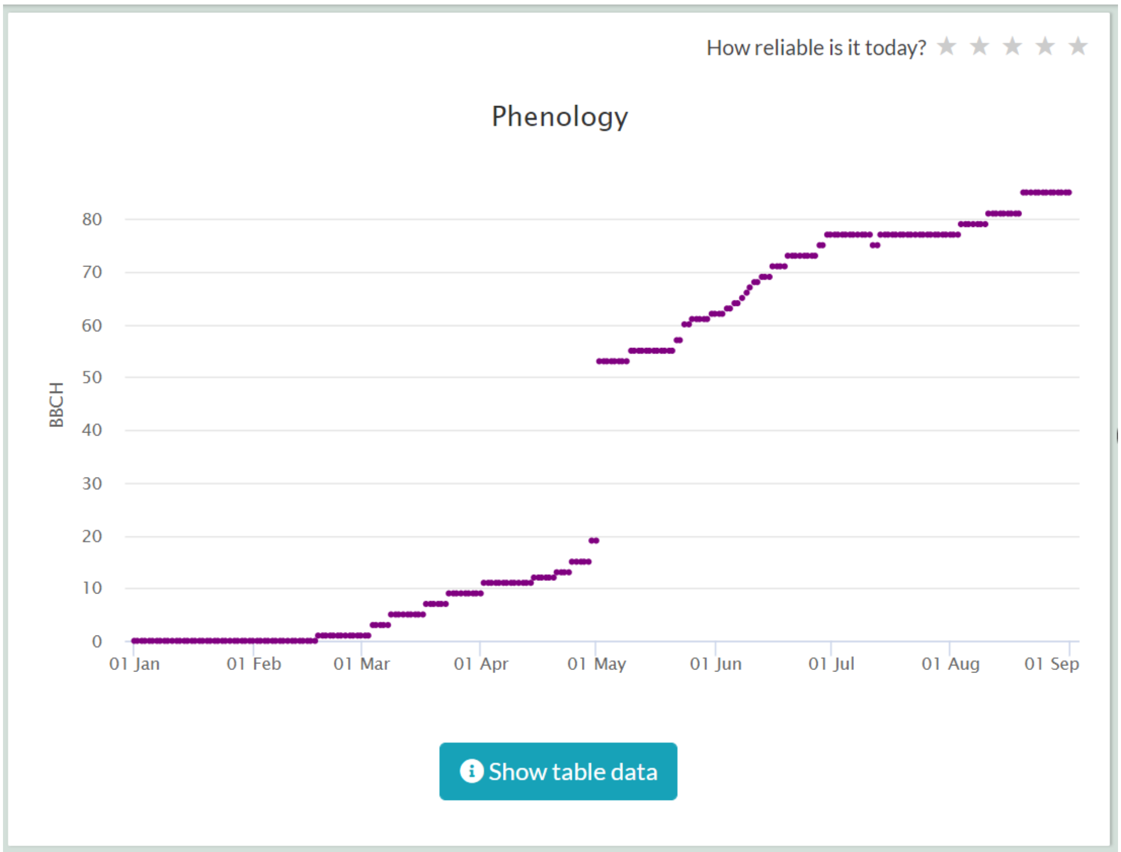

Figure 22: Example of phenological model visualization for grape.

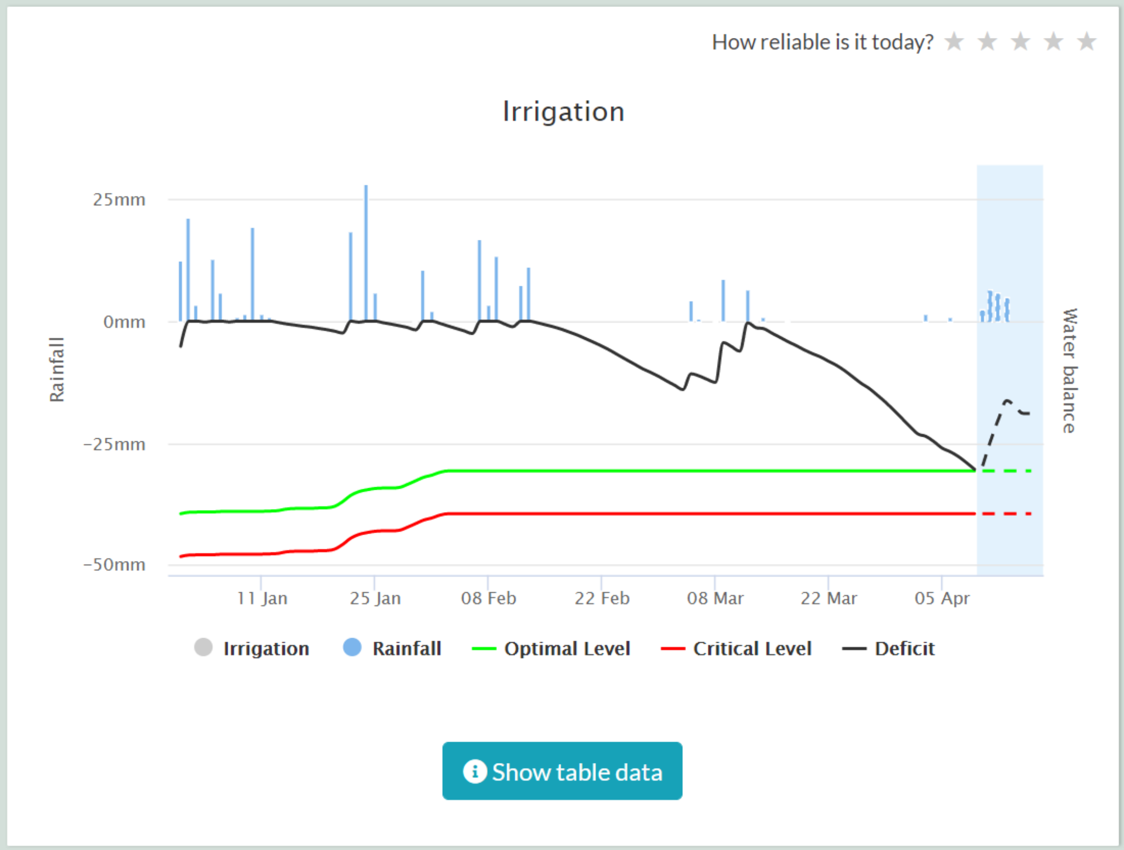

Figure 23: Example of irrigation model visualization where deficit line (black line) is compared to the two thresholds (red = critical, green = optimal). The part of the model calculated with the forecasted weather data is embedded in the blue section on the right.

4.2 Nutrient balance model

A macro-nutrient crop requirements model based on nitrogen, phosphorous and potassium balance in the field has been developed and integrated in the AGRICOLUS platform. The model provides insights on the different nutrient needs in the entire lifecycle of the selected crop and it is currently available for about 108 crops with related crop uses.

The model is fully automated in the AGRICOLUS platform architecture, requiring just a few additional inputs from the user such as fertilisation log. The algorithm gathers data from the field history as well as from crop traits, operations carried out in the field, soil type and both current weather and 30-years climatic data.

The nutrient balance is composed by the following different modules that estimate the main components of the balance:

1. Negative components (loss of nutrients)
    a. Crop uptake
    b. Leaching
    c. Denitrification and volatilization;
2. Positive components (increase of nutrients)
    a. Mineralization of the soil organic matter
    b. Residuals from previous crop

c. Nutrient contained in rain and irrigation water
d. Nutrients coming from mineral and organic fertilisation.

The model uses as input the farm data, the soil analysis and the weather data from the weather stations. The balance needs to evaluate the crop requirements also for future period. To estimate the future dynamics, climatic data from an external provider were integrated. These are geo-localized thirty-years average data, providing a reasonable level of approximation for many computing operations. When new measurement data are available, the climatic data are progressively replaced by real data tuning and increasing the accuracy of the model.

4.2.1 Balance - negative components

The **crop uptake** is the main component of the balance which expresses the nutrient the plant requires in the entire cycle from seeding/transplant or dormancy (in case of tree crops) to the end of the agronomic cycle (typically harvest).

This is dependent on several attributes such as the crop yield, harvest index, dry matter content, nitrogen content, among others. Many of these values are parametrized and are stored in the model database while some others (e.g., yield) need to be entered by the users. If the estimated yields are not available, a reference value for the crop is adopted.

The methodology to calculate crop uptake is different for herbaceous crops, tree crops or in case of nitrogen fixing crop such as legumes. For permanent crops, the nutrient uptakes related to the structural growth of the plant are taken into account.

Leaching is an important agronomical and environmental issue, representing the loss of water-soluble nitrogen and potassium from the soil. The leaching coefficient is calculated on the basis of the precipitation amount and it is used to estimate nutrient leached from the portion of nutrient available for leaching.

Denitrification and **volatilization** are also considered using standard approximation values for the majority of the situations, excluding particular cases correction (flooded field).

4.2.2 Balance - positive components

Mineralization is a critical process for soil fertility since it is the process that converts organic nitrogen and phosphorous to mineral inorganic forms available for plants assimilation. Mineralization is computed for the period between the previous crop-harvest and the harvest of the crop. The coefficient of mineralization is calculated on a monthly basis and updated as a function of temperature, precipitation and soil parameters. Optimal mineralization conditions may tremendously concur to the nutrient mineral content in the soil for plant nutrition.

Residuals represent previous crop leftovers in the soil or pruning left in the field. The residuals contribution is computed in a period comprehended from the previous crop-residuals landfill (in the same field) and the harvest of the crop. This contribution may widely vary according to the harvest index, reaching a considerable amount in case of legume green manure.

Nitrogen dispersed in **rainfall** is estimated using monthly precipitation and a standard concentration value. If there are available data on irrigation water quality and nutrient content these data can be used to fix the balance. It has been performed an analysis of the potential use of the model for fertigation practices, but this function is out of the scope of the project objective.

Fertilisation logs are fully integrated in the model (see section 3.1.3. - irrigation and fertilisation log) being a register of crop operations and a direct model interaction tool where several input methods are possible depending on the type of fertilisation. The **fertilisation** contribution is finally recorded as positive inputs of the balance itself.

4.2.3 User interface

The nutrient balance model produces a summary of the results and a plot showing the nutrient dynamics.

The summary card (Figure 24) shows for each nutrient the total amount (kg/ha) required to balance the positive and the negative components, and the amount that needs to be distributed considering the amount distributed and entered in the fertilisation logs section.

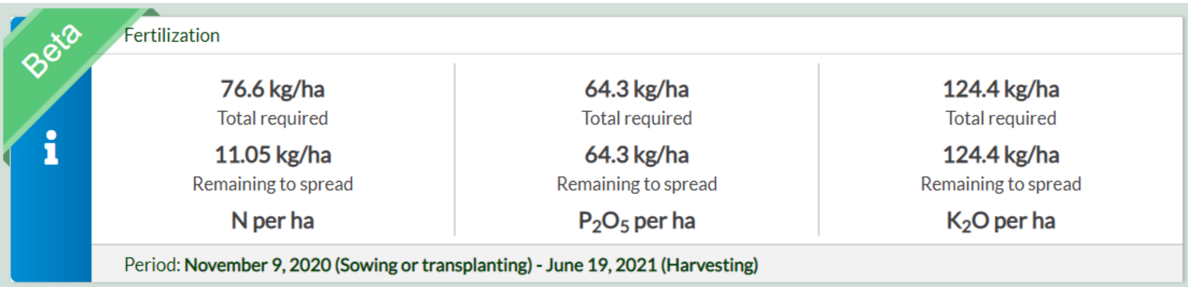

Figure 24: Summary card view of the fertilisation model.

A table (Figure 25) shows for each nutrient the amount of the single components of the balance.

Parameter	Type	N per ha	P_2O_5 per ha	K_2O per ha
Remaining to spread	-	193 kg/ha	132.2 kg/ha	246.9 kg/ha
Spreaded	-	0 kg/ha	0 kg/ha	0 kg/ha
Total required	-	193 kg/ha	132.2 kg/ha	246.9 kg/ha
Crop uptake	⇊	225.3 kg/ha	100.37 kg/ha	214.03 kg/ha
From denitrification	⇊	5 kg/ha	-	-
From volatization	⇊	0 kg/ha	-	-
From leaching	⇊	26.13 kg/ha	-	32.91 kg/ha
From crop residuals	⇈	0 kg/ha	0 kg/ha	0 kg/ha
From mineralization	⇈	45.01 kg/ha	1.24 kg/ha	-
From rain	⇈	18.45 kg/ha	-	-

Figure 25: Estimated amount for each component of the balance for each nutrient.

For each nutrient a chart compares the actual distribution with the estimated total crop demand (Figure 25). The part of the model calculated with real data is (visually) separated from the part calculated with climatic data by a different background colour.

Moreover, the system allows the user to intuitively jump from models to sensors/soil data, fields, and fertilisation log, thanks to a side tool-section and the possibility of filtering and grouping data per crop, field or farm centre.

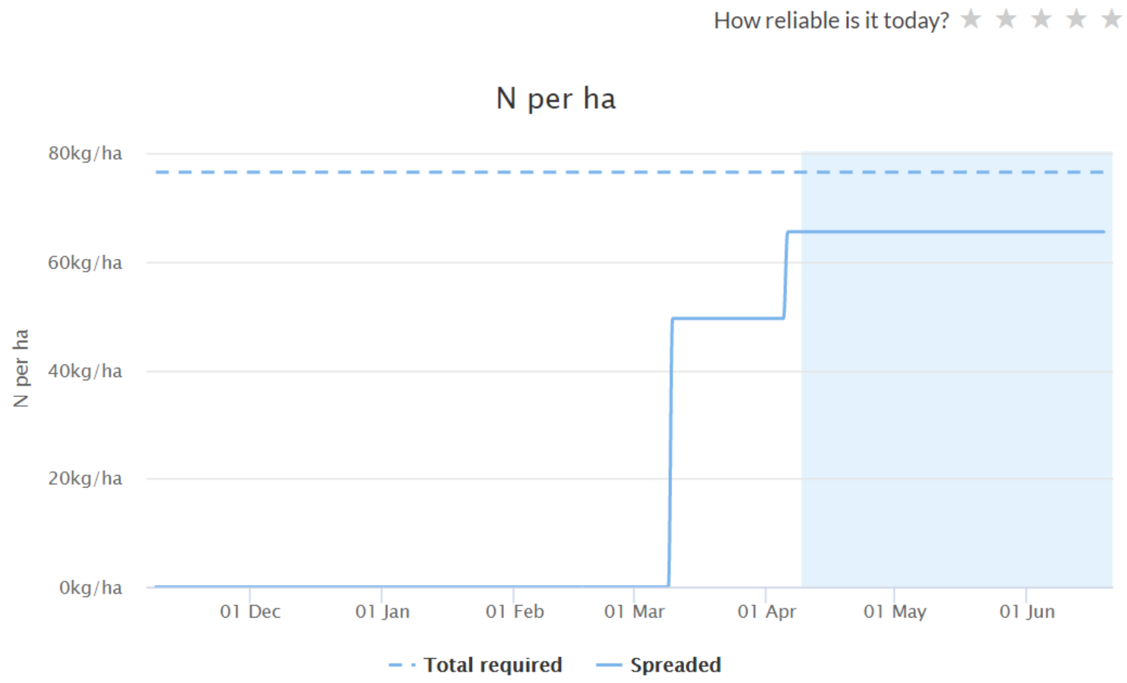

Figure 26: Fertilisation plot for nitrogen distribution. Solid line: spread fertilizer; dotted line: required fertilisation.

4.3 Hydrological predictions at the farm catchment scale

To produce seasonal weather forecast for the field sites, the System 5 forecasts (SEAS5) from the European Centre for Medium-Range Weather Forecasts (ECMWF) have been used. SEAS5 forecasts are provided as monthly outputs with steps of 1 to 7 months, and have been evaluated against historical observations in the WATERAGRI field sites in Finland, Germany, Poland, and Sweden. For application in farm model predictions, forecasts on monthly precipitation and temperature have been evaluated. The following sections describe the forecast data, access procedure, and evaluation results.

4.3.1 SEAS5 forecasts

The SEAS5 forecasts is ECMWF's fifth generation of seasonal forecast systems (see Johnson et al., 2019 for full description). Due to the complex and chaotic features of the climate system, there is a limited potential for precise forecasts beyond 10-15 days. Monthly or seasonal averages can however be predicted for longer periods due to the slow evolution of certain components of the climate system, such as the ocean and cryosphere (Johnson et al., 2019). The SEAS5 forecasts are based on numerical models which solve hydrodynamic equations for processes in the atmosphere and ocean, and consist of 51 ensemble members.

4.3.2 Accessing forecasts

Accessing the SEAS5 forecasts requires authentication from ECMWF and can only be used for research purposes. After receiving authentication, the main steps for accessing the forecasts through API and Python on Linux consists of downloading the ECMWF *Mars* script, installing the ECMWF API client library, and creating script-based data requests to download data in either NetCDF or GRIB format. Detailed descriptions for this access procedure are provided in ECMWF (2020).

4.3.3 Expert advice algorithm

To estimate the monthly forecasts based on the 51 forecast ensemble members in SEAS5, the *Expert Advice Algorithm* was used (Cheng & AghaKouchak, 2015). This algorithm uses a pool of expert estimates, in this case the forecast ensemble members, to arrive at a single estimate for each iteration. The mathematical properties of the algorithm ensure that the single estimate is at least as good as the best expert estimate at each iteration. In many weather forecast applications, the ensemble mean is used as the single estimate, but results have showed that this estimate can lead to biases due to strong similarities between the included climate models (Cheng & AghaKouchak, 2015).

4.3.4 Forecast performance at selected field sites

Historical data for forecast evaluation were acquired for the field sites in Finland (Siikajoki Ruuki), Sweden (Gårdstånga Nygård), Poland (Wroclaw), and Germany (Selhausen) for 1981-2020. While SEAS5 produce current forecasts for 51 ensemble members, the re-forecasts from 1981 consist of 25 ensemble members (ECMWF, 2021). The re-forecast evaluations were performed for the agricultural season (May-Sep) for all forecast steps (1-7 months). Due to the high uncertainty in weather forecasts over several months, the evaluations were performed on both the values and the sample terciles of the distribution for each evaluation period (Low, Mid, High). The evaluation results are presented as the percentage of correctly forecasted terciles, and the root mean squared error (RMSE) between the forecasted and observed values (monthly average temperature in °C and monthly total precipitation in mm).

Figure 27-30 show the evaluations for monthly forecasts of 1-3 steps for precipitation from 2012-2020 for Gårdstånga Nygård, Selhausen, Siikajoki Ruuki, and Wroclaw. The RMSE for the 1st forecast month varies between 23-32 mm per month, and 28-35 mm per month for the 3rd forecast month. The higher forecast skill in Julich can be explained by the clearer seasonal distinction in precipitation patterns compared to the other sites. In general, the results show that forecasts on total monthly precipitation are not reliable even for steps of 1 month, and with only slight differences in forecast skill between 1 and 3 forecast months.

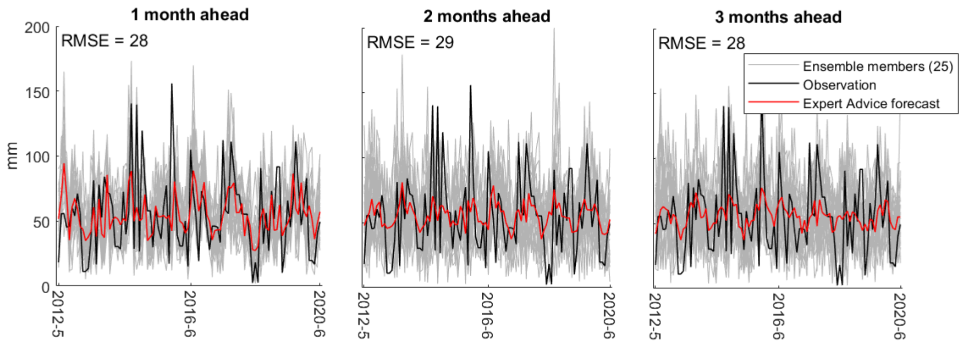

Figure 27: Monthly precipitation observation and forecasts for Gårdstånga Nygård (Swe) for 2012-2020.

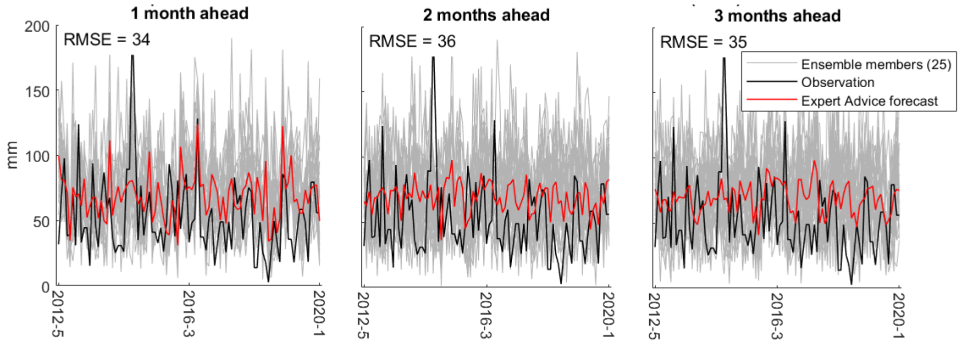

Figure 28: Monthly precipitation observation and forecasts for Selhausen (Ger) for 2012-2020.

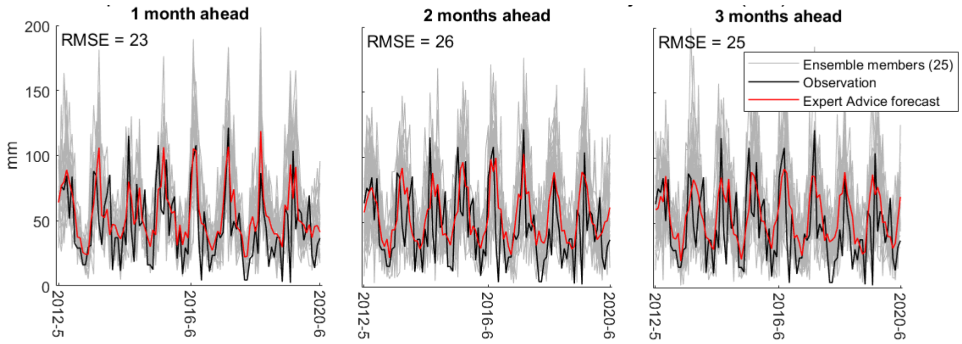

Figure 29: Monthly precipitation observation and forecasts for Siikajoki Ruuki (Fin) for 2012-2020.

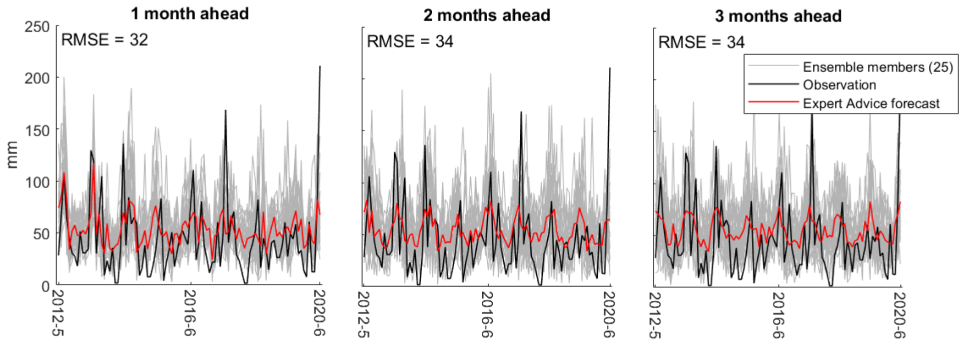

Figure 30: Monthly precipitation observation and forecasts for Wroclaw (Pol) for 2012-2020.

Figure 31-33 show the results for the temperature forecasts for Gårdstånga Nygård (Swe), Siikajoki Ruuki (Fin), and Wroclaw (Pol). In comparison to the precipitation patterns, temperature follows distinct seasonal patterns with only slight interannual variations. The RMSE for the monthly average temperatures is between 1-2 °C for the 1st forecast month, and 2-3 °C for the 3rd forecast month. Contrary to precipitation forecasts, variations in monthly average temperatures can thus be forecasted with high reliability up to 3 months in advance.

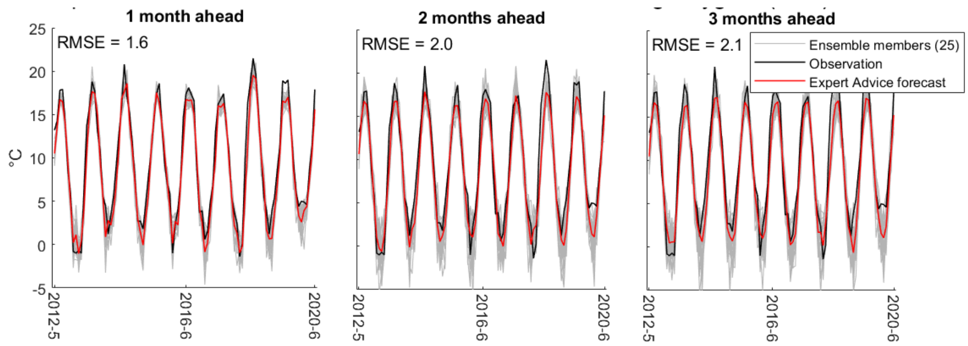

Figure 31: Monthly temperature observation and forecasts for Gårdstånga Nygård (Swe) for 2012-2020.

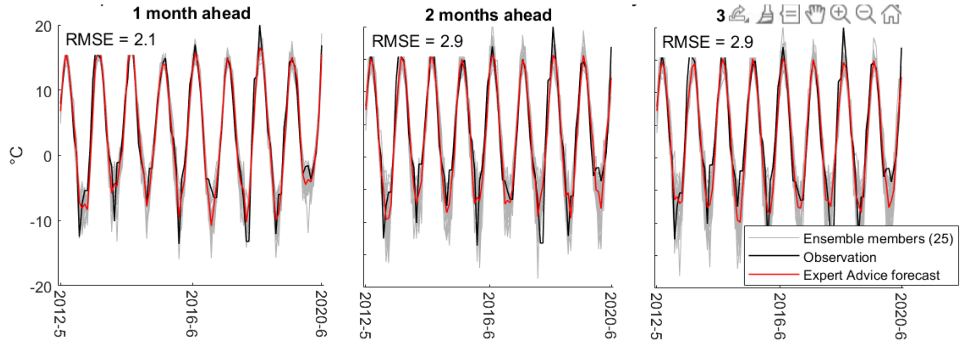

Figure 32: Monthly temperature observation and forecasts for Siikajoki Ruuki (Fin) for 2012-2020.

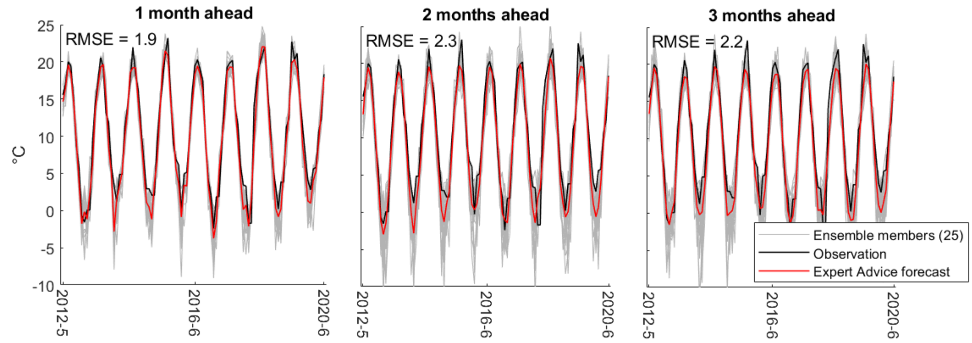

Figure 33: Monthly temperature observation and forecasts for Wroclaw (Pol) for 2012-2020.

Evaluation results for forecast steps of 1-7 months for the full sample periods of 1981-2020 are presented in Table 4. Comparison between the forecast months shows that longer forecasts only have a slightly lower skill. Similarly, to the results in Figure 26-32, the RMSE for precipitation ranges between 29 and 40 mm, and for temperature between 1.4 to 2.3 °C. The tercile class prediction skills are however consistently low for both precipitation and temperature, as they are only slightly better than chance (33%) in most cases. There is also a clear drop in tercile prediction skill between the first and the remaining forecast months, with initial skills for precipitation of 36-42 % and 48-56 % for temperature. This confirms that while the RMSE is low for temperature forecasts, the forecasts' capacity to accurately predict monthly variations is low for both precipitation and temperature. Due to the stability of the temperature variation over time, the forecasts can still generate low RMSE, which makes them useful for agricultural seasonal planning. Precipitation forecasts, on the other hand, display too large RMSE for the evaluated field sites to be useful for seasonal agricultural planning.

Table 4: Forecast skill on monthly terciles and root mean squared error for the agricultural season (May-Sep) for 1981-2020 for Gårdstånga Nygård (Swe), Julich (Ger), Siikajoki Ruuki (Fin), and Wroclaw (Pol).

Variable	Forecast month	G. Nygård (% / RMSE)	Julich (% / RMSE)	S. Ruuki (% / RMSE)	Wroclaw (% / RMSE)
Precipitation	1	0.42 / 34	0.36 / 34	0.39 / 29	0.38 / 37
	2	0.35 / 38	0.32 / 36	0.33 / 32	0.29 / 40
	3	0.36 / 38	0.33 / 36	0.39 / 31	0.28 / 39
	4	0.34 / 38	0.35 / 36	0.33 / 31	0.33 / 39
	5	0.34 / 38	0.31 / 36	0.35 / 31	0.32 / 39

	6	0.33 / 38	0.36 / 37	0.31 / 31	0.31 / 39
	7	0.32 / 39	0.31 / 36	0.33 / 31	0.29 / 40
Temperature (monthly average)	1	0.48 / 1.4		0.47 / 1.7	0.56 / 1.2
	2	0.34 / 1.9		0.34 / 2.0	0.42 / 1.6
	3	0.35 / 2.0		0.35 / 2.1	0.40 / 1.6
	4	0.34 / 2.1		0.34 / 2.2	0.42 / 1.7
	5	0.34 / 2.1		0.35 / 2.2	0.37 / 1.7
	6	0.32 / 2.2		0.32 / 2.2	0.37 / 1.8
	7	0.33 / 2.3		0.36 / 2.3	0.38 / 1.8

5 Next steps

In the present document a set of farm-related solutions has been presented and discussed, the overall objective of the tools is to support farmers in decision making and to make the WATERAGRI solutions interoperable with sensors, FMISs and data sources.

The solutions presented will be a core component of the WATERAGRI Framework and the solutions have been designed to be integrated with the other WATEGRAI solutions.

The soil and agrometeorological data which are now available in the AGRICOLUS system, as outlined in this deliverable, together with other agronomical information like crop traits, are crucial input for the physically based models HydroGeoSphere and CLM-ParFlow which are used in the WATERAGRI project.

These models use further soil and vegetation parameters as input, which are also available in the system. It is planned that at a later stage in the project these models can run also in the Cloud. The HydroGeoSphere and CLM-ParFlow models will be applied for some of the study sites, like the German and Hungarian project sites (CLM-ParFlow) and the Swiss, Finnish and Polish study sites (HydroGeoSphere).

In addition, the physically based models will also assimilate measurement data in order to correct model simulations so that the simulated values are closer to the measured values. It can be expected that the future model predictions made with the physically based models corrected with data assimilation, will be improved as well then.

This forms the basis for informed farmer decisions concerning irrigation scheduling, or drainage control, to name a few. The data which will be assimilated are now also the water content simulated by the water balance model, the soul moisture measured by the sensors and result the remote sensing data, that will be described in detail in the next D4.3 Deliverable. The physically based model runs in combination with data assimilation will generate large output files. The most important results of these simulations, relevant for stakeholders, will also be made available in the Cloud and in an attractive format for the stakeholders.

6 References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. Irrigation and Drainage Paper No 56. FAO, Rome

Cheng, L., & AghaKouchak, A. (2015). A methodology for deriving ensemble response from multimodel simulations. *Journal of Hydrology*, 522, 49–57. https://doi.org/10.1016/j.jhydrol.2014.12.025

ECMWF. (2021). SEAS5 user guide: Vol. 1.2. European Centre for Mid-range Weather Forecasts. https://www.ecmwf.int/sites/default/files/medialibrary/2017-10/System5_guide.pdf

ECMWF. (2020). Access Mars. https://confluence.ecmwf.int/display/WEBAPI/Access+MARS

Hargreaves, G.H., Samani, Z.A., (1985). Reference crop evapotranspiration from temperature. Appl. Eng. Agric. 1, 96–99.

Howell, T. A. (2003). Irrigation efficiency. Encyclopedia of water science, 467.

Johnson, S. J., Stockdale, T. N., Ferranti, L., Balmaseda, M. A., Molteni, F., Magnusson, L., Tietsche, S., Decremer, D., Weisheimer, A., Balsamo, G., Keeley, S. P. E., Mogensen, K., Zuo, H., & Monge-Sanz, B. M. (2019). SEAS5: The new ECMWF seasonal forecast system. *Geoscientific Model Development*, 12(3), 1087–1117. https://doi.org/10.5194/gmd-12-1087-2019

Zadoks, J.C.; Chang, T.T., Konzak, C.F., (1974). "A decimal code for the growth stages of cereals". Weed Research. 14 (6): 415–421. doi:10.1111/j.1365-3180.1974.tb01084.x.

Annex I for D 2.2 Farm Models and Interoperability Mechanism: Irrigation technology description and guideline

02/2021

WP 2 Water and nutrient resources management at farm scale

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B	blue
BOD	biological oxygen demand
CAMS	Copernicus Atmoshphere Monitoring Service (EU)
CDI	combined drought indicator
COD	chemical oxygen demand
DEM	digital elevation model
EDO	European Drought Observatory
EM	electromagnetic
fAPAR/FAPAR /FPAR	Fraction of Absorbed Photosynthetically Active Radiation
G	green
GIS	geographic information system
GPS	global positioning system
GSM	global system for mobile communications
GW	grey water
HCWI	heat and cold wave index
IRT	infrared thermometer
ISE	ion-selective electrodes
LFI	low-flow index
LISFLOOD	In-House Hydrological Precipitation Mode
MBR	membrane batch reactor
MF	microfiltration
NDRE	Normalized Difference Red Edge Index
NDVI	Normalized Differential Vegetation Index
NDWI	Normalized Water Content Index
NF	nanofiltration
PaDI	Palfai Drought Index
PAI	Pálfai Aridity Index
PDSI	Palmer Drought Severity Index
R	red
RO	reverse osmosis
SMA	soil moisture anomaly
SPEI	standardized precipitation evaporation index
SPI	standardized precipitation index
SWRM	small water retention measure
Tc	canopy temperature
TDS	total dissolves solids
TM2/TM3/ TM4	thematic mapper sensors, numbered (in relation with satellite)
UAV	Unmanned Aerial Vehicle
UF	ultrafiltration
UWWTP	urban waste water treatment plant
VI	vegetation index

Introduction

Climate change has a significant impact on Europe. Global warming-related climate change is projected to increase temperatures by 0.5 °C to 1.0 °C by 2020 and 2 °C to 4 °C by 2080, and to reduce precipitation by 5 to 30 % by 2080. Such patterns increase the onset of floods and other natural disasters and lead to changes in water availability which will primarily affect agricultural sectors (Flores et al. 2012). The economic effects are followed by floods (38%), storms (25%), droughts (9%) and heatwaves (6%). Even if global warming is limited to 1.5 °C the water stress will increase by about 50 % (IPCC 2018), making droughts more frequent. The severity and frequency of droughts have increased in some parts of Europe. The consequences of global climate change and preparing for and adapting to expected regional change is a major challenge for the 21st century, as the impact of climate change on water resources is significant at the regional level (Nerantzaki & Nikolaidis 2020). Growing concerns about the future availability of agricultural water supply, coupled with the increased risk of climate change and new environmental regulations, mean that farms need to assess the reliability of irrigation permits and adapt their business plans to achieve acceptable results. To achieve these results, measures to mitigate climate change are needed to ensure that long-term agricultural productivity and food security are not compromised, ensuring the sustainability of agricultural production. Several documents help the adaptation process and suggest the development of a strategy coordinated climate adaptation activities in a wide range of river basins:

- 2007: Communication on water scarcity and droughts in the European Union, COM (2007) 414 final
- 2009: EU White Paper "Adapting to climate change: Towards a European framework for action"
- 2009: EU CIS Guideline 24: River Basin Management in a Changing Climate
- 2009: UNECE Guidelines for Adaptation to Water and Climate Change
- 2012: A plan to protect Europe's water resources A review of European water scarcity and droughts policy was carried out in 2012 (SWD (2012) 380 final).

The European Commission (EC) presented an EU strategy for adapting to climate change in 2013, (COM / 2013/216 final) with the overall aim of contributing to more in a climate-resilient Europe. Specifically, water management adaptation involves investing in the development of irrigation infrastructure, which provides greater security of water availability for irrigation, which in turn reduces dependence on rain cycles, while allowing evapotranspiration to be reduced and thus providing greater productivity with less water consumption. Similarly, the implementation of crop and variety changes as well as sowing calendar changes as adaptation strategies provides a higher level of production (Khanal et al. 2019).

Successful implementation of these tools requires citizen involvement through policy implementation to active behavior change (Lacroux & Gifford 2018). Agriculture is the basis for achieving food security from a social point of view, essential for community livelihoods in rural and marginal areas. In this context, agricultural policies and public intervention in rural communities are necessary tools to contribute to poverty reduction as part of an approach to economic and social development (Croppenstedt et al. 2018).

The characterization of the drought and the determination of the drought sensitivity of each area become an important task, as we can experience significant differences in the conceptual system of the drought. In the case of preparing for the treatment of drought, problems are necessary to quantify the drought, the practice of which is not uniform, and the comparability is constrained both domestically and internationally. During observations is important to determine at what time of year, for how long, and with what intensity drought appears. Drought can cause significant damage to vegetation, human communities, and the economy, so monitoring the severity of the drought is important. It may be appropriate to use indices for which more detailed databases are available for better data access. Early monitoring is an essential part of drought monitoring, as well as taking appropriate measures to mitigate expected damage (Son et al. 2021).

At the Hungarian case study site, the droughts occur more frequently and some estimates suggest that some parts of the Carpathian Basin may become a semi-desert area soon based on regional climate models, due to the increase in the extent and frequency of droughts (Bartholy et al. 2007, Tamás 2016, Juhász et al., 2020). As a result, a significant part of Hungary's territory is endangered by drought. The inland excess water phenomenon is also characteristic of flat areas even in the same place and year with drought. Sometimes drought periods are interrupted by high-intensity rains. Therefore, it is important for prevention to explore the relationship between local and global hydrological processes more accurately (Lehner et al. 2006). In the Hungarian case study site, there are inland excess water and/or drought every 2-3 years.

In agriculture, there are water-saving, water retention (Gálya et al., 2018) and soil salinization prevention technologies that reduce deep leakage, soil evaporation, and groundwater level control, and these have often been used to alleviate water-deficient pressures. However, these strategies can only reduce agricultural water scarcity to some extent.

Irrigation investments are driven by the need to maximize yield and quality, as most irrigated crops have significant financial benefits but are sensitive to short periods of water scarcity or drought stress, especially when they coincide with critical growth stages (Nagy and Tamás, 2013). Farmers generally manage drought risks through crop production and the planning of expected irrigation needs, taking into account the fixed allowable quantities set out in the annual abstraction permits.

In the case of irrigation, sustainable water supply is one of the most important requirements for irrigation (Haro-Monteagudo et al. 2019). The pollution and direct pressure from inadequate water management practices, the quantity and quality of surface and groundwater resources are likely to decline. Due to population growth, concerns about irrigation water reliability are becoming more common due to increasing water demand. This increases the pressure on water resources, making areas more vulnerable to drought. In arid areas, water scarcity and soil salinization have become a critical problem and thus it severely limited the development of sustainable agriculture and directly affected food security (Jesus et al. 2018).

This guideline is highly related to integrated water management from agricultural aspects, and study of elevation, soil, climatic and hydrological conditions of a certain area both in local and sub-regional scales hoping it is a great helping tool both for farmers and experts.

Concept of Precision Irrigation

Precision irrigation can boost the economy and reduce water use as efficiency increases by optimizing inputs, aligning with the area. Precision irrigation consists of several parts (Smith et al. 2010), and operating conditions of irrigation are considered as a complex system concept of which is shown in Fig. 1. According to this concept, one of the most fundamental conditions, besides the presence of water of adequate quality and quantity at the right time and place, is the installation system. Irrigation technology has an impact primarily on irrigation costs and workload management, secondarily on biological efficiency of water used for irrigation, and also closely related to production standards and the certain crop structure.

Similarly to other agro-technical processes, irrigation works properly only if all the necessary production inputs are provided in sufficient proportions and quantities. Irrigation as an input has direct effect on yield and also may increase the efficiency of other agro-technical factors. The reveal, uptake and utilization of nutrients, a more favorable chemical effect, lower energy consumption, etc. are factors that justify the role of irrigation in increasing production efficiency. In several cases, irrigation affects the growing season of certain crops. In addition to irrigation, there is an increased need for attention on nutrient management, plant production and deep cultivation.

The task of precision water management is to optimally meet the current water supply needs of cultivation technology. Thereby, it uses automated real-time data collection and evaluation systems on the observed crop sites. It continuously processes the elements of the water balance systems, 2 or 3 dimensionally, and controls the technical equipment of water supply or drainage. Depending on the design, it is suitable for the operation of individual irrigation elements or drainage elements. In moving systems, it is able to adapt to the constant changes of soil and plant water balance with GPS control during transportation. It is also suitable for performing special functions such as colouring, humidification, frost protection, etc. within the same system.

Nevertheless, the spatial and temporal framework of precision water management is broader and more detailed than it seems at the farm-level since precision water management is part of integrated water management of a geographical unit wider than an average farm. During the performing of these functions, precision agriculture strongly relies on the possibilities provided by GIS and environmental modeling. Soon tasks of precision water management are expected to intensify in the following areas:

- increase the number of solutions for water and energy savings,
- application of real-time technologies in the GPS-sensor-control-regulation system,
- increased use of remote sensing in the detection of extreme weather events and the related prevention acts,
- increase the predictive reliability of hydrological events based on spatial and environmental models with standardized data traffic (HydroGIS),
- protecting the water quality of water resources from the point and non-point sources,
- receiving alternative water resources,
- increasing risk reduction tasks related to food safety and supply,
- further developments and application of indicators and methods for measuring and evaluating the sustainability of water resources (e.g. water footprint, virtual water, GHG, LCA) specifically regionally and technologically.

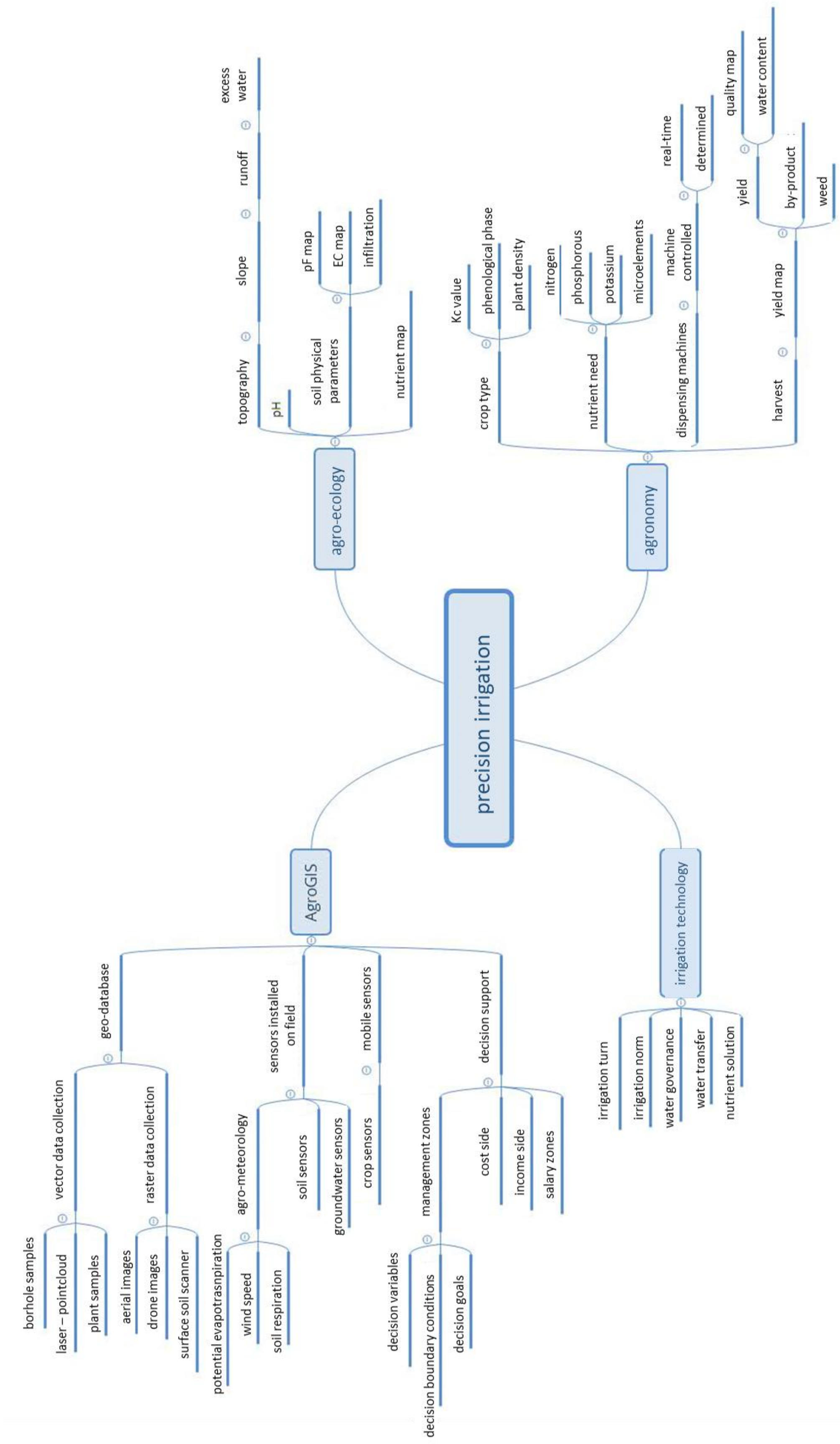

Figure 1. The concept of precision irrigation

Today, "Variable rate irrigation" (VRI) can be used to identify precision irrigation technologies, as sprinkler irrigation equipment installed in the area can create different numbers of zones on the field. VRI offers options where we can feed up to date plant related data, soil characteristics, topography map (Boluwade et al. 2016, Colaizzi et al. 2017, Yari et al. 2017). Machines with VRI technology require a complete set of computer tools. Irrigation is monitored and controlled by real-time data transmission via radio, Internet or GSM, with GPS positioning accuracy of 2-3 cm. VRI technology is also suitable for older machines, only the adaptation costs. A field map and a soil map containing soil information are required to apply the technology. The investment comes at an additional cost, but it offers many benefits to farmers, and VRI technology should be seen as an opportunity to increase farming results and profits (Gonzalez et al. 2017).

1 Data and Monitoring for irrigation

1.1 Available drought indices

The European Drought Observatory's website (I1) provides a wealth of important information on the emerging and changing drought situation in the world. The EDO is currently compiling the following drought indicators at the European level:

- **Anomaly of Vegetation Condition** (FAPAR Anomaly): It measures the anomalies of the fraction of absorbed photosynthetically active radiation measured by the satellite, FAPAR. It is used for high areas of relative vegetation stress due to agricultural drought.
- **Combined Drought Indicator** (CDI): It integrates information on anomalies in precipitation, soil moisture, and satellite-measured vegetation status into a single index that is used to track the onset of agricultural drought and its evolution over time and space.
- **Heat and Cold Wave Index** (HCWI): It is used to detect and characterize extreme temperature anomalies such as heat waves and cold waves. Temperatures are calculated based on a daily minimum and maximum.
- **Low-Flow Index** (LFI): They are derived from river water flows produced by the JRC In-House Hydrological Precipitation Model (LISFLOOD) and are used for real-time monitoring of hydrological flow drought at the European level.
- **Standardized Precipitation Index** (SPI): This indicator measures the anomalies of accumulated precipitation over a certain amount of time and is the most commonly used indicator to detect and characterize meteorological droughts.
- **Soil Moisture Anomaly** (SMA): It measures anomalies in daily soil moisture, or water content, and is used to measure the onset and duration of agricultural drought conditions.
- **Total Water Storage** (TWS): Anomaly used for determining the occurrence of long-term hydrological drought conditions

In addition to these, various available and queries are also available at the precipitation SPI 3 value per NUTS-3 region, the Soil Moisture Index (SMI) by NUTS-3 Area and the fAPAR Anomaly development by NUTS-3 Regions in Europe broken down into months throughout the year.

Several other indices can also be used to monitor drought:

- **Normalized Differential Vegetation Index** (NDVI): The NDVI vegetation index can be calculated by normalizing the difference in reflectance for two wavelength ranges (NIR, RED). NDVI values can also be used for yield estimation, yield prediction, and analysis. NDVI values can be calculated from images taken by LANDSAT, MODIS, and SENTINEL satellite images, among others, which can be downloaded from https://earthexplorer.usgs.gov/ or https://sentinel.esa.int/web/sentinel/home. These sites are free, registration is required.
- **Normalized Difference Red Edge Index** (NDRE): The index can be used to analyze whether images from multi-spectrum image sensors contain healthy vegetation or not. NDRE is a better indicator of plant conditions than NDVI for mid and late-season plants that have already accumulated large amounts of chlorophyll. The index gives a complete picture of the chlorophyll content, which is one of the main nitrogen indicators and helps in the application of the fertilizer (https://eos.com/agriculture).
- **Normalized Water Content Index** (NDWI): It may refer to one of the indices from at least two remote sensations for liquid water. One is for near-infrared and short-wave infrared

wavelengths that can be used to track changes in leaf water content, and the other is for tracking changes in water content using water bodies using green and NIR wavelengths.

- A version of the **Palfai Drought Index** (PaDI) for international use has also been developed. **Pálfai Aridity Index** (PAI): one of the most widely used drought indices in Hungary in the last few decades, has been developed and used in the Carpathian Basin and Hungary, and requires only temperature and precipitation data. The index describes the drought with a numerical value that expresses the evaporation and precipitation conditions, taking into account the position of the groundwater level according to the time-varying water demand of the plants.
- **Palmer Drought Severity Index** (PDSI): Soil moisture is based on a demand-supply model. The index has proven to be effective in determining long-term, multi-month droughts, but not as good over weeks. It can be used as a global drought monitoring (https://climatedataguide.ucar.edu/climate-data/palmer-drought-severity-index-pdsi).
- **Standardized Precipitation Evapotranspiration Index** (SPEI): It can be used to determine the occurrence, duration, and magnitude of drought relative to normal conditions in a variety of natural and managed systems such as plants, ecosystems, rivers, water resources. It can be used as a global drought monitoring (https://spei.csic.es/).

Drought risk analysis contributes significantly to the planning and management of water resources in a given region. However, as with many other natural hazards, drought has a characteristic multivariate character, i.e., it is characterized by the correlated contemporary presence of several characteristics. In this situation, traditional univariate risk analysis based on the distribution of frequency (or probability) of individual characteristics can lead to misleading, inappropriate, or incomplete interpretations of the phenomenon. Different indices have different input data, different time scales, and indicate drought in different ways. Various satellite-based drought indicators are suitable for different study areas for drought research (Tamás et al., 2015). However, drought indices developed at the local or regional level are not generalized to larger areas. Some drought indices based on remote sensing performed poorly under different environmental conditions because vegetation status and soil moisture range vary from region to region (Jiao et al. 2019a). The drought indices, on the other hand, target only a single drought type or surface drought index as a dependent variable. However, the use of a single dependent variable cannot be generalized to cover different drought conditions because each drought index takes into account different factors. In addition to the indices, the use of weighted linear combination, machine learning and principal component analysis (PCA) can also be used to develop drought indices (Fang et al. 2019). Therefore, sensing the site is important from more field-specified information.

1.2 Topographic data

Elevation measurements are useful tools for small and mid-scale discharge area mapping by which the site characteristics can be studied. This is necessary information to adequately plan sprinkle irrigation with high precision. The process requires many steps and different tools, as shown in Fig. 2. including field measurements, remote sensing measurements and GIS processings.

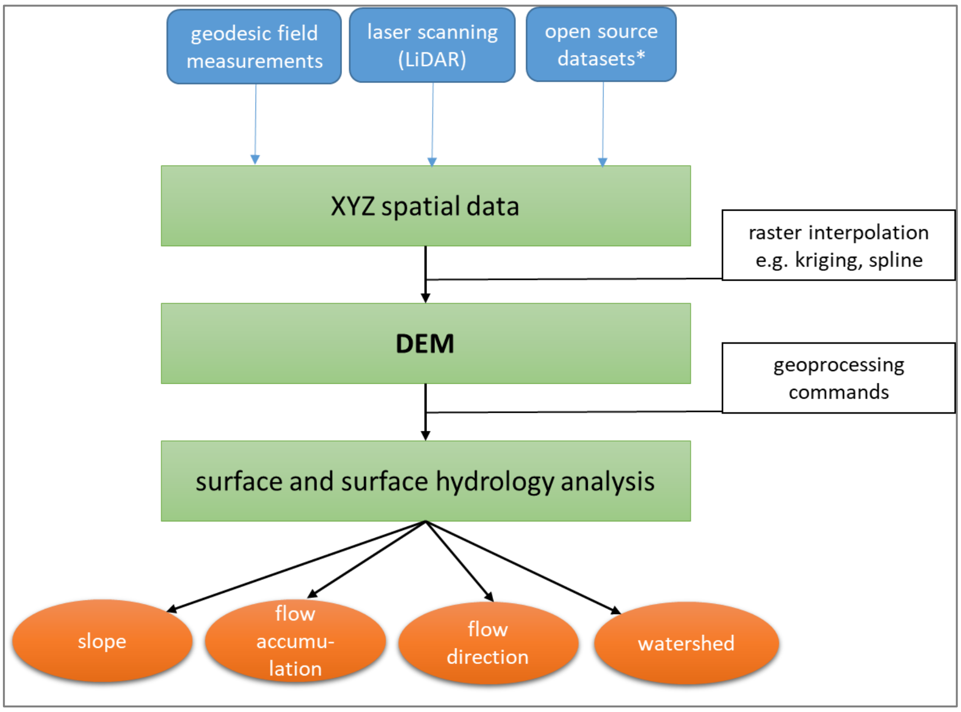

*Figure 2. Digital Elevation Modelling and generated spatial information for small and mid-scale discharge area mapping (*refers to national open data sources which may vary country by country)*

Several methodologies of discharge area predetermination exist which are based on the elevation model and carried out by setting and running GIS commands. Many free data sources are available providing information about elevation with a resolution of approx. 30 m, such as USGS elevation datasets (SRTM, ASTER) (Farr & Kobrick 2001, Rabus et al. 2003, Rana & Suryanarayana 2019) and small-scale high precisional elevation mapping can be carried out nowadays by Unmanned Air Vehicles (UAV) on which LiDAR sensors are installed even by farmers after they got education and license.
Data management and spatial analysis of raw elevation data require GIS expert work during which firstly from the measured point data elevation and surface objects are distinguished from each other resulted in elevation data (X, Y, Z). The resulted Digital Elevation Model (DEM) from which surface characteristics can be generated in order to visualize and provide terrain landform, slope characteristics, and surface flow conditions, flow length, stream link, watershed (I2; Strager et al. 2010). Especially slope is essential from an irrigation planning point of view (e.g. in the calculation of loss of pressure in irrigation tubes, or limits the utilization of central pivot irrigation machines).

1.3 Monitoring for Irrigation

Precision irrigation monitoring has an essential part containing high-resolution spatial and temporal information gathering, continuous monitoring of certain environmental conditions and the management of these data sets. The most important agrometeorological, hydrological monitoring for irrigation are the followings:

- agrometeorological monitoring
- soil moisture monitoring
- relief

- groundwater monitoring
- surface water

1.3.1 Agrometeorological monitoring

Agrometeorological information is extremely important. This data can be obtained from a nearby meteorological service provider or from own meteorological station. Meteorological datasets contain spatial and temporal information on several climatic elements, such as

- temperature
- precipitation
- evaporation
- evapotranspiration
- wind speed and wind direction in different heights
- solar radiation
- relative humidity,
- air pressure

The data can come from three sources (Fig. 3). Most countries have a national meteorological network with long term data based on standardized weather stations. Such data can provide larger-scale data for the study area. Besides national databases, integrated, publicly available datasets (e.g. data hub from EU Copernicus Atmosphere Monitoring Service (CAMS), EUMETNET) are also created typically in GIS background. In addition, there are available platforms available for farmers helping their work providing much spatial environmental information for instance Agricolus platform (Guidotti et al., 2019).

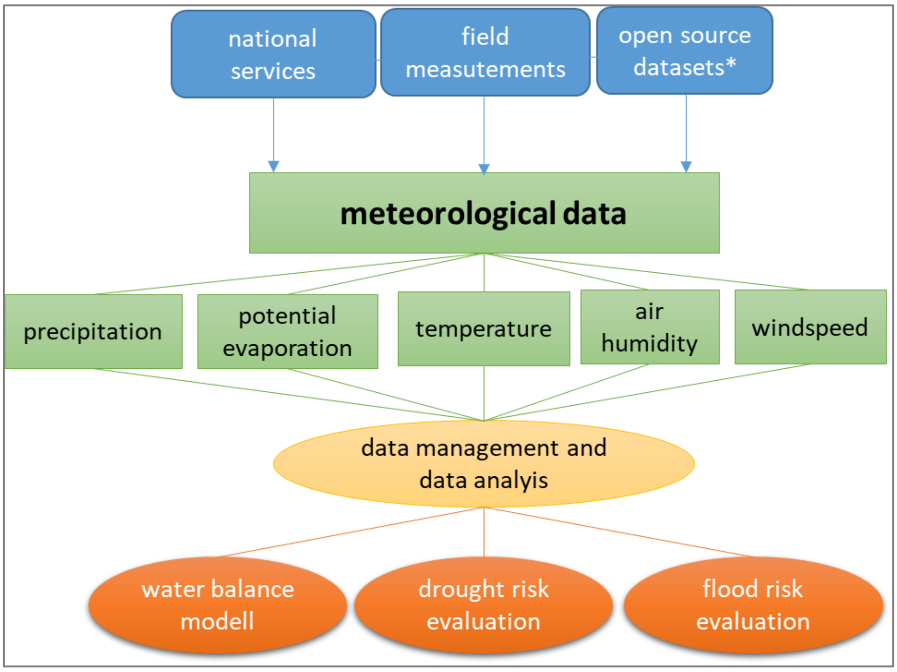

*Figure 3. Steps of data collection for agrometeorological characterization of a certain area (*refers to national open data sources which may vary country by country)*

However, the spatial density of meteorological stations belonging to the base network is not always adequate, or local (e.g. microclimatic) effects may occur, due to which the data of nearby stations in an area can be used only to a limited extent. It may then be necessary to create on-field meteorology stations.

Nowadays, *automatic weather stations* are becoming more common. Data are stored or transmitted completely or partially automatically, the reliability of observations is increased. In the long run, their operation is economical. The sampling frequency, the number of values to be averaged, thus the recording frequency and the transmission frequency can be specified, in Hungary, these values are typically 2 seconds, 10 minutes and 1 hour.

Automatic meteorological stations consist of three main parts, sensors, data acquisition units, and peripherals as power supply units, reading aids, or input devices (Fig. 4). The location, accuracy, and reliability of the sensors are essential for data comparability and spatial and temporal pattern analysis. Based on the data reference crop evapotranspiration, and several drought indices (such as SPI), can also be calculated and used for irrigation scheduling purposes.

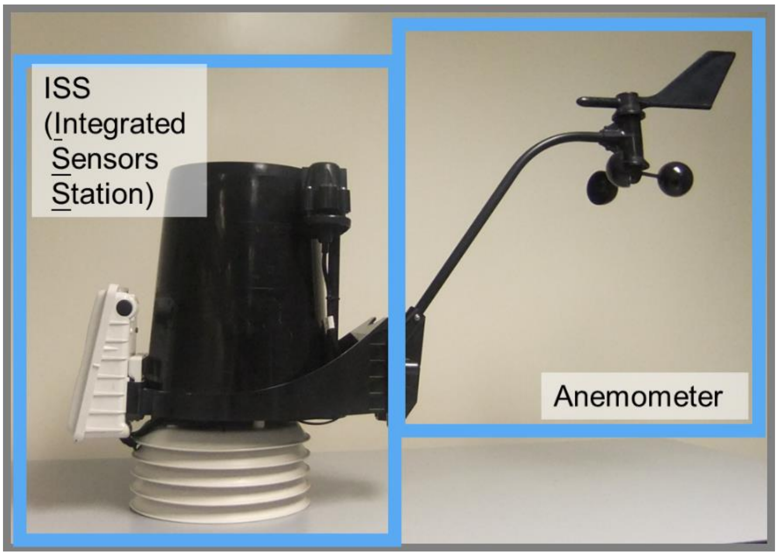

Figure 4. An example for AWS solution, used at the Hungarian case study site

Though evapotranspiration can be measured by different types of open evaporation pans. However, measuring the (real) actual evapotranspiration is a difficult task. The measured ET is usually higher than the reality because of the limited amount of water, and the effect of its environment. On the other hand, the amount of precipitation should be excluded from the daily results. (Fig. 5).

Figure 5. 'A' type evaporation pan (I3)

Evapotranspirometers or lysimeters can also measure the evaporation or evapotranspiration of crops. An undisturbed soil block is installed in a container that isolates it hydraulically from the underground. The weight, the moisture content of the block and precipitation are measured so as to survey the water balance. While lysimeters are relatively complex systems they are usually installed in research institutes.

New versions of modern tools for meteorological monitoring and analysis are high precision weather radar. Heavy rainfall, which is unfortunately, has become more common in the last decades due to climate change, can be monitored with high efficiency with Doppler weather radar. Heavy rain and thunderstorms have strong returns with approx. 45-65 dBz, while lower values indicate moderate or light precipitation. The equipment does not only show precipitation but calculates its development, directions and move.

Figure 6. Doppler Weather RADAR on a rooftop at UNIDEB site

A great advantage of the equipment and the method is that it produces not only point data but rather provides accurate and reliable continuous 2-dimensional spatial data which may cover 100 km^2 area with 50m spatial resolution, depending on the specification of the certain product. By such radars, even hail storms can be mapped and the amount of ice can be estimated with higher accuracy.

Installation of such radar systems requires not more than a higher, regular building (e.g. farm machinery station building) (Fig. 6). Purchasing the equipment is maybe a financial challenge for one farmer, but installing it in cooperation with others, can be beneficial.

1.3.2 Soil moisture monitoring

Soil is considered as a complex system including many phases (solid, liquid and gas) (van Es, 2017) and can be characterized by several properties such as moisture content, its texture, nutrient content, humus content, column characteristics and geometric properties such as the thickness of soil layers (Nelson et al. 2020). Measurement of these parameters, out of which many vary on the field, is essential to understand how the soil can support crops in the best way and what to improve during agricultural activities and how to plan and carry out irrigation, nutrient supply, or how to schedule irrigation (Fig. 7). The soil type, texture, topography, slope are important factors that influence soil diversity. Soil texture influences several water balance-related parameters, such as water holding capacities, total available water content, field capacity, etc. These soil parameters hardly can change rapidly in time. On the other hand, the soil moisture content is varying rapidly in time and space as well, and its availability highly dependent on the soil's physical characteristics.

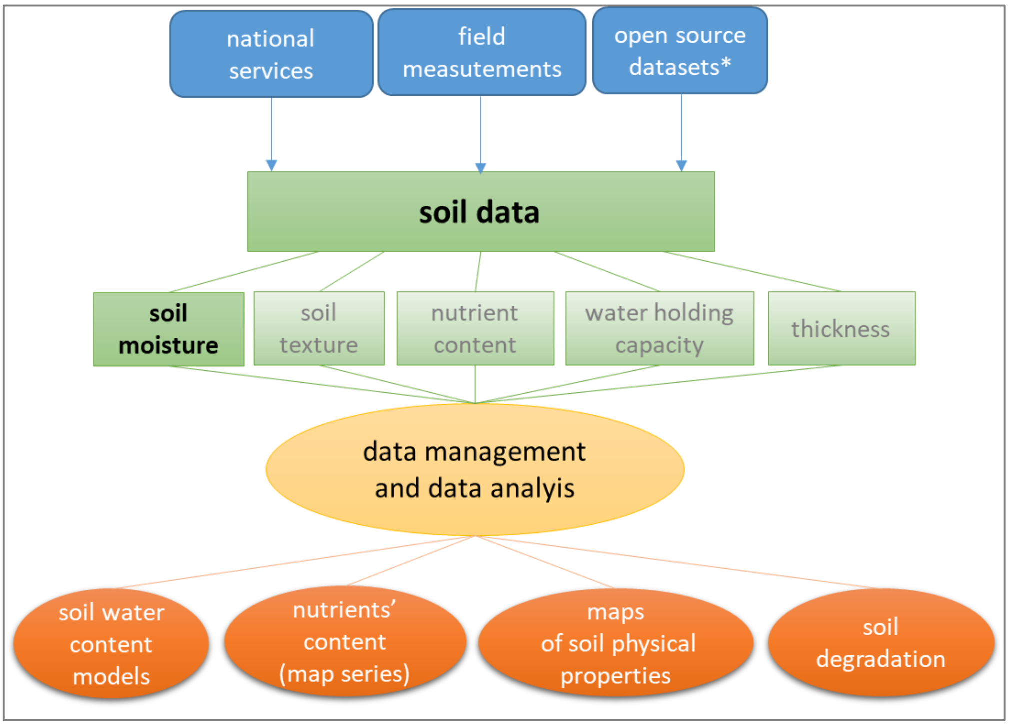

*Figure 7. Soil data management flow chart emphasizing soil moisture measurements (*refers to national open data sources which may vary country by country)*

The installation of the soil sensors is located in the optimal field location to maximize productivity in the specified majority of soil type. Probes can be used to make quick, trained irrigation decisions. Moisture meter data controls the irrigation schedule. Combined with plant modeling and weather data, a proper irrigation schedule can be formulated. Soil moisture content can be measured by several direct and indirect methods:

- Direct method: Gravimetric method when water content can be directly measured using a known volume of the material, and a drying oven.
- Indirect methods:
    - Tensiometric (energy status – related to moisture)
        - Tensiometers Measures water potential, need to related tension to volumetric water content to know available water, requires soil water characteristics curve. Limitations are slow response, needs maintenance, manual reading, lack of contact in sandy soils
        - Resistance blocks Porous blocks to measure electrical resistance as a function of water content, easy to use. Limitations are delayed response in sandy soils, dry conditions – reinstallation, errors in soils with high salinity.
        - Psychrometer Laboratory scale method, which measures the vapor pressure of soil samples to calculate moisture content in V/V%.
    - Volumetric (most widespread used, automatic methods)
        - Nuclear method (Neutron probe) brings a source of neutrons below the surface, and the neutron loses in collision with the protons in the water molecule (Monerris & Schmugge, 2009). This method, depending on its resolution capacity, may be more advised to carry out measurement vertically, along soil profiles.
        - Dielectric methods Based on medium's capacity (dielectric constant) to transmit high frequency electromagnetic wave/frequency
            - Time Domain Reflectometry (TDR) Estimate the dielectric constant by the travel time for electromagnetic wave to go through a transmission line. The wave strongly depends on the dielectric constant thus the water content of the soil around the electrodes has better accuracy (Topp 2003).
            - Frequency Domain Reflectometry (FDR) the sensor act as a capacitator, in which the soil is the dielectric medium. Physical parameters of this capacitator are based on the dielectric constant of the soil, which strongly depends on the water content (Starr et al. 2002) and some other parameters. These sensors have moderate cost and accuracy and fast response time, but soil type dependent calibration is needed. (Campbell et al. 2004).
            - Capacitance, TDT, ADR, Phase Transmission. Measures the Dielectric properties of soil (Fig. 8).
    - Other (e.g. spectral methods) Calibrated spectral data allow rapid detection of soil moisture in the laboratory or in the field, and systems in the air or on the ground allow the spatial distribution of surface moisture to be assessed. The main effect of moisture is observed in the middle infrared (MIR) range, which has the greatest influence on the reflectance results obtained. The higher the soil moisture level, the lower the reflection values will be, and the reflectance will increase at higher wavelengths (Nagy et al. 2014).

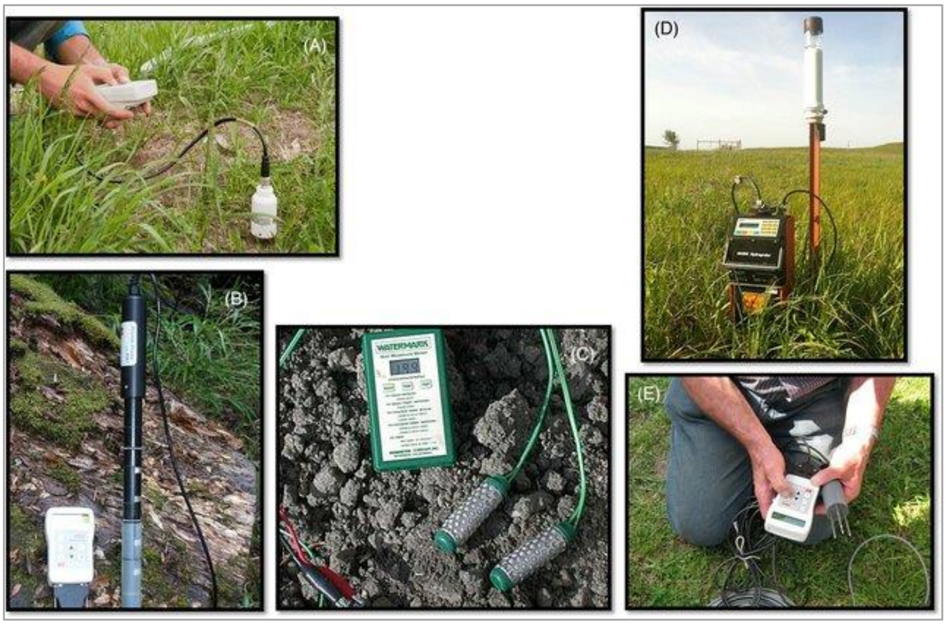

Figure 8. Sensors for soil moisture content on field ((A) Time domain reflectometry (TDR) sensor, (B) frequency domain reflectometry (FDR) sensor, (C) gypsum blocks, (D) neutron probes, and (E) amplitude domain reflectometry (ADR) sensor) (Dwevedi et al., 2017)

There are several factors for selecting locations. Besides the size and management of the farm, one of the most important to know the soil variability, and place at least one sensor for the most relevant soil spots where the water management properties of the soils are differs significantly at an irrigated site. The relief is also a determining factor , since even the soil type is the same, the moisture conditions can vary between the hilltops and spots situated at lower altitudes. The type of the crop also determines where to, and how to install the sensors. In general, sensors should be put to the root zone. In the case of most of the crops, which has deeper rootzone (deeper the 30 cm) at least two sensors are recommended to install, on et the upper part of the root zone, the other at the bottom of it so as to schedule irrigation properly. Thy type of irrigation is also a factor. For instance, in the case of drip irrigation, sensors should be installed in the wetted area of the drip/microsprinkler. Farmers should also be aware of the sensor accuracy, especially in sandy soils, where for instance the total available water content can be not more than 5 %. In such circumstances, sensors with 3 % accuracy are not providing considerable data.

There are modern apps, tools and developments, e.g. Agricolus platform (Guidotti et al., 2019), using which farmers both can upload and download data, in addition, they can share data. Proper irrigation control requires real-time data on both the area under crop production and the condition of the crop. Soil moisture (at different depths or at great distances from each other) is considered basic data, installing soil moisture sensors in a critical location and sending information to the central unit or peripheral on a permanent basis via radio or Internet-based transmission.

On the other hand, setting point measurements also raise some important questions: Which site is represented by the point measurement? How accurate the representation of the concerned site? Therefore, such technology is required by which the spatial variations of the field can be monitored. Changes in vegetation patterns can provide more detailed data on the variation and changes in field conditions, especially, if it is monitored by remote sensing technology.

1.3.3 Vegetation monitoring

The impact of irrigation management on the use of plant water is a practical consideration to improve yield and water productivity for the plant. Irrigation scheduling is usually based on the measurement of soil water content or meteorological parameters to model or calculate evapotranspiration. Plant-based methods, such as leaf water potential and plant water stress index, have great potential for controlling irrigation, although there may be problems in setting reference or threshold values (Jones 2004).

With the increase of publicly available satellite data combined with scientific algorithms and cloud computing capacity, developing affordable operational monitoring systems for irrigation management is now feasible. The use of virtual field sensors can help farmers to improve irrigation management for increased water savings and better crop production. Verification of remotely sensed data is one of the perquisites of proper utilization and understanding of the data and translating to leaf area, or biomass amount, etc (Nagy et al., 2018). Drone measurements are used to verify the satellite images. On-field data acquisition contributes to verifying drone data. The development of these tools helps to study the spatial variability of plant biomass, enabling more precise spatial and temporal scheduling of irrigation (Tsutsumi & Itano 2005) (Fig. 9).

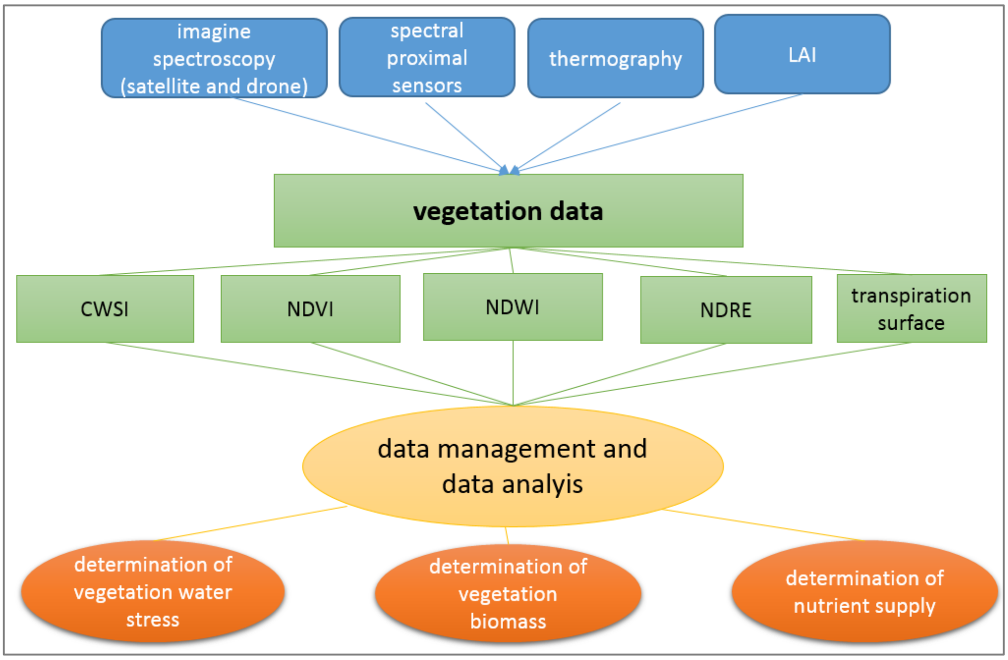

Figure 9. Steps of data collection for vegetation monitoring of a certain area

1.3.3.1 Thermography in irrigation

Canopy surface temperature measured with infrared thermometers (IRT) or other far-infrared sensors is an important tool for detecting plant water stress. Canopy temperature (T_c) provides an effective method for rapid, non-destructive monitoring of the response of an entire plant to water stress (Fig. 10). The behavior of T_c under both stress and non-stress conditions leaves traces of crop water status and yield during drought (Gonzalez-Dugo et al. 2013). Thermographic vegetation monitoring can be operated manually or used remotely to survey biomass in a relatively fast and inexpensive way. It can be installed permanently on field and can work automatically.

Thermographic monitoring is a good tool to detect water scarcity before causing any long-term damage to crop production (Kaukoranta et al., 2005; Nagy et al., 2014). The reason for this is stoma responses differed for changing environmental conditions. If the temperature of the foliage increases, the stoma is closing due to lack of water (Ballester et al. 2013) Therefore this technology is suitable for monitoring of water supply, but also for mechanical injuries, determining the depth of early bruises, detecting quality parameters and tissue damage. The monitoring of water supply of the plants makes it possible to use it for irrigation scheduling (Szabó et al. 2020).

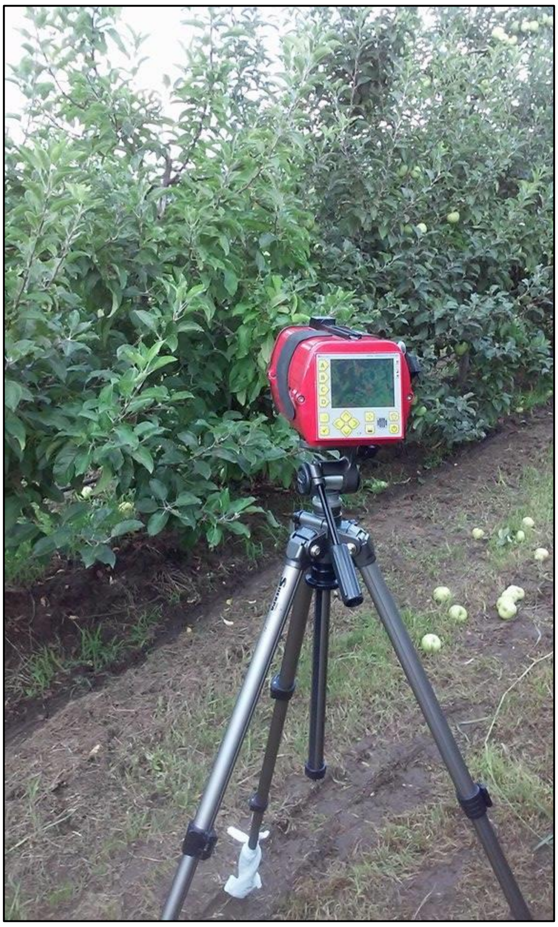

Figure 10. Examination of the moisture content of apple foliage by means of a thermographic device (Hungarian example at the case study site)

There are several canopy temperature-based indices to monitor the water status of the canopy. The Stress Day Index (SDI) developed by Hiler (1974) is affected by how sensitive the plant is and how much water supply is present. Another indicator is the stress-degree-day (SDD) method. This is based on the energy relationship between the leaf and the air temperature. The Crop Water Stress Index (CWSI), measures canopy-air temperature differences (Tc - Ta) is suitable for quantifying plant water supply and designing irrigation (Idso & Reginato 1982, Jackson 1982, Abdullah et al. 2001). If the CWSI value is greater than 0.3, reflects water shortage for the plants. In addition to examining the leaves, it also proved effective in examining fruits. It is suitable for monitoring mechanical damage, determining the depth of early bruises, detecting quality parameters and tissue damage.

Kjelgaard et al. (1996) developed a model for determining the integrated daily evaporation rate (ET) with possible applications for determining irrigation requirements in addition to CWSI measurements, both techniques are irrigation scheduling tools that use largely the same data.

1.3.3.2 Imaging spectroscopy

Hyperspectral and multispectral imaging are versatile tools for obtaining environmental information, of which they are increasingly used in agricultural fields to assess quality, biomass, plant type, the spread of plant diseases and even the need for irrigation. Hyperspectral data is more versatile than multispectral data because it contains more information - the channels of the multispectral sensor usually need to be carefully selected to meet the requirements of the application.

As a summary of imaging spectroscopy:

- Satellite remote sensing is preferred, hyperspectral satellites are still rare.
- A popular alternative to satellite data collection is aerial remote sensing of aircraft or unmanned aerial vehicles (UAVs).
- Today's hyperspectral recorders are complex imaging spectrometers, i.e., recording cameras and radiation meters.
- The wavelength ranges most commonly used in hyperspectral remote sensing are the visible light and the infrared range.
- The first step in designing hyperspectral aerial photography is to provide: research area data, desired spatial resolution, spectral resolution, and channel number.
- The most commonly used satellite images are the LANDSAT (https://landsat.gsfc.nasa.gov/), MODIS (https://modis.gsfc.nasa.gov/data/) and SENTINEL (https://www.sentinel-hub.com/) (Reyes et al., 2020).
- Different indices (listed in chapter 1.1.) can be calculated from the obtained values.

Traditionally, remote sensing and in particular multispectral cameras can be associated with unmanned aerial vehicles (drones) (Fig. 11), which can take images with very high spatial and temporal resolution combined with increasing radiometric resolution, making them suitable for detecting weeds and diseases (Abdulridha et al. 2019) to assess vegetation coverage and typology, to analyze, monitor, and evaluate biomass and vegetation (Modica et al. 2020).

Currently, the drones equipped with multispectral cameras represent the most commonly used remote sensing systems in agriculture. The advantage of these systems is their ability to access spectral information in the red (R) and near-infrared (NIR) regions of the electromagnetic spectrum, which allows the use of vegetation indices (VI) (Yao & Qin 2019).

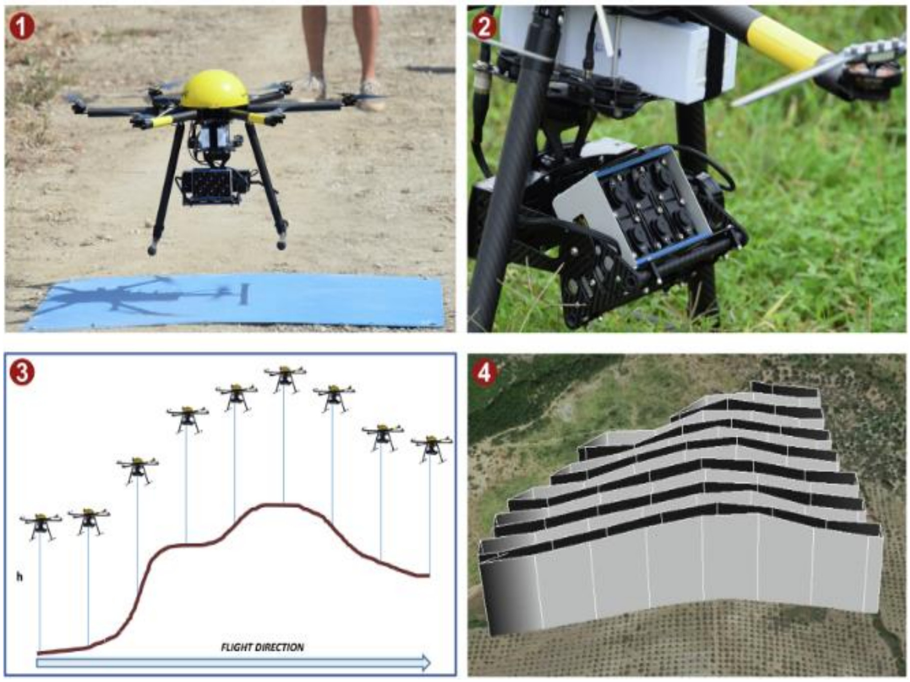

Figure 11. Upper side (1), the UAV Multirotor G4 Surveying-Robot (Service Drone GmbH) equipped with Tetracam µ-MCA06 snap multispectral camera; camera mounted on UAV gimbal and ready to capture images (2). Lower side (3), a graphical scheme showing how the UAV takes into account the 3D morphology of the surveyed area, guaranteeing a constant height of flight and (4) a 3D view of a flight plan (Modica et al. 2020)

Today's most emerging technology is using LIDAR in vegetation monitoring (Riczu et al., 2015). Lidar provides enhanced abilities to remotely map leaf area index (LAI) with improved accuracies. A LiDAR terrestrial laser scanner was used to calculate the leaf area in apple, pear, and vines pointing out a strong correlation between the leaf area index (LAI) and the number of points obtained with LiDAR (Sanz-Cortiella et al., 2011; Sanz et al., 2013; Arnó et al., 2013).

1.3.3.3 Spectral proximal sensors

The application of crop detection technologies in cereals and other crop production sectors is a method that increases the potential for irrigation besides plant health and yield. The vegetation sensors generate real-time measurement and record data on plant health. Crop sensors mainly collect at least the following VIs:

- NDVI for small crops such as early-growing wheat (Reyes et al. 2020),
- NDRE for large crops such as maize and late-growing wheat

The crop sensors provide real-time biomass related data. Growers can simply identify the variability of biomass on the field in real-time and can contribute to variable rate applications of nutrients, or pesticides, and variable rate irrigation. The sensors use the red-edge wavelength range, which responds the most to the stress level of vegetation. In the visible region of the spectrum, the reflectance is primarily influenced by chlorophyll pigments in leaf tissues, which are associated with leaf N concentration and water supply. Most of the proximal sensors are active sensors emitting energy in several channels (e.g. a sensor has three channels: 670 nm and 730 nm, and 780 nm). Since active sensors have their own light source, weather or daylight conditions are not limiting factors in vegetation surveys. There are optimal adjustments for a proper survey: it is best if the sensor is 50-70 cm above the plant canopy, and sensor horizontal frequency is 3.5 m (Simonović et al. 2018). Using fast and efficient georeferencing tools (i.e. GPS RTK) can simplify site monitoring and processes. The survey of the spatial and temporal variability of the vegetation is the basis for estimating available nutrient or water supply, making it an essential decision support tool in irrigation management (Serrano et al. 2014).

Example for vegetation survey at the Hungarian case study site

At the Hungarian case study site, proximal sensors are mounted on the pivoting lateral moving irrigation system on the site every 3 meters (Fig. 12) with GPS guidance. The sensors measure NDVI and NRDE. The data verification is made by leaf area index measurement. LAI measurement is widely used to observe various plant properties, such as canopy growth, canopy productivity, canopy load, or even modeling of air pollution deposition. The plant canopy meter is suitable for measuring simple and accurate leaf area index (LAI) without destruction.

Figure 12. OpTRX Crop sensor on the linear irrigation system (Hungarian example at the case study site)

1.3.4 Groundwater monitoring

Groundwater use in irrigation shows an increasing trend globally but it is a more common option in arid and semi-arid areas (Siebert et al. 2010). According to FAO's AQUASTAT database at the country level, the area where groundwater is used for irrigation was estimated as approx. 89 million ha, before 2000 (Burke 2002), but more recent studies calculated it may be greater than 500 million ha (Giordano 2006, Shah et al. 2007).

Among the advantages of utilization of groundwater are that it is less vulnerable compared with surface water, more is available during drought periods. However, it holds uncertainty as well, for instance in volume and recharge volume calculations.

However, water quantity and quality conditions have high importance from agricultural aspects thus their monitoring is required and it can be as shown in Fig. 13.

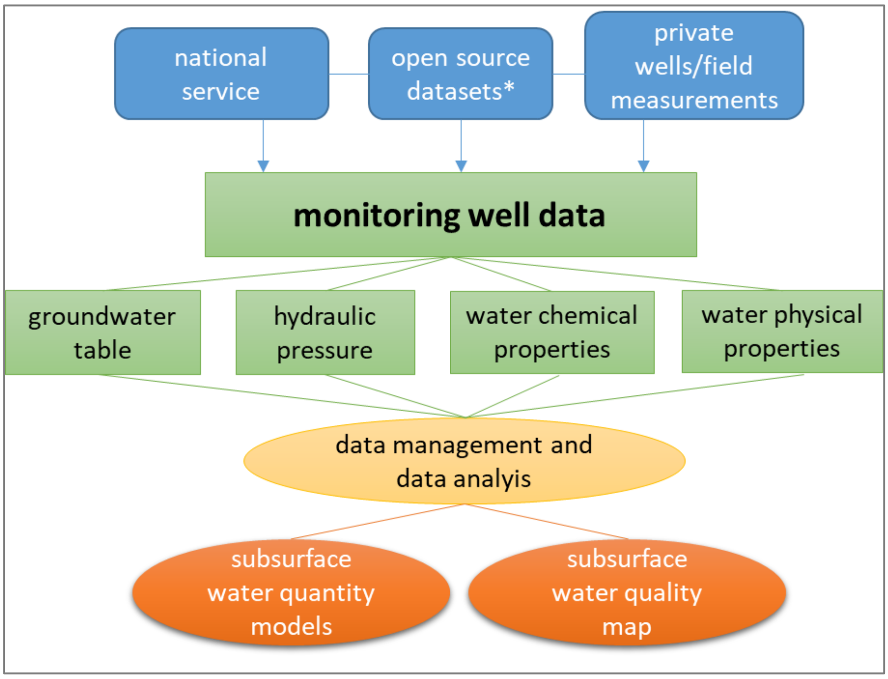

*Figure 13. Monitoring of ground water bodies: measurements (input data), properties and resulted thematic maps (*refers to national open data sources which may vary country by country)*

Water table and static head information, temperature data can be measured and logged easier by installed sensors within the well lining pipe. The equipments can be operated by PV systems. Data transfer usually needs GSM mobile internet access. Water table information is very important from the aspect of drought or inland excess water forecasting, as well.

The water chemical properties such as pH, electric conductivity, turbidity, nitrite, nitrate, phosphate, iron, manganese, sodium, potassium, magnesium, calcium, sodium, chloride, chlorine, biological oxygen demand (BOD), chemical oxygen demand (COD), sodium bicarbonate, hydrogen carbonate are required to measure by analytical methods in laboratories instead of in situ measurements. Certified measurements are usually required to follow and keep the applicable standards but the results provide useful information for farmers too. Using portable water level and quality measurement sets or sensor installed within the borehole can give immedate information on the decrease of water level, and changes in quality.

1.3.5 Surface water monitoring

Surface water bodies are considered good water resources for irrigation, however, monitoring is necessary in order to provide adequate water quality information besides quantity since surface water bodies are extremely vulnerable (Ayers & Westcot 1985, Clesceri et al. 1998, Simsek & Gunduz 2007).

Knowledge about the hydro system, including how the water level changes during the year, especially during the irrigation perdiod, what is the recharge characteristics, what volume can be out-taken and how the certain water body is located, is essential. Therefore, it is advised to measure hydromorphologic parameters of the certain waterbody: perimeter, surface area, depth at several points, average depth, inlets/outlets and discharge. From these parameters, the actual volume, the rate of discharge and evaporation can be calculated.

Successful irrigation is also highly dependent on the water of good quality and hence physicochemical properties, such as temparature, pH, electric conductivity (EC), TDS, nitrate, nitrite, phosphates, hydrogen carbonate anion are advised to be measured and data logged (Ayers & Westcot, 1985). Besides these, turbidity, potassium, chloride and chlorine, sodium, biological oxygen demand (BOD), chemical oxygen demand (COD) are also useful information in the case of living water.

Numerous surface water is monitored for many reasons (environmental, industrial, transportation, etc.) and generally, in Europe, these are freely available, as open -ource datasets (Fig. 14).

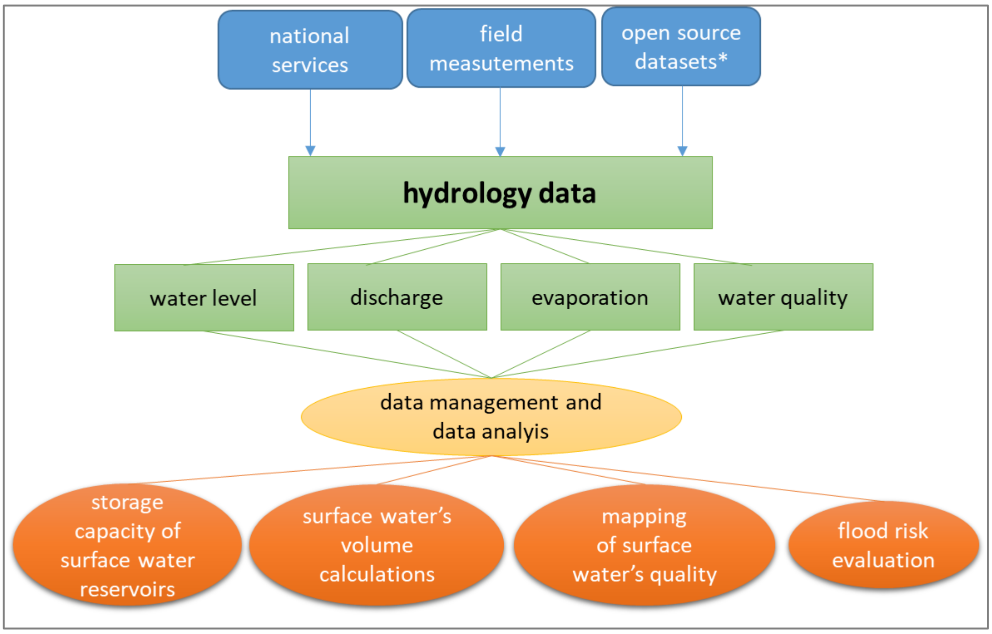

*Figure 14. Hydrology data gathering and the resulted information/maps (*refers to national open data sources which may vary country by country)*

Besides this option farmers can also carry out water sampling and basic field measurements to get information to describe the storage capacity, the volume or water quality of the surface water bodies they have, and in addition, the flood risks on their lands or their environment. Nowadays, several products are available to water sampling and to measure parameters on the field, "in situ". (Fig. 15). To carry out in situ physicochemical measurements, portable equipment sets can be installed and left on the field for several weeks to provide mid-term monitoring even using telemetry.

WATERAGRI

Figure 15. Water sampling from surface water body and in situ pysico-chemical measurement

Probes by which water quality measurements can be carried out are categorized as general sensors, ion-selective electrodes (ISE), and fluorometers. General sensors, including temperature, pH sensors, conductivity (EC), optical dissolved oxygen (HDO), turbidity. Fluorometer sensors, applying electromagnetic (EM) rays within the visible spectrum, are also helpful tools to determine the chlorophyll, algae, rhodamine, tryptophan, fluorescein dye and oils. Ion-selective probes respond to the presence of certain ions, for instance, ammonium, nitrate, calcium, sodium, chloride, bromide, potassium, etc. It must be considered that calibration should be re-done periodically depending on the sensor type, moreover, sensors have an expiration date after which replacement of the sensors is required. It is advisable to contract with the distributor of the equipement covering this background service work.

2 Alternative Water Resources and Irrigation Systems

2.1 Alternative Water Resources as Water Supply for Irrigation

Before planning an irrigation system, some of the first questions are always “Do we have water resources?”, “Do we have enough water to fulfill the irrigation needs?” In certain cases, due to quantitative or qualitative problems of surface or subsurface water resources, the answer is: “There is no, or not enough water for irrigation.” But in many cases several other types of so-called alternative water resources available or potentially available locally for irrigation purposes. Besides quantity, quality is also important. This chapter summarizes the potential of alternative water resources in irrigation.

2.1.1 Alternative water resources from natural sources

Alternative water resources from natural sources are essential for irrigation purposes in certain areas where there are limited surface water resources. Especially in lowlands, a significant amount of inland excess water may concentrate more than once in a year directly hindering agricultural activities and harming crop vegetation (Mittra & Stickler 1961), which is undoubtfully unfavorable. Though inland excess water is usually the subject of drainage by many practices to reduce damages. On the other hand, the water drained from fields is often missing in summer. Therefore the excess water should be collected and used in crop production as an alternative water source in drought-affected summer period (Lilienfeld & Asmild 2007). Besides excess water, especially at those sites, where there are large impervious surfaces, rainwater harvesting can also be a solution for an alternative water source.

2.1.1.1 Excess water and small scale water retention measurements

Excess water can be a common problem since it limits agricultural production possibilities, can cause serious crop loss and result in both physical and chemical soil degradation. The presence of excess water is greatly disadvantaging especially when it occurs at the time of preparatory work, seeding period, growing period, or even at harvest time. Furthermore, drought and inland excess water often occur in the same year at the same site. Since excess water is mainly driven by climatic factors, excess water is usually a seasonal problem but it is highly connected to soil and terrain conditions (geometry, column, state, structure, compaction rate). Clay soils are particularly sensitive to compaction, which can increase the likelihood of inland excess water formation. Sandy areas are in a more favorable situation from a lithological point of view (e.g. the case study site in Nyírség), where the risk of excess water occurs only in areas where the groundwater table is close to the surface or where a silty sediment layer is present. Local climatic conditions of the recharge area are also important factors. More importantly, many of the reasons for excess water formation can not be modified quickly and advantageously by humans, but with an application of adequate complex melioration plans, the harmful effects of excess water may be significantly decreased.

On the other hand, if excess water is gathered and stored with success, the amount of the stored water can be utilized in crop production for irrigation. One of the most commonly applied technical measures in the melioration of lands is the removal of excess water through drainage system which may contain solutions are listed based on Brouwer et al. (1985):

- surface drains
    - ditches
    - grassed waterways
    - humps and hollows
    - excess water channel system
- subsurface drains
    - mole drains
    - gravel mole ploughs
    - raised bed cropping.

Then the drained water can be collected in larger insulated reservoirs for further irrigation purposes.

Another solution to collect surplus water are Natural Small Water Retention Measures. Experts in irrigation and water management emphasize the importance of planning natural small water retention measures in case of excess water retention as well (GWP 2015, EU 2014, Mioduszewski et al. 2014, Mioduszewski 2014).

The salt content of excess water is often the barrier to irrigation utilization.

2.1.1.2 Rainwater harvesting

When rainwater is accumulated and stored in order to reuse it before reaching the aquifer that is rainwater harvesting (FAO, 2014). Rainwater is used for domestic water supply in many countries (Thomas & Martinson 2007, Rovira et al. 2020), and in some cases, for agriculture and livestock supplies and more increasingly for irrigation, as well. In farms, rainwater can be collected from several surfaces such as roofs of houses and farms sheds, road surfaces, concrete or plastic surfaces e.g. greenhouses.

Elements of rainwater catchment systems should contain proper, prepared surface on the area from which rain water is collected, channel system (e.g. gutters) by which water is led to a container (e.g. cistern) or reservoir, due to possible contamination proper filter system and, in case, cleaning system (Zhu et al. 2015).

It is considered to be sustainable, however, the effects of modification in infiltration characteristics should be calculated and taken into account during rainwater harvesting. In addition, the precipitation characteristics may vary in a wider range.

As usual, initial investments are required to install such systems, but it is widely considered to be cost-effective application. The running costs are low and by the development of rainwater harvesting technology, it may be more effective.

In order to know, whether rainwater harvest can provide enough water for the farm or not, the amount of rainwater collected (V) can be calculated very easily based on the amount of precipitation (mm), footprint of the collection surface (m^2), k – conversion, if necessary (SI, non-SI), e – efficiency coefficient dependent on type/material of the collection surface (no dimension).

The amount of harvested rainwater can be thousands of liters which may be a good source for small and micro- even for urban-farming scale. By increasing the footprint of the collection surface the amount of the harvested rainwater can be increased. It is important to note that precipitation may vary in wide ranges which significantly modify the amount of collected water thus in planning and installing such systems both statistical time series analysis of precipitation and future prognosis model calculations are recommended.

Hungarian case study example for alternative water source utilization for irrigation

The 21% (930 km^2) broad region of the case study site (Nyírség) was covered by water for all or part of the year in the middle of the 19th century. Most of the Nyírség was a runoff area before the commencement of flood relief and inland drainage works (Túri & Szabó 2012). Nowadays, most of these wetlands are not present anymore, and the lack of them, as water source have effects on agriculture. Therefore, case study site alternative water sources utilization system was set up for irrigation to adapt to climate change and reduce fertilizers. The case study site now is 16 ha of pasture with irrigation for cattle grazing and 50 ha of irrigated arable land (maize and wheat). Furthermore, the physical characteristics of the case study site are mostly sandy with disadvantageous water management properties (Tamás et al. 2019) (Fig. 16).

Since there is no available surface water at the case study site, alternative water resources are used. The basis of the alternative water resources are:

- excess water
- treated wastewater
- fermentation sludge

which is collected in a water reservoir with 114000 m^3 capacity.

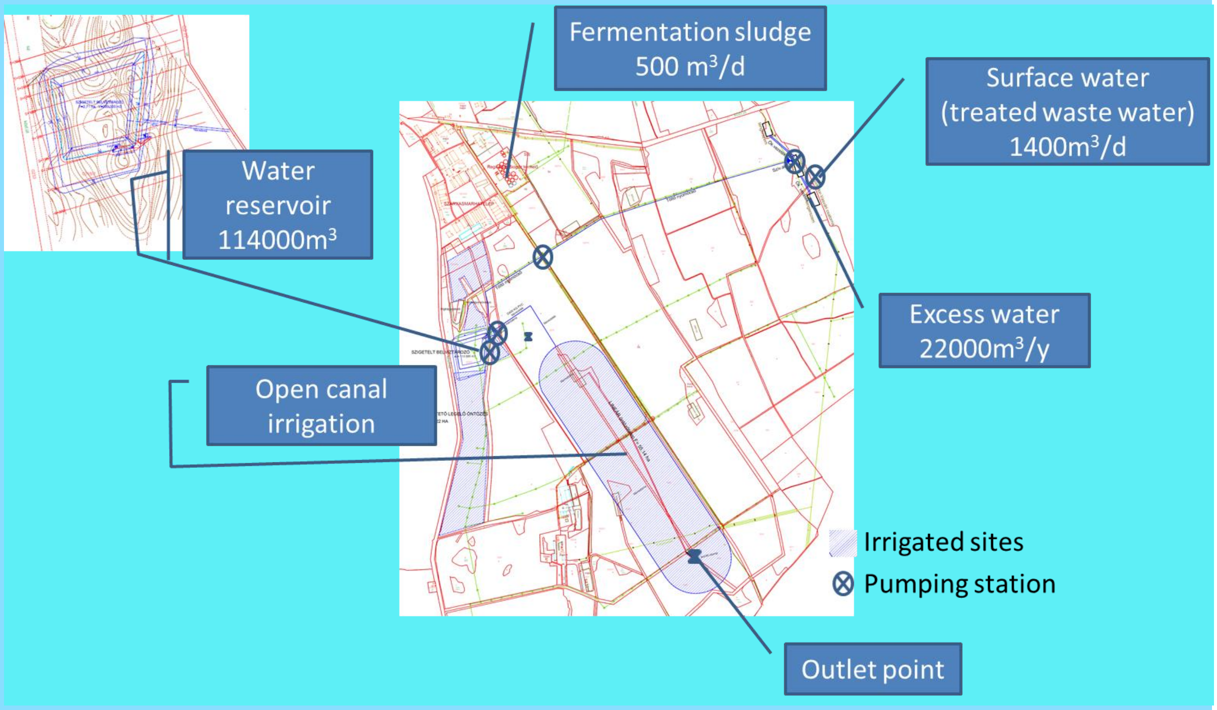

Figure 16. Alternative water resource management at the case study site

3 excess water surface reservoirs in which annually, depending on the seasonal characteristics, 10-30000 m^3 excess water can be collected in early spring from the neighboring agricultural fields. Water from the central reservoir can be pumped to the insulated water reservoir. The water level of the reservoir is measured with an ultrasonic water level meter, which is a water level measurement that controls the water discharge from the central excess water reservoirs.

The excess water is not enough in itself for irrigation. The volume of treated wastewater in the city of Nyírbátor is more than 500.000 m^3 per year. The recipient of the treated wastewater is the Nyírbátor-Vasvár watercourse/channel, from which, in the absence of inland water, the 3 inland water reservoir bodies can be filled by gravity, from where the water flows, as already described, to the water reservoir, which collects the water for the irrigation systems. The treated wastewater reaches water extraction point after flows 4.8 km in Nyírbátor-Vasvári channel.

From the water reservoir, the irrigation water enters the drain line through gravity valves and gate valves and flow meters in gate valves, then it reaches the open canal, where a pivoting lateral moving irrigation system is set for irrigation. At the gate valve, a fermentation sludge is added to the irrigation providing fertigation possibilities. The fermentation sludge is coming from a biogas plant, after separating most of the dry material content.

2.1.2 Reclaimed water resources

There are certain areas and, more importantly, drought-affected periods of the year, when a sufficient amount of water is not available neither from rainwater harvesting nor excess water reservoirs for agriculture (Mateo-Sagasta et al. 2013, Gatto D'Andrea et al. 2015). Therefore, it is worth emphasizing the benefits of using recycled water with the food industry, or wastewater origin considering their potential contaminant or high salt contents (Levy et al. 2011).

Reclaimed water utilization in agriculture shows an upward trend in certain areas. Treatment processes, such as microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), UV disinfection, chlorination, ozonation, membrane batch reactor (MBR), are necessary and the related costs can be high. The general financial statement about the installation and operation of wastewater treatment plants is that the higher the treatment capacity is the lower costs (euro/m^3) occur.

The benefits are, for instance, lower cost compared to some other sources and consistency of supply regardless of neither climatic conditions nor associated water restrictions. Moreover, reclaimed water is utilized in agriculture for irrigation, the nutrient content of the treated wastewater can act as fertilizer. European and national standards must be taken into consideration in each case (WHO 2006).

2.1.2.1 Treated waste waters of urban areas

A European assessment was performed by Pistocchi et al. 2018 about the annual amount of theoretically available water at the outlet of urban wastewater treatment plants (UWWTPs) according to which 48 billion m^3 water is available calculated for EU2012 members.

Irrigation with treated wastewater has long been a well-known practice that enables efficient and inexpensive water utilization (FAO 2003). Their agricultural utilization depends on many factors, the most important of which is the degree of treatment and the composition of the initial effluent.

During wastewater treatment, first, the larger solids are removed from the wastewater, followed by multi-stage biological wastewater treatment. The process can be completed by post-treatment or tertiary purification, in which mainly the decomposition of the chemicals remaining in the water can take place. The steps also depend on the use and recipient of the treated wastewater, which is much more important when it is used for irrigation than when it is discharged into a river.

The main chemical quality problems with treated wastewater are total dissolved solids (TDS), trace elements and excessive nutrients (Bedbabis, 2015; FAO 2003, Pedrero 2010). Of these, nitrate, phosphate and potassium enrichment is to be the most significant in the case of basically residential water use. Irrigation with excess nutrient water can be a good solution from a fertigation point of view, but improper utilization can induce pollution and eutrophication or inadequate nutrients can interfere with plant development. Since the concentrations of N, P and K ions measured at the end of the wastewater treatment process change so it is required to monitor nutrient and element content of the water at a farm site.

Microbiological contamination is primarily due to the presence of E. coli bacteria. Higher levels of wastewater treatment also reduce the number of bacteria and viruses in irrigation water and soil (Vivaldi et al., 2015). Depending on the method of irrigation, the use of treated wastewater can be prohibited or permitted based on the number of germs. Concentrations of drug residues in treated wastewater can also be significant.

2.1.2.2 Grey water sources

Besides these significant potential reclaimed water resources, it is important to note other possibilities such as greywater utilization possibilites of both municipal and industrial wastewaters. Greywater (GW) consists of diluted domestic wastewater streams coming from the shower, laundry facilities and/or the washbasins, whereas in some studies greywater also includes the kitchen wastewater (Nolde 1999, Dixon et al. 1999).

The most common application for GW reuse in urban areas is toilet flushing which can reduce water demand within dwellings by up to 30% (Karpiscak et al. 1999, Lu & Leung 2003). The use of GW for irrigation is one of the methods which is currently widely used. This is particularly important in arid zones, where water is scarce and reuse of GW for irrigation could reduce potable water use by up to 50% (DHWA, 2002). In some arid and semi-arid areas, municipal water consumption typically increases by 40–60% in summer months due to landscape irrigation. The use of treated greywater for irrigation in countries with low precipitation is an attractive option, as greywater is low in salts.

The easiest way to use greywater is to pipe it directly outside and use it to water ornamental plants or fruit trees. Greywater can also be used to irrigate vegetable plants as long as there is no contact with the produce grown for human consumption. In any greywater system, it is essential to use “plant friendly" products, those without lots of salt, boron, or chlorine bleach. The build-up of salts and boron in the soil can damage plants.

Many new technologies have been developed to treat greywater (GW) (Gross et al. 2007). The major difficulty presented for the treatment of GW is the large variation in its composition. Reused GW originating from industrial (animal husbandry, fermentation units) should fulfill four criteria: hygienic safety, aesthetics, environmental tolerance, and technical and economical feasibility (DHWA 2002).

2.1.2.3 Other alternative resources

Groundwater excess due to mining activities and tailing ponds

During the mining activity, a significant amount of water usually has to be extracted. In order to maintain mining, it is necessary to lower the water level, the quality of the extracted water depends on the soluble phases of the solid geological medium (Grewar 2019, Annandale et al. 2018). This amount of groundwater must be collected and utilized.

In the case of mining sand, igneous rocks and limestone, the water usually contain a moderate amount of solute, due to the geochemical nature of the environment. In the case of coal mining, due to the dissociation of the pyrite present, the pH of the water becomes acidic, which also promotes the mobility of heavy metals. If mining is done from a deeper zone, the amount of total dissolved material can increase significantly.

The enrichment of the fluoride content of water brought to the surface in connection with coal mining caused severe maize yield loss in the soil (Sun et al. 2014) and is not suitable for irrigation of winter wheat without treatment (Ma et al. 2015). Phosphate mine water may be suitable for nutrient return, but negative effects cannot be ruled out either (Al-Hwaiti 2016).

In a conclusion, goundwater excess due to mining activities can be used in only those cases, where the geological origin is acceptable, and continuous monitoring is available.

Industrial Cooling Water Bodies

A significant amount of water is used during freshwater cooling: here the industrial process is cooled by water taken from water bodies, the heated water usually returns to the same water bodies. During the process, the cooling water temperature can increase by up to 8-10 °C, depending on the yield and the heat output, but in general, the solid content and other characteristics change only slightly.

There is a possibility of using cooling water in irrigation. The cooling of industrial facilities can also be done with the help of cooling ponds. In this case, the lake can be designed to be multifunctional. If water can be used for cooling, by treating it and carefully managing the irrigation to avoid the accumulation of salts in the soil and contamination of the groundwater, irrigation can be competitive water disposal (Jury et al. 1980).

In general, in the case of open reservoirs, it is important to calculate with evaporation. The bigger open-air surface water is stored by, the more evaporation loss must be expected. By evaporation not only the volume of the alternative water resource decrease but also the concentration of dissolved solids increases.

2.2 Precision irrigation system at Hungarian case study

There are 3 main types of irrigation:

- In the case of surface irrigation, the irrigation water leaks into the soil when it is conducted on the surface. There are several solutions for this, the so-called flooding, dripping and soaking procedure.
- Whilst sprinkler irrigation, the water is sprayed with machine equipment and turned into a rain-like spray.
- In micro-irrigation, the water is continuously dispensed in small portions.

The application possibilities, criteria and other effects of irrigation methods are listed in Table 1.

Table 1 Possibilities, criteria and other effects of irrigation systems

factors	irrigation method			
	surface	subsurface	sprinkler	micro (drip irr.)
special goals (in addition to moisture supply)	salt leaching	control of groundwater	colouring, antifreeze, irrigation for germination	water saving
Topography	flat or one-directional even slope (max. 15–20%)	plain	varying	varying
Soil conditions: physical soil type	loamy clay, clay	loamy clay, clay	sand, sandy loam	sandy loam, loamy clay, clay
topsoil thickness	thick or moderately thick	thick	thin	varying
soil infiltration rate	low or moderate	–	high	moderate
water holding capacity	high	high or moderate	low	low or moderate
Cultivation, crop	rice, meadow pasture, high-growing crops with high-water needs	high-growing crops with high-water needs	crops that require frequent watering with high demands	high-value crops with high water needs
Amount of irrigation water	high	high	low	low
Frequency of irrigation	low	moderate	high	high
Loss: surface runoff	high	–	low	none
leakage	high	high	low	very low
evaporation	low	–	high	none
Additional measures required	landscaping	landscaping, groundwater level control	–	-
Risk of harmful side effects: surface runoff	high	–	low	low
structural destruction	moderate	low	high	moderate
overmoisturization	moderate	high	low	low
groundwater level rise	high	very high	low	none
salinization	moderate	(very) high	low	none

Based on Table 1. the sprinkler irrigation system was set up at the Hungarian case study site. As an overview, a pivoting lateral moving sprinkler irrigation machine with a total structural length (including the basic machine and the end console) of 209.09 m was installed in the field (Annex I.). The irrigation system consists of four 47.54 m long irrigation sequences and an 18.59 m long end arm, with a total irrigation radius of approximately 235 m. The maximum water demand of the system is 180 m^3/h and the minimum water demand is depending on the aim of the VRI, as the pump must operate at 65 m^3/h, which requires a minimum operating pressure of 2.2 bar at the central tower. The type of nozzle used has relative throw distance and is equipped with 15 PSI pressure regulators and is located at a height of 2.1 m from the ground. The GPS control is located on the central tower consisting of two antennas and a receiver with steering electronics.

As a first step at the design, the shape, and the topography of the site should be analyzed. In the case study, the total area of the block, where the irrigation should be planned is ~132 hectare, the longest side is ~2450m, and the average width is ~420-440m (Fig. 17). The terrain is quite flat, there is only some meter difference in most places. Only the northern part of the field has a considerably higher spot, and the south-west has some low spot. There is electricity close to the field, and a reservoir (introduced in chapter 2.1.1.) at the north-west from the site. The site has sandy soil which is not so sensitive for system intensity.

Figure 17. The case study site, before irrigation

Near the reservoir, there is a hump area, so with the lateral moving irrigation system, it is recommended to avoid this area because of the high relief (Fig. 18). There is a canal in the middle of the field coming from the reservoir, and going to the southern direction which can feed the irrigation machine. From the reservoir to the canal, the water goes through gravity, and the canal has a separate water level control which is connected back to the electric gate valve which controls the water flowing out from the reservoir.

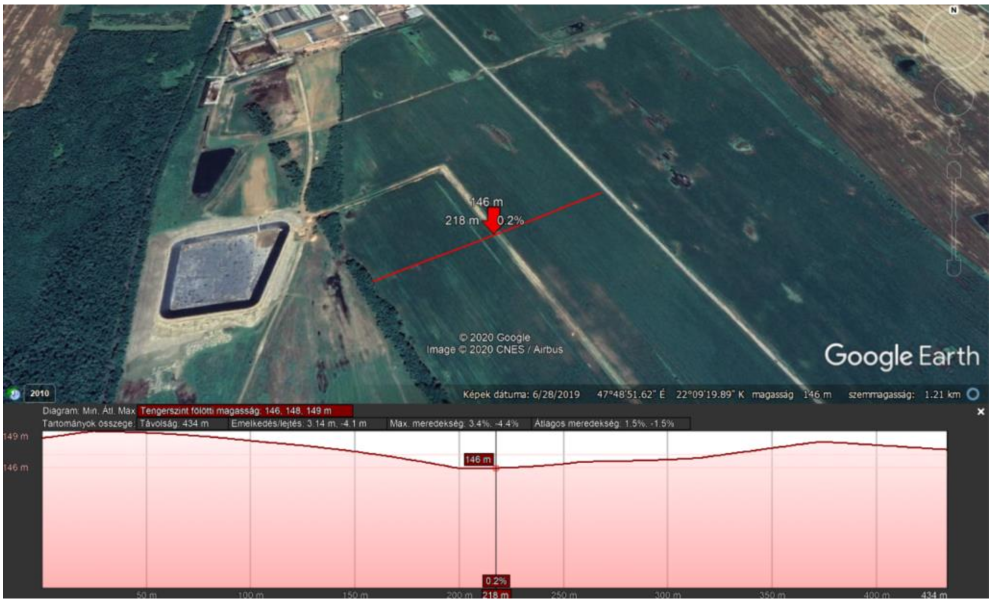

Figure 18. Cross section of the site

In general, there is two types of machine would be available, Center feed canal feed lateral, and canal feed pivoting lateral. As the northern side of the field narrows in, the perfect solution could be the pivoting one. The maximum system length has to be less than 210m, and it is recommended to equip an end gun on it, to get the maximum coverage out of the system. The length of the run could be ~1500m, and the system has to go through a road in the middle of the field (Fig. 19).

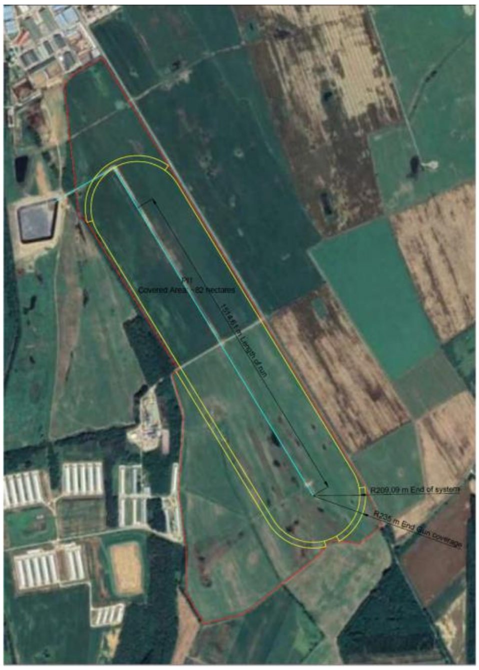

Figure 19. The outline of the planned irrigated area

The starting point for design is to determine the required daily irrigation rate (mm/day). This value depends on what kind of crop they would like to produce, on what climatic conditions. The design minimum has to meet the maximum evapotranspiration/day of the crop, but it is better if we are above it to eliminate the continuous operation of the unit. In Hungary, the usual daily irrigation rate is 6-8mm/day.

Another important design point for these machines is to keep the inlet pressure demand below 4 bar most often, to reduce the operation cost. The pressure requirement of sprinklers equipped with a pressure regulator usually 1,04-1,4 bar (15-20PSI) above the pressure regulator at the end of the system.

Four-wheel canal feed power cart is recommended for pivoting lateral irrigation (Fig. 20). It has four independent motors running each wheel on the cart. The cart is equipped with a generator to power the pump. The standard design is a diesel engine attached together with a horizontal centrifugal pump and installed on a towable frame, which is also the fuel tank. Usually, it has some kind of protection on it, like a roof, side protection or a total soundproof canopy. To control the engine and the pump functions the unit requires a control panel. The key features of a standard control panel for mechanical diesel engines from an irrigation point of view are digital instruments (hour-meter, oil pressure gauge, water or oil thermometer, timer, pump water pressure gauge, fuel level indicator, tachometer, battery voltmeter), motor pump failure automatic monitoring, manual starting with key, pump protection exclusion, accompanied by an electronic transmitter of water pressure adjust engine speed through the actuator maintaining constant the pressure of the irrigation system, controls the flow of water in the pipe, equipped with a built-in GSM modem for full remote control, acceleration and deceleration automatically adjusted upon starting and stopping of the pump, frost protection and pressure boost functions.

Figure 20. Four-wheel canal feed power cart

The guidance is mounted on the cart. To ensure that the cart will not run into the canal. The canal feed cart can be a center feed. The guidance can be furrow, cable, fence, buried wire, or GPS. The most updated solution is GPS. It requires an RTK correction for cm accuracy (as in the case study site). GPS guidance is getting more widespread. The advantage of GPS guidance is that it does not requires any maintenance during the season, accurate, easy to change the path of the lateral, and really reliable. The MCP (main control panel) should also be mounted on the cart. To control the system and VRI a modern Main Control Panel is required, with GPS positioning and VRI control. Because of a road going through in the middle of the field, for guidance only GPS allowed. It has to take place on the cart, to align it precisely on the cart path.

For proper guidance, tower boxes, alignment circuits and percent timer are used. The alignment circuit: It determines when the tower is to move. The percent timer is a variable setting control mounted on the main control panel that controls the end tower, which determines the water application. All intermediate towers are controlled by microswitches in the tower boxes to keep the towers "in line" between the pivot point and the last tower. The steering method of a lateral move system is: The percent signal is sent out by the main control panel to the guidance box. This box will decide which end of the system will get this signal. If the system is on the path, then both end of the system is going with the main percent timer signal. If one end of the system falling behind, then that end of the system will use the main percent timer signal, and the other end will get a secondary percent timer setting to slow that end down, and let the other end catch up. The final result will be that a lateral move system will swing through its path.

As the system is equipped with VRI, it would be required that the pump has to be controlled through the Frequency driver. A pressure reducing control valve is also required if the system is equipped with VRI, to keep the base of inlet pressure always constant for the system. It has to be controlled with electricity from the Main control panel of the system.

The canal feed power cart also has a stinger that pumps the water into the pipe out of a canal. At the case study site, the stinger should be equipped with an automated electric winch as it has to go through a road.

Since the canal is an opened one, water filtering technology is recommended to avoid the clogging of the nozzles, as the minimum nozzle diameter is only some mm.

Depends on the soil type, and application rate it is really important to choose the optimal tire size and tower type according to the weight of the span. In this case, it is possible to avoid deep wheel tracks, reduce the chance of stuck in the mud, increase the lifetime of the center drives and wheel gears. At the case study site, the farm has sandy soil, so the cart has to has the best traction and flotation, so wider tires would be required on it, a minimum 16,9x24.

There is also an auto stop switch, that includes the physical barricade, auto stop / auto reverse box, and the arms that trip the switches in the boxes to control the machine.

The span is the metal structure which delivers the water to the direction of the end of the system. It has an outlet at the top of the pipes, where usually a U pipe (gooseneck) is going to, with a drop pipe, and a pressure regulated sprinkler on it. The end of the Span is a tower. It has an electric motor, wheel gears, and tires on it. There is a maximum slope limitation between the spans, which is unique for all manufacturers. There are no theoretical limitations, that how many spans is available to use for a system, but the electric, flow, and pressure requirement will limit it. There are different high options for Spans, from low (~1,5m ground clearance under it) to ultra-high (6,1m ground clearance under it) (Fig. 21.).

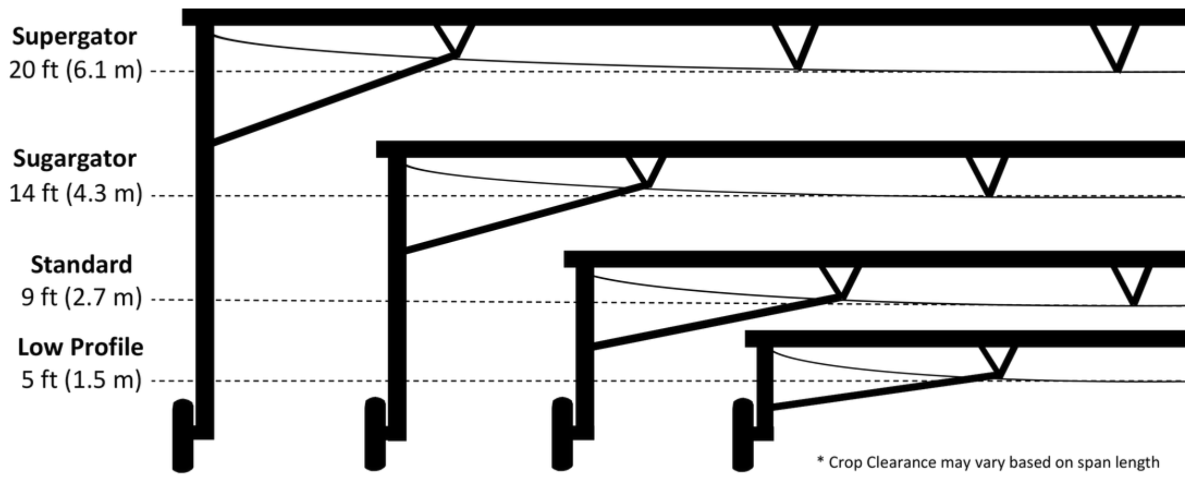

Figure 21. Different gator systems

At the end of the system there is usually an end boom, (or Swing Arm Corner if it is a center pivot and its equipped with it), which can be 1-32m long. At the case study site standard gator was installed. The spans have to be galvanized against corrosion and equipped with a dual sprinkler package. To get a perfect uniformity from the sprinkler, it is required to have an outlet spacing ~1,5m. In this case on both operation mode (pivoting, lateral) there would be a sprinkler on every ~3m, which generates a good uniformity if the sprinkler throw diameter is ~14m. Also, every outlet has to be equipped with ¾" valve for sprinkler control (Fig. 22). An air compressor is required if the valves are air controlled diaphragm ones. Valve control boxes have to be equipped, too.

Figure 22. ¾" valve for sprinkler control

Since the irrigation machine set at the Hungarian case study site should work in lateral and pivoting mode as well, the system has been equipped with a double sprinkler package. Except in the middle of the irrigation machine, where there are 8 nozzles working both in lateral and pivot mode with similar nozzle size. Overall, there are 118 nozzles equipped on the machine and arranged in 18 zones. In pivot mode, only Z9 (4 nozzles), and Z10 (4 nozzles) and Z11 (48 nozzles) zone is allowed to be operated. This means 56 nozzles are used in pivoting mode, out of this 56, 48 is working only in pivoting mode in zone 9., the remaining 8 nozzles (zone 9 and 10) is working in lateral and pivoting mode as well. Pivot nozzle size is growing from 18 to 45 starting from the cart. All the other zones (1-8; 12-18 each zone equipped with 4-6 nozzles) can be controlled in lateral mode only, mostly equipped with 34-36 nozzle sizes. This means 70 nozzles are used in lateral moving mode. All the 17 zones working in lateral moving mode are VRI controlled by a pulse signal, with a 180 sec cycle time. For example, if a zone has to be on for 50%, then that zone will be on for 90 sec., and off for 90 sec., irrigation half amount of water than those zones with permanent (180 sec) open.

An end gun adds additional irrigation coverage area by spraying water beyond the end of the end boom (the exact distance is determined by water pressure). The end gun can be set to turn on and off as needed. This on/off function can be controlled by a switch, actuated by a stop, or by GPS location if the system is equipped with end of system GPS. A booster pump extends the water throw distance by raising the water pressure at the end gun. A big volume end gun is required, with a control valve and a booster pump to help reduce the required base of inlet pressure. A big gun usually requires 3-4 bars for operation. A booster pump can produce this pressure from the available 1.04-1.4 bar end of system pressure. Run-dry protection also has to be installed at the end of the system for the booster pump.

The irrigation machine at the case study site is equipped with a self-cleaning screen, plus a booster pump for the backflush line. When the pump is operating, there is an outlet above the delivery line, where the booster and the backflush line is installed. There are two sprinkler lines installed inside the filter drum, so it is always rotated and cleaned by the water.

In center pivot systems, a swing arm corner can be installed to irrigate those corners which are out from the parent system coverage. The swing arm corner opens out and closes on the desired locations, to get the maximum coverage out of your field, controlled by GPS guidance. In the past, all the sprinklers banks on every manufacturer corner arm was controlled by mechanically, like a cam stack or a potentiometer. As the angle changed between the parent system last tower top and SAC, so the nozzle banks were opened or closed. This resulted over-irrigation in opening and closing. Nowadays there are several solutions to avoid this (e.g. zone control of the sprinklers through the SAC, cyclically open and close these zones as a VRI (Fig. 23).

Annex I. Pivoting lateral moving sprinkler irrigation system at the Hungarian case study site

1 TOWER BASE-PIVOTING-LATERAL

1 PROX SWITCH KIT

2 Tire Option, 16.9 x 24 New Tires, Galvanized Wheels, 1 Forward, 1 Reversed

1 PIVOT JOINT ASSY 6-5/8 EII

1 PVT CTR-6-5/20,3cmEII-GALV-PIV-LAT

1 CROSSPIPE/LONG RISER-15,2cm PL

1 Wheel gear (4) UMC 760 Bronze

1 RPM TOUCH PIVOTING LATERAL

1 Generator Switch-RPM Touch Screen

1 Lightning Arrestor

1 TRANSDUCER OPT PREF TOUCH MCP

1 GPS RESOLVER OPT-PIVOT-MAXI

4 Spans, 47,5m, 15,2cm dia., Galvanized Pipe, 144,8cm Outlet Spacing

3 JOINT-SPAN-E2065

4 Long System Alignment Package

1 LAST TWR TOP E2065

4 Tower Assembly, Galvanized, Standard Profile

4 Tire Option, 14.9 x 24 New Tires-Tubeless, Galvanized Wheels, 1 Forward, 1 Reversed

4 Wheel Gears, Reinke, Non-Towable

4 Helical Center Drive-Std Speed-EII

1 End Boom, 18,6m, Galvanized Pipe

1 End Gun, KOMET Twin MAX

1 Reinke Valve for use w/BP

1 Strainer - Last Tower Top, Flange Mount

1 Booster Pump, End Gun, 2 Hp

2 Light Assembly, Pivot Center, Strobe

118 19mm REINKE VALVE W/TEE

3 TUBE OPT-9.5mm PER 76,2m

1 TOWER BOX-RETRO MNT KIT-15,2cm

1 VALVE BOX-DUAL SPRKLR-PIV LAT

3 VRI BOX 6 Zones

1 Air Compressor Option - Jenny - Tower Mount

118 Sprinklers, Nelson Rotator (R3000)

118 Pressure Regulators, Nelson 1 BAR

118 Hose Drops, Flexible with Fittings

1 Flush Valve, End Boom

1 Nelson 800 Series 15,2cmMedium pressure (5,5 BAR) sleeve

3 Reference list

Abdullah, A., David, A., Nielsen, C. (2001): Use of crop water stress index for monitoring water status and scheduling irrigation in wheat. Agricultural Water Management. Volume 47, Issue 1, February 2001, Pages 69-75

Abdulridha, J., Ehsani, R., Abd-Elrahman, A., Ampatzidisa, Y. (2019): A remote sensing technique for detecting laurel wilt disease in avocado inpresence of other biotic and abiotic stresses. Computers and Electronics in Agriculture Volume 156, January 2019, Pages 549-557
Al-Hwaiti M.S., Brumsack, H.J., Schnetger, B. (2016): Suitability assessment of phosphate mine waste water for agricultural irrigation: an example from Eshidiya Mines, South Jordan. Environ Earth Sci 75:276

Annandale, J.G., Meiring du Plessis, H., Tanner, P.D., Burgess, J. (2018): Using a risk based, site-speci¬fic Decision Support System to determine the suitability of mine water for irrigation. 11th ICARD | IMWA | MWD Conference – “Risk to Opportunity”

Arnó, J., Vallès, J. M., Llorens, J., Sanz, R., Masip, J., Palacín, et al., (2013): Leaf area index estimation in vineyards using a ground-based LiDAR scanner. Precision Agriculture, 14(3), 290-306

Ayers, R.S., Westcot, D.W. (1985): Water Quality for Agriculture, FAO Irrigation andDrainage. Paper No.(29), Rev.(1), U.N. Food and Agriculture Organitation, Rome

Ballester, C., Jiménez-Bello, M.A., Castel, J.R., Intrigliolo, D.S., (2013): Usefulness of thermography for plant water stress detection in citrus and persimmon trees. Agricultural and Forest Meteorology, 168 120-129.p.

Bartholy, J., Pongrácz, R., Gelybó, Gy. (2007): Regional climate change expected in Hungary for 2071-2100. Applied Ecology and Environmental Research.1-17.

Bedbabis, S., Triguia, D., Ahmed, C.B., Clodoveo, M.L., Camposeod, S., Vivaldi, G.A., Rouina, B.B. (2015): Long-terms effects of irrigation with treated municipal wastewater on soil, yield and olive oil quality. Agricultural Water Management 160 (2015) 14–21

Boluwade, A., Madramootoo, C. Yari, A. (2016). Application of unsupervised clustering techniques for management zone delineation: Case study of variable rate irrigation in Southern Alberta, Canada. Journal of Irrigation and Drainage Engineering. 142(1): 1–8 p.

Brouwer, C., Goffeau, A. and Heibloem, M. (1985) Irrigation Water Management: Training Manual No. 1-Introduction to Irrigation. FAO, Rome.

Burke, J.J. (2002): Groundwater for irrigation: productivity gains and the need to manage hydro-environmental risk, in: Intensive use of groundwater challenges and opportunities, edited by: Llamas, R. and Custodio, E., Balkema, Abingdon, UK, 478 pp.

Campbell C.S., Campbell G.S., Cobos D.R. (2004): Response of Low Cost Dielectric Moisture Sensor to Temperature Variation. Eos Trans. AGU, 85(17), Jt. Assem. Suppl. Abstract NS44A-05.

Clesceri, L.S., A.E. Greenberg, Eaton, A.D. (1998): Standard Methods for the Examinationof Water and Waste Water. 20th Ed., Washington

Colaizzi, P. D., O'shaughnessy, S. A., Evett, S. R., Mounce, R. B. (2017): Crop evapotranspiration calculation using infrared thermometers aboard center pivots. Agricultural Water Management. 187: 173–189 p.

Croppenstedt, A., Knowles, M., Lowder, S. (2018): Social protection and agriculture: introduction to the special issue. Glob. Food Sec., 16 (2018), pp. 65-68

DHWA (Department of HealthWestern Australia) (2002): Draft Guidelines for the Reuse of Greywater in Western Australia, Department of Health, Perth, Australia, 2002, p. 37.

Dixon, A., Butler, D., Fewkes, A. (1999): Water saving potential of domestic water reuse systems using grey water and rain water in combination, Water Sci. Technol. 39, 2532.

EU Commission, 2014. EU Policy document on Natural Water Retention Measures. Technical Report - 2014 – 082

Fang, W., Huang, S., Huang, Q., Huang, G., Wang, H., Leng, G., Guo, Y. (2019): Probabilistic assessment of remote sensing-based terrestrial vegetation vulnerability to drought stress of the Loess Plateau in China. Remote Sensing of Environment, 232 (2019), p. 111290

FAO (2003): Users Manual for Irrigation with Treated Wastewater, FAO Regional Office for the Near East, Cairo,

FAO (2014): Feasibility Study of Rainwater Harvesting for Agriculture in the Caribbean Subregion, p. 74

Farr, T., Kobrick, M. (2001): The Shuttle Radar Topography Mission. Eos, Transactions of the American Geophysical Union, 81(48):583-585.

Flores, L.. Arzola, J., Ramírez, M., Osorio, A. (2012): Global climate change impacts in the Sinaloa state, méxico. Cuad. Geogr. Rev. Colomb. Geogr., 21, pp. 115-129,

Gálya, B., Tamás, J., Blaskó, L., Riczu, P., Nistor, S., Fehér, J., Bozsik, É., Nagy, A. (2018): Water retention possibilities in soils – Hungarian part of the Tisza river basin Natural Resources and Sustainable Development 8 (1): 35-40.

Gatto D'Andrea, M.L., Salas Barboza A.G.J., Garcés V., Rodriguez-Alvarez M.S., Iribarnegaray M.A., et al. (2015): The Use of (Treated) Domestic Wastewater for Irrigation: Current Situation and Future Challenges. Int J Water and Wastewater Treatment 1(1): doi http://dx.doi.org/10.16966/ ijwwwt.107

Giordano, M. (2006): Agricultural groundwater use and rural livelihoods in Sub-Saharan Africa: A first-cut assessment. Hydrogeology Journal, 14:310-318.

Global Water Partnership Central and Eastern Europe (2015). Natural small water retention measures combining drought mitigation, flood protection and biodiversity conservation. Guidelines, Global Water Partnership Central and Eastern Europe ISBN: 978-80-972060-2-4

González Perea, R., Fernández García, I., Martin Arroyo, M., Rodríguez Díaz, J. A., Camacho Poyato, E., Montesinos, P. (2017): Multiplatform application for precision irrigation scheduling in strawberries. Agricultural Water Management. 183: 194–201 p.

Gonzalez-Dugo, V., Zarco-Tejada, P.J., Nicolás, E., Nortes, P.A., Alarcón, J. J., Intrigliolo, D. S., Fereres, E. (2013): Using high resolution UAV thermal imagery to assess the variability in the water status of five fruit tree species within a commercial orchard. Precis. Agric. 2013, 14, 660–678.

Grewar, T. (2019): South Africa's options for mine impacted water re-use: A review. Journal of the Southern African Institute of Mining and Metallurgy 119(3):321-331

Gross, A., Shmueli, O., Ronen, Z., Raveh, E. (2007): Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households, Chemosphere 66. 916–923.

Guidotti, D., Marchi, S., Antognelli, S., and Cruciani, A., "Water Management: Agricolus tools integration." 2019 Global IoT Summit (GIoTS). IEEE, 2019.

Haro-Monteagudo, D., Knox, J. W., Holman, I.P. (2019): D-Risk: A decision-support webtool for improving drought risk management in irrigated agriculture. Computers and Electronics in Agriculture. Volume 162, Pages 855-858

Hiler, E. A., Howell, T. A., Lewis, R. B., Boss, R. P. (1974): Irrigation timing by stess degree day method. Trans ASAE 17 393-398.p.

Idso, S. B., Reginato R. J. (1982): Soil and atmosphere-induced plant water stress in cotton as inferred from foliage temperatures. Water Resour. Res., 18, pp. 1143-1148

Intergovernmental Panel on Climate Change (IPCC) (2018): Global Warming of 1.5 °C. IPCC, Geneva.

Jackson, R. D. (1982): Canopy temperature and crop water stress. Adv. Irrig., 1 (1982), pp. 43-85

Jesus, A., Tenza-Abril, A. J., Malcolm, B., John, G., Lucila, C. (2018): Agricultural irrigation of vine crops from desalinated and brackish groundwater under an economic perspective. A case study in Siġġiewi, Malta. Sci. Total Environ., 650, pp. 734-740

Jiao, W., Tian, C., Chang, Q., Novick, K. A., Wang, L. (2019): A new multi-sensor integrated index for drought monitoring. Agric. For. Meteorol., 268, 74-85 pp.

Jones, H. G. (2004): Irrigation scheduling: advantages and pitfalls of plant-based methods. J Exp Bot 407:2427–2436

Juhász, Cs., Gálya, B., Kovács, E., Nagy, A., Tamás, J., Huzsvai, L. (2020): Predictability of weather and crop yield in regions of continental four-season climate. Computers and electronics in agriculture, 173: Paper: 105400.

Jury, W.A., Vaux Jr., H.J, Stolzy, L.H. (1980): REUSE OF POWER PLANT COOLING WATER FOR IRRIGATION. JAWRA Journal of the American Water Resources Association 16(5):830 - 836

Karpiscak, M.M., Foster, K.E., Schmidt N. (1990): Residential water conservation, Water Res. 26. 939–948.

Kaukoranta, T., Murto, J., Takala, J., Tahvonen, R. (2005): Detection of water deficit in greenhouse cucumber by infrared thermography and reference surfaces. Scientia Horticulturae, 106 447-463.p.

Khanal, U.. Wilson, C., Lee, B. L., Hoang, V. N., Managi, S. (2019): Influence of payment modes on farmers' contribution to climate change adaptation: understanding differences using a choice experiment in Nepal. Sustain. Sci., 14 (4), pp. 1027-1040

Kjelgaard, J.F., Stockle, C.O., Evans, R.G. (1996): Accuracy of canopy temperature energy balance for determining daily evapotranspiration. Irrig. Sci., 16, pp. 149-157

Lacroux, K., Gifford, R. (2018) Psychological Barriers to Energy Conservation Behavior: The Role of Worldviews and Climate. Change Risk Perception Environment and Behavior, 50 (7) (2018), pp. 749-780

Lehner, B., Böll, P., Alcamo, J., Henrichs,T., Kaspar, F. (2006): Estimating the impact of global change on flood and drought risks in Europe: A continental, integrated analysis. Climatic Change. 75.273–299.

Levy, G.J., Fine, P., Bar-Tal, A. (2011): Treated Wastewater in Agriculture. Use and Impacts on the Soil Environment and Crops. Blackwell Publishing

Lilienfeld, A., Asmild, M. (2007): Estimation of excess water use in irrigated agriculture: A Data Envelopment Analysis approach. Agricultural Water Management, Volume 94, Issues 1–3, 2007, pages 73-82

Lu, W., Leung, A.Y.T. (2003): A preliminary study on potential of developing shower/laundry wastewater reclamation and reuse system, Chemosphere 52 (2003) 1451–1459.

Ma, S. C., Zhang, H. B., Ma, S. T., Wang, R., Wang, G. X., Shao, Y., Li, C. X. (2015): Effects of mine waste water irrigation on activities of soil enzymes and physiological properties, heavy metal uptake and grain yield in winter wheat. Ecotoxicology and EnvironmentalSafety113(2015)483–490

Mateo-Sagasta, J., Medlicott, K., Qadir , M., Raschid-Sally, L., Drechsel, P., Liebe, J. (2013): Proceedings of the UN-Water project on the Safe Use of Wastewater in Agriculture.

Mioduszewski W. (2014): Small (natural) water retention in rural areas. Journal of Water and Land Development. No 20 p. 19–30.

Mioduszewski W., Querner E., Kowalewski Z. (2014):. Analysis of the impact of small water retention on water resources in the catchment. Journal of Water and Land Development. 22: 67-78.

Mittra, M., Stickler, F. (1961): Excess Water Effects on Different Crops. Transactions of the Kansas Academy of Science (1903-), 64(4), 275-286.

Modica, G., Messina, G., De Luca, G., Fiozzo, V., Praticò, S. (2020): Monitoring the vegetation vigor in heterogeneous citrus and olive orchards.A multiscale object-based approach to extract trees'crowns from UAV multispectral imagery. Computers and Electronics in Agriculture Volume 175, August 2020, 105500

Monerris, A., Schmugge, T. (2009): Soil moisture estimation using L-band radiometry, Advances in Geoscience and Remote Sensing, Gary Jedlovec, IntechOpen, DOI: 10.5772/8334.

Nagy, A. Tamás, J.: 2013. Non-invasive water stress assessment methods in orchards. Communications in Soil Science and Plant Analysis, 44(01-04): 366–376.

Nagy, A., Fehér, J., Tamás, J. (2018): Wheat and maize yield forecasting for the Tisza river catchment using MODIS NDVI time series and reported crop statistics. Computers and electronics in agriculture, 151:41-49.

Nagy, A., Riczu, P., Gálya, B., Tamás, J. (2014): Spectral estimation of soil water content in visible and near infra-red range. Eurasian journal of soil science (EJSS) 3(3):163-171

Nagy, A., Riczu, P., Juhász, Cs., Tamás, J. (2014): Evaluability of apple orchard water balance parameters based on the spectral and thermographic parameters of the canopy Hungarian Agricultural Research 2014/1. 14-17.

Nelson, C.J., Moore K.J., Collins, M., Redfearn D.D. (2020): Perspectives, Terminology, and Classification, Forages, 10.1002/9781119436669, (3-21)

Nerantzaki, S. D., Nikolaidis, N. P. (2020): The response of three Mediterranean karst springs to drought and the impact of climate change. Journal of Hydrology, 591.

Nolde, E. (1999): Greywater reuse systems for toilet flushing in multi-storey buildings over ten years experience in Berlin. Urban Water, 1, pp. 275-284

Pedrero, F., Kalavrouziotis, I., Alarcón, J-J., Koukoulakis, P., Asano, T. (2010): Use of treated municipal wastewater in irrigated agriculture—Review of some practices in Spain and Greece. Agricultural Water Management 97 (2010) 1233–1241

Pistocchi, A., Aloe, A., Dorati, C., Alcalde Sanz, L., Bouraoui, F., Gawlik, B., Grizzetti, B., Pastori, M., Vigiak, O., (2018): The potential of water reuse for agricultural irrigation in the EU. A Hydro-Economic Analysis, EUR 28980 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-77210-8, doi:10.2760/263713, JRC109870

Rabus, B., Eineder, M., Roth, A., Bamler, R. (2003): The shuttle radar topography mission – a new class of digital elevation models acquired by spaceborne radar. ISPRS Journal of Photogrammetry and Remote Sensing, 57(4):241-262.

Rana, V.K., Suryanarayana, T.M.V. (2019): Visual and statistical comparison of ASTER, SRTM, and Cartosat digital elevation models for watershed. J geovis spat anal 3, 12.

Reyes, J. R. L., Ranieri, E., Antognelli, S., Taibi, S., Cruciani, A., Natale, A., & Guidotti, D. (2020). Early prediction of winter cereals yield : A preliminary study based on machine learning technique as a strategic tool for fertilization and field management. 2020 Global Internet of Things Summit (GIoTS). doi:10.1109/giots49054.2020.9119598

Riczu, P., Nagy, A., Tamás, J., Lehoczky, É.: (2015): Precision weed detection using terrestrial laser scanning techniques. Communications in Soil Science and Plant Analysis 46(S1): 309-316

Rovira, C., Sánchez-Masferrer, M., Rovira, M.D. (2020): Is Rainwater Harvesting a Solution for Water Access in Latin America and the Caribbean?: An Economic Analysis for Underserved Households in El Salvador. Inter-American Development Bank

Sanz, R., Rosell, J. R., Llorens, J., Gil, E., & Planas, S. 2013. Relationship between tree row LIDAR-volume and leaf area density for fruit orchards and vineyards obtained with a LIDAR 3D Dynamic Measurement System. Agricultural and forest meteorology, 171, 153-162.

Sanz-Cortiella, R., Llorens-Calveras, J., Arnó-Satorra, J., Ribes-Dasi, M., Masip-Vilalta, J., Camp et al., 2011. Innovative LIDAR 3D dynamic measurement system to estimate fruit-tree leaf area. Sensors, 11(6), 5769-5791

Serrano, J., Peça, J., Silva, J. M., Shahidian, S. (2014): Aplicação de fertilizantes: tecnologia, eficiência energética e ambiente. Revista das Ciências Agrárias, 37(3), 270–279 (in Portuguese).

Shah, T., Bruke, J., Vullholth, K., Angelica, M., Custodio, E., Daibes, F., Hoogesteger van Dijk, J. D., Giordano, M., Girman, J., van der Gun, J., Kendy, E., Kijne, J., Llamas, R., Masiyandama, M., Margat, J., Marin, L., Peck, J., Rozelle, S., Sharma, B., Vincent, L.F., Wang, J. (2007): Groundwater: a global assessment of scale and significance Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture ed D Molden (London: Earthscan) (Colombo: IWMI) pp. 395–423

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., and Portmann, F. T. (2010): Groundwater use for irrigation – a global inventory, Hydrol. Earth Syst. Sci., 14, 1863–1880

Simonović, V., Delić, S., Tasić, M., Tasić, N., Pešić, P. , Joksimović, A., Cvetković, I. (2018): Research correlation vegetation index of corn with speed of movement sensor and elevation of field. Machine design, Vol.10(2018) No.3, ISSN 1821-1259 pp. 123-128.

Simsek, C., Gunduz, O. (2007): IWQ Index: A GIS-Integrated Technique to Assess IrrigationWater Quality. Journal of Environmental Monitoring and Assessment 128:277-300

Smith, R.J., Baillie, J.N., McCarthy, A.C., Raine, S.R., Baillie, P. (2010): Review of Precision Irrigation Technologies and their Application, NCEA Publication 1003017/1

Son, B., Park, S., Im, J., Seohui, P., Park, S., Ke, Y., Quackenbush, L. J. (2021): A new drought monitoring approach: Vector Projection Analysis (VPA). Remote Sensing of Environment. Volume 252, 112145

Starr, J.L., Paltineanu I.C. (2002): Methods for Measurement of Soil Water Content: Capacitance Devices. p. 463-474. In J.H.Dane, and G.C.Topp (ed.) Methods of Soil Analysis: Part 4 Physical Methods. Soil Science Society of America, Inc., Soil Science Society of America, Inc. 2002.

Strager, M. P., Fletcher, J. J., Strager, J.M., Yuill, C.B., Eli, R., Petty, J.T., Lamont, S.J. (2010): Watershed analysis with GIS: The watershed characterization and modeling system software application, Computers&Geosciences,

Sun, Y., Ling, P., Li, Y., Li, Q., Sun, Q.,Wang, J. (2014): Influences of coal mining water irrigation on the maize losses in the Xingdong Mine area, China, Environmental Geochemistry and Health, volume 36, pages99–106.

Szabó, A., Tamás, J., Nagy, A. (2020): A jégvédő háló használatának hatásai az alma gyümölcsös vízháztartására és lombozatának pigment tartalmára. KERTGAZDASÁG 52 (2020) 3.

Tamás, J. (2016): Kihívások az aszálykutatás területén. Hidrológiai közlöny. 2. 13-21.

Tamás, J., Gálya, B., Demelezi, F., Nagy, A. (2019): Water scarcity problem treatment using precision irrigation techniques on Tisza-river basin. 3rd World Irrigation Forum (WIF3), 1-7 September 2019, Bali, Indonesia

Tamás, J., Nagy, A., Fehér, J., 2015. Agricultural biomass monitoring on watersheds based on remote sensed data.. Water Science and Technology. 72(12): 2212-2220.

Thomas, T.H., Martinson, D.B. (2007): Roofwater Harvesting: A Handbook for Practitioners." Technical Paper 49. Delft, The Netherlands : IRC International Water and Sanitation Centre

Topp, G.C. (2003): State of the art of measuring soil water content, Hydrological Process 17, 2993–2996

Tsutsumi, M., Itano, S. (2005): Variant of estimation method of above-ground plant biomass in grassland with gamma model 1.Use of an electronic capacitance probe.Grassland Science, 51, 275–279.

Túri, Z., Szabó, G. (2012): A Nyírség felszíni hidrológiai viszonyainak térképezése kvantitatív adatbázisok és űrfelvételek alapján. VI. Magyar Földrajzi Konferencia. 921-930.

van Es, H. (2017): A new definition of soil. CSA News. doi:10.2134/csa2017.62.1016. Published online October 5, 2017

Vivaldi, G.A, Camposeo, S., Rubino, P., Lonigro, A. (2013): Microbial impact of different types of municipal wastewaters usedto irrigate nectarines in Southern Italy. Agriculture, Ecosystems and Environment 181 (2013) 50–57

WHO (2006): WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater - Volume IV: Excreta and greywater use in agriculture. World Health Organization (WHO), Geneva, Switzerland

Yao, H., Qin, R. (2019): Unmanned Aerial Vehicle for Remote Sensing Applications – A Review, Remote Sensing 11(12):1443

Yari, A., Madramootoo, C. A., Woods, S. A., Adamchuk, V. I. (2017): Performance Evaluation of Constant Versus Variable Rate Irrigation. Irrigation and Drainage. 66(4): 501– 509 p.

Zhu, Q., Gould, J., Li, Y., Ma, C. (Ed.) (2015): Rainwater Harvesting for Agriculture and Water Supply. Springer Science+Business Media Singapore and Science Press, Beijing

Internet sources:

I1: https://edo.jrc.ec.europa.eu/edov2/php/index.php?id=1000

I2: https://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/an-overview-of-the-hydrology-tools.htm

I3: http://piercecollegeweather.com/wp-content/uploads/2015/03/evap2.jpg