TRAINING MANUAL

DIGITAL WATER MANAGEMENT FOR SUSTAINABLE IRRIGATION

Water is the "lifeblood" of agricultural practice, worldwide

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SUMMARY

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Introduction

This Manual intends to provide valid support for the dissemination of knowledge and advanced training activities on a topic of primary importance for the planet: the sustainable water management for agriculture.

The contents of this Training Manual was developed using resources and activities carried out during the Summer School for PhD Student in "Digital Water Management for Sustainable Irrigation" which took place at the BF Auditorium and Farm at Jolanda di Savoia (FE), Experimental Farm of the University of Bologna at Cadriano (BO) and Acqua Campus of the Consorzio Emiliano Romagnolo at Budrio (BO), from 12 to 16 September 2022.

The Manual was enriched with the comments received during the training activities which were used to adapt the training material and the approach according to the experience of the participants.

The purpose of Summer School is to minimize the impact of drought, soil needs to capture the rainwater that falls on it, store as much of that water as possible for future plant use, and allow for plant roots to penetrate and proliferate. Problems with or constraints to one or several of these conditions cause soil moisture to be one of the main limiting factors for crop growth.

Recognizing the importance of irrigated agriculture to food security improved management strategies must be developed to improve water productivity within present farming systems. Under low and variable rainfall conditions, efficient soil moisture management is a good way to improve water use efficiency.

The question is how to optimize soil moisture and water use efficiency, which is a key parameter for drought-proofing the soil and increasing productivity in irrigated agriculture while protecting water resources.

In order to create a drought-resistant soil it is necessary to understand the most important factors influencing soil moisture. There are management options that can increase the soil's ability to store water for plant use. Soil can be managed in ways that reduce the need for supplementary watering and increase the sustainability of the farm. Any worthwhile strategy for drought management optimizes the following factors:

- capture of a high percentage of rainfall (infiltration);
- maximum storage of water in the soil for later use (water holding capacity);
- efficient recovery of stored water (plant rooting).

To address these issues, the Summer School was organized in key sessions in-door, trial training directly on open field and experimental sites. The study tour was enhanced by multidisciplinary presentations and case studies illustrated by qualified speakers who explored some peculiar emerging aspects and the innovations available for soil moisture management and conservation, irrigation scheduling for annual crops and orchards.

Donato Cillis | IBF Servizi SpA

▶ Remote, ground and proximal measurement: design/methodology/approach for long-term plan/vision and management

Precision agriculture is a management strategy that aims to meet the actual crop needs, managing their spatial and temporal variability with differentiated agronomic interventions within individual plots according to the particularities of the targeted area. “Doing the right thing, in the right place, at the right time”: promptly intervening only when and where necessary and with the correct strategy for managing inputs (**slide 3-4**).

The creation of a digital infrastructure is a fundamental step to take advantage of precision agriculture as this approach is based on the collection and analysis of data during the entire crop cycle from different sources. An open platform can make collected data and their processing usable and, at the same time, hosting, implementing, and developing models, systems, and other external platforms (**slide 5**).

Precision agriculture is based on the study of field variability, which is performed through soil mapping by using different tools like geoelectrical sensors and/or with statistical analysis of crop vigour with satellite imagery. These activities are preparatory to the identification of areas with different characteristics, on which soil sampling will be done to characterize those areas.

The study of field variability can be carried out with proximal sensing, for example with the use of geoelectrical sensors. These are specific tools that measure soil electrical resistivity as a proxy of the main soil properties (**slide 6**).

The study of field variability can also be conducted by multi-temporal analysis of yield maps. This is possible thanks to grain flow sensors installed on the combine harvester, which can measure the amount of product harvested in real time within the field. The following step is processing and analysis of data using specific software to generate yield maps. These maps can be realized for one single year, multiyear or other time scales. The result is the generation of maps indicating zones characterized by specific productivity classes (for example: high, mean and low) (**slide 7**).

One of the most important methods to study field variability is remote sensing, which is based on measuring the reflected or emitted electromagnetic radiation from a sensor placed at a certain distance. In precision agriculture, remote sensing is mainly carried out using sensors installed on satellites, which can provide information on crop vigor by detecting specific vegetative index like NDVI (Normalized Difference Vegetation Index) or MSAVI (Modified Soil-Adjusted Vegetation Index) at 10 m spatial resolution. There also indexes that can provide information from soil like the SOCI (Soil Organic Carbon Index) as this index is highly correlated with important characteristics like organic matter content and texture (**slide 8**).

Field variability can be examined on a smaller scale using drones equipped with sensors to detect information at 2-3 cm spatial resolution. Drones are commonly used in arboriculture and in all situations where canopy is not continuous, as well as in case data must be acquired in small areas or plots (**slide 9**).

Regardless of the methods to be used, the study of field variability has the purpose of identifying homogeneous zones, i.e. sub-regions of the field in which the effects on the crop induced by seasonal differences in the climate, soil and agronomic management can be considered uniform. The definition of homogeneous areas is the basis of the methodological approach of precision agriculture, which is based on site-specific practices to be implemented to optimize agronomic management. Once homogeneous areas are identified, selective soil sampling is carried out according to field variability to characterize those areas in terms of chemical-physical characteristics (i.e: texture, organic matter content, pH, cation exchange capacity, electrical conductivity, etc.). The result of such characterization is the generation of Management Unit Zones (MUZ), which are field areas that will be managed in different ways in terms of agronomic operations (i.e: sowing, irrigation, fertilization, etc.) (**slide 10**).

Water management is essential for agricultural production as its increasing scarcity represents a major concern in the last few decades. In this context, precision agriculture can contribute to the optimization of this important resource through Decision Support Systems (DSS) for irrigation management. These DSS are fed by data from different sources like real weather station, virtual weather stations and soil moisture sensors. Real weather station are instruments generally composed by a single module integrating all sensors for measuring atmospheric parameters. The standard type stations integrate sensors for air temperature, air humidity, rainfall and leaf wetness. Precipitation and temperature data can be used to remotely monitor climatic conditions for planning interventions in the field, especially in case the company is in several estates.

Weather stations data and soil sensors are useful to feed Decision Support Systems, or DSS, for optimizing irrigation management. Such DSS are based on two models: the models based on soil water deficit by soil moisture sensors and models based on water balance:

Models based on soil water deficit by soil moisture sensors are based on the evidence that water movement in soil depends on several forces that plants must overcome by spending energy. The sum of this forces is the water potential, and it has three components:

- Matrix component: defined by colloidal adsorption and soil micropores.
- Osmotic component: defined by salts dissolved in soil water.
- Gravitational component: defined by water weight.

For a better definition of an irrigation practice it is useful to know the soil moisture constants, which are constants able to identify water content in a specific soil type:

- Saturation point: it is the amount of soil water at saturation.
- Field capacity: It is the capacity of the soil to retain water against the downward pull of gravity force. It represents the ideal situation for plants.
- Wilting point: It represents the point where soil is unable to supply water to the plant.

The water fraction contained between the saturation point and the field water capacity is defined as gravitational water (GW). The fraction contained between the field water capacity and the wilting point is called available capillary water (ACW). The fraction contained between the field water capacity and 50% of the available water is the readily usable water (RAW).

Models based on water balance model: it defines the amount of water to be distributed by calculating the difference between water inputs and outputs from soil. Inputs are rainfall, groundwater and irrigation, while outputs are run-off, percolation and evapotranspiration. This concept is expressed in the following formula:

$$\mathbf{I = ET + RO + P - R - G}$$

Where:
I= Irrigation
ET= Evapotranspiration. It is the amount of water transferred into the atmosphere due to evaporation from soil and transpiration from vegetation.
RO= Run-off. It is the surface water flow after rainfall. It depends on the amount of precipitation and soil type.
P= Percolation. It is the downward water movement by gravity through soil.
R=Rainfall. It is the amount of water that enters the soil through precipitation from the atmosphere.
G= Groundwater. Inputs from water stored into the soil.
(**slide 11-12**)

Thanks to precision irrigation and its remote and proximal sensing tools it is possible to optimize water management in a wide range of contexts, rendering the process scalable from small to large companies (**slide 13**).

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▶ Field exercises

Field exercises concern the methodologies for in situ determination of those soil-related parameters that are necessary for:

- drawing up a soil water balance
- be aware that the ability of soils to store water does not depend entirely on the nature of the soil or climatic conditions. Agricultural practices play a predominant role in the soil's ability to retain water. Sustainable soil management techniques improve water relations and the intaking capacity of soils.

The field exercises are divided into two blocks.

The first part of the exercise block (**slides 1 - 28**) covers the following topics:
1) soil properties (**slides 2 - 12**) and, in detail:

- granulometry (**slides 2 - 4**), definition of soil texture (**slide 2**), soil classification using the triangular diagram (**slide 3**). Two exercises are proposed to classify soil texture from the percentage of components (**slide 3**) or from the weight of soil particles (**slide 4**)
- structure (**slides 5-7**), definition of structure (**slide 5**), mechanisms promoting particle aggregation (**slide 6**). Soil structure (**slide 7**) is modified largely by agricultural practices but is also affected by climate and the thermo-pluviometric regime.
- porosity (**slides 8 - 12**), pores in the soil system (**slide 8**), classification of porosity (**slide 9**), factors affecting porosity (**slide 10**), the difference between particle density and bulk density (**slide 11**), and how porosity is measured (**slide 12**)

2) infiltration (**slide 13**) is the phenomenon that indicates the entry of water into the soil and it varies depending on whether the soil surface is under saturated and unsaturated regime, or whether it has surface crust (which prevents the storage of water within the soil and favors runoff), or whether it has cracking (which in some cases represent actual by-passes that move water away from the soil layer colonized by the crop's root system). Crusting and cracking also depend in part on the nature of the soil (especially soil structure), but they definitely result from agronomic soil management.
3) direct evaporation from the soil (**slide 14**) varies from bare soil to cropped soils. The transition of water from liquid to gas is governed by physical laws (incident radiation reaching the soil surface, amount of water at the soil surface, soil temperature). Agro-techniques change the physical parameters that determine the loss of water from the soil by direct evaporation.
4) drainage (**slide 15**): an agricultural soil with good hydraulic functionality must ensure that excess water is drained away and conveyed to a surface hydraulic network or within the soil profile and deep percolation. Undoubtedly, there are agronomic advantages of a soil that retains water without being waterlogged. Artificial drainage (**slide 16**) is becoming more and more important because of the rainfall regime becoming characterized by high rainfall intensity. The table on **slide 16** provides basic indications for dimensioning a drainage system.
5) water rising (**slides 17-20**) is a soil water balance parameter that is often overlooked (because it is not easily measurable on field, while in the laboratory it can be studied using hydraulic capillarity technique). The phenomenon concerns the transfer of water from soil horizons of different water content (and from the water table, **slides 18-20**) up to the root system of the crop.
6) Surface runoff (**slide 21**), in case of sloping soil, is an 'offer' of water to the cultivated plot (run-in) or a loss (run-off) from the cultivated plot to the surroundings. Run-off is also a phenomenon that is more urgent under changing rainfall conditions.
The methodologies for determining water status (**slides 22-28**) include one direct method (**slide 22**, thermo-gravimetric, but not automatable) and a series of indirect methods that have the advantage of continuously monitoring water status. Monitoring systems consist of two elements: a datalogger and a number of sensors (which can be located at different depths and at different sites across the field). Cables connecting sensors and dataloggers are a hindrance to field operations and limit the distance of the sensor from the datalogger. To limit the number of sensors and improve sampling (**slide 23**), remote and proximal sensing techniques (e.g., to measure soil conductivity) are applied to define in advance the

homogeneous zones of the plot within which the soil moisture probes are installed. In this way, it is possible (**slide 24**) to reconstruct the trend in soil water content during the irrigation season as a function of the irrigation regime (full irrigation or deficit irrigation) and rainfall inputs.
The water balance concerns the soil layer colonized by the root system (**slide 25**). It changes during the crop cycle and determining actual root depth remains highly inaccurate. Destructive techniques to measure root system depth (**slide 26**) are laborious, monitoring (with optical fibres) the dynamics of root depth in the soil is also affected by great uncertainty, and indirect determinations through proximal sensing systems (**slide 28**) are still subject of research and have not yet found practical application in the field.

The second part of the exercise block (**slides 1-28**) concerns the compilation of soil water balance and the dimensioning of irrigation variables. Water balance can be achieved after defining evapotranspiration (**slides 2-3**). To estimate reference evapotranspiration, the Penman-Monteith model (**slide 4**) is introduced. Inputs to the model are radiation (**slides 5 and 9**), temperature (**slide 6**), moisture (**slide 7**), wind speed (**slide 8**). Calculation procedures (**slide 10**) are detailed in the FAO Handbook 56. To determine operatively crop evapotranspiration, the two-step approach (**slide 11**) is used. It involves 1st estimating reference evapotranspiration; 2nd determining crop coefficient (Kc). Kc can be calculated in two ways (**slide 12**): single or dual approach. The latter requires more complexity in calculation (**slides 13-15**) but it has been demonstrated to be more accurate. Once daily evapotranspiration has been estimated (**slide 16**), the time evolution of water balance during the crop cycle can be followed on a daily scale. Irrigation variables can be quantified based on soil water reserve and readily available water. Uptake water by crop from the soil (**slide 17**) is the resultant of two terms: 1) natural and artificial water inputs; 2) water losses by soil and crop. To correctly quantify irrigation variables, available water (AD) for plants (**slide 18**) and readily available water (**slides 19 and 20**) should be defined.
To estimate the amount of water used day-by-day by the crop (Ur), it is enough to update the balance parameters (**slides 21 and 22**). Once the Ur value is known, it is possible to answer two questions (**slides 23-27**): when to irrigate? how much to irrigate?
Soil water amount depends mainly on the physical characteristics of the soil, climatic trends and the current crop (**slide 28**), but soil management does influence the structural characteristics of the soil and its capacity to store water. Conservation agriculture techniques aim to improve the use of ‘Green water’ by crops.

Luigi Ranghetti | IBF Servizi SpA

▶ Mapping intra-field variability: DSM elaboration and softwares

Performing variable rate irrigation is strategic in the framework of a sustainable usage of water resources. Existing machinery can do it in an automatic way ingesting a map of water dosages **[slide 2]**. To produce it, the definition of Management Unit Zones (MUZ) – intra-field zones with defined soil characteristics – represents a fundamental step. The topic of this lesson is to show how to build MUZ maps from two inputs: i) electroconductivity (EC) dense point data collected in field *or* optical remote sensing data, and ii) field samples of soil characteristics **[slide 3]**. This is a practical lesson, so the aim is to provide to students the instruments to be able to reproduce the processing workflow with their own data: at this scope, all is done using free software (QGIS – with some plugins – for most of the work; R for few specific operations) and through Graphical User Interfaces (GUI) **[slide 5]**.
[slide 4] Management Unit Zones can be produced from a variety of input data. In this lesson we see two possible inputs: the use of conductivity point data – VERIS data, similar to the ones already collected by the students on field – and the use of remotely sensed images. While the first ones have the benefit of representing a physical quantity – EC – directly related to soil properties, an intensive field work is necessary to collect them. When this sampling effort is not sustainable, remotely sensed imagery represents an indirect proxy of soil properties with the advantage to be freely available. In both the cases, the proposed processing chain is made of the following main steps **[slides 6-7]**:

1 interpolating input data (EC points or remotely sensed images – in this case, a previous step 0 is required to search and download them) to produce one or more informative input rasters;
2 clustering them to produce a polygon layer with homogeneous soil classes;
3 measuring soil characteristics with a field sampling (in this case, not necessarily intensive);
4 creating MUZ from considered soil classes.

In this presentation the first example is exposed in full; then, optical remote sensing was rapidly introduced to provide the concepts required for the second examples, for which the first part (different from the first example) is exposed, while the subsequent points are left to the students as exercitation.

Step 1. Input VERIS data are provided by the instrument as a text file in which three fields are of interest: X and Y coordinates and the Z variable of interest **[slide 8]**. This file is imported in QGIS and converted in a spatial point layer **[slides 9-10]**; then, the style of visualization can be changed to highlight spatial variability and exported in a common vector file format **[slide 11]**. At this stage some interpolation techniques – required to convert points in a spatially homogeneous format – are theoretically introduced: after basic techniques **[slides 12-14]** the focus was on IDW **[slides 15-17]** and ordinary kriging **[slide 18]**, highlighting their pro and cons. IDW interpolation was performed in QGIS **[slides 19-22]**, showing a suggestion to bypass possible spatial flaws intrinsic in this method. Ordinary kriging, whose implementation in QGIS is convoluted, was instead shown in a dedicated R graphical interface, guinterp **[slides 23-24]**, which allows importing point data, filtering them, setting the interpolation parameters, and launching the interpolation.

Step 2. The processing chain necessary to produce a polygon layer from the continuous raster was explained after a brief theoretical introduction to clustering and to possibility to use it **[slide 25]**. Two tools were considered: the SAGA plugin **[slides 26-28]** and the Semi-Automatic Classification plugin **[slides 29-30]**. The output is in any case a categorical raster of *n* classes (being *n* automatically or *a-priori* determined, depending on the clustering method); before vectorizing it, two cleaning operations were shown: the application of a kernel filter to smooth class boundaries **[slide 31]** and the removal of small groups of isolated pixels **[slides 32-33]**. Then, polygonization was performed **[slides 34-37]**: the output of this step is a vector layer cut on parcel borders containing *n* polygons.

Step 3. Once polygons were delineated, a field sampling design must be defined to correctly position samples. Methods to generate random points are briefly introduced **[slide 38]**; then, a procedure is done in QGIS by determining the correct number of samples per cluster **[slide 40]** and randomly generating them **[slides 41-42]**. Field campaign can now be conducted using the created points **[slide 43]**.

Step 4. Soil characteristics measured over points defined in step **3** must be assigned to clusters delineated in step **2**. Statistical methods could be used at this stage (including measuring the significance of the variation of characteristics over clusters); instead, a simplified deterministic approach was preferred for the sake of simplicity and to allow performing the whole processing chain with free GUI software. With this approach, we assume MUZ boundaries to correspond to clusters (this can be done if a single crop field – or crop fields with the same crop and management – is considered, like in the example), so we aggregated soil characteristics of points overlapping each cluster (using averaged values for continuous variables and the majority for discrete variables) **[slides 44-46]**. Among possibility offered by QGIS the tool Join Attributes by Location was chosen, because it allows defining different aggregation methods for different variables.
Before going through the second example **[slides 47-48]**, remote sensing was briefly introduced: what we are speaking about **[slide 49]**, which information can be derived from optical remotely sensed data to characterise vegetation **[slide 50]**, in particular with some commonly used spectral indices: NDVI **[slide 51]**, EVI **[slide 52]**, and NDRE **[slide 53]**. An example of spectral indices used as a proxy of a different soil property – NDWI for soil moisture – was also shown **[slide 54]**. A note about data resolutions – spatial, temporal, and spectral **[slides 55-57]** – was required to justify the use of Sentinel-2 data among the available datasets **[slides 57-58]**. The common steps performed to search, download and pre-process Sentinel-2 data were presented **[slides 59-62]**.

Step 0. Among the available tools to perform them, the R package sen2r was chosen for its simplicity **[slides 63-64]**, also providing indications about alternative possibilities with respective pros and cons. Before doing that, the QGIS plugin GEE Time Series Explorer was introduced, as it represents an easy to use instrument to visualize time series of optical satellite data without the needing to download the whole images (exploiting the Google Earth Engine architecture) but simply clicking on the map in correspondence of area on interest **[slides 67-68]**; this is useful to identify the time windows in which the images of interest (e.g. beginning and peak of the growing season) have to be searched. After that, the use of the sen2r GUI to search and download data and to perform pre-processing steps was shown **[slides 69-70]**. The output of this operation is a series of spectral indices rasters (one per filtered date) **[slide 71]**: the aggregation of each index was done with the QGIs tool Cell Statistics **[slide 72]**. Next **slides [slides 73-77]** show a GIS procedure to remove a frequent noise effect caused by features located on field boundaries (vegetation, canals, tracks). Finally, the possibility of using a multispectral image of bare soil instead of a proxy of the vegetation is discussed **[slide 78]**: although this is possible and in some ways preferable, the computation of a vegetation proxy is more linear and less prone to errors, and however the two outputs are generally well correlated; for these reason, a vegetation proxy was considered in this example, while a bare soil image was provided as additional material to be eventually used by the students.
Finally, steps 1 to 4 applied to this second examples were proposed as practical exercitation to the students **[slide 79]**.

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▶ Why do we worry about water? Uptake, transport and utilization in the Soil-Plant-Atmosphere continuum

This talk provides a few basic elements regarding water uptake and its movement within the plant. Such movement requires energy, which is provided by different mechanisms, occurring both at the root and the leaf level.

Roots provide ‘priming’ of the system, i.e. they can allow hydration of tissues at a time when no leaves are present yet in the canopy, at the onset of a new growing season in perennial plants, such as trees. When the leaves activate their transpiratory stream, root pressure is still fundamental for the recovery of embolism, which occurs in trees on a daily basis.

By far, the largest fraction of water in a plant is represented by the transpiration factor (liters day^{-1} plant^{-1}). The second largest is the water held in the tissues of the plant (a handful of liters). The smallest, but not less important, is the fraction of water, of which a few hundred grams per day is used, which participates to biochemistry as a reagent and not a solvent.

Plant anatomy, at the root, trunk and leaf levels, is deeply connected with water uptake and movement. Because water movement requires energy, its direction follows lines of gradients of water potentials, going from tissues/parts of the plant towards regions/parts having a more negative water potential.

The Vapor Pressure Deficit between leaf and air is the ultimate force driving water out of the plant. Plants can adopt different strategies to control their water potential to adapt to changing VPD values, which exhibit a daily pattern, affected by canopy size, dimension, orientation and inclination.

Water potentials are also affected by the physiological conditions of the plant, in particular the crop load, the level of irrigation, the nature (isohydric or anisohydric) of the specific genotype, and climate.

In conclusion: plants extract from the soil and release to the atmosphere large quantities of water; from this flow they obtain several benefits:

1 Transport of solutes from roots to canopy
2 Control of leaf temperature (also fruit, for those species whose epidermis is permeable, such as peach, pear, apricot, plum)
3 Leaf gas exchanges, which allow absorption of CO_2 from the atmosphere, which is used in photosynthesis.

Luigi Manfrini | DISTAL UNIBO

▶ Assessment of fruit traits variability in orchards: sensors & analysis

The basis of precision orchard management (POM) is strictly connected to the traditional plant physiology indicators as stem/leaf/fruit water potential measured through the Scholander chamber, gas exchange measurements (i.e., Licor-6400/6800), and easy to implement biometric measurements (i.e., caliper measurements of fruit volume displacement) (**slides 2 and 3**).

Perennial plants are difficult organisms to be monitored. This comes out also at word level with the lack of symposium speaking about precision orchard management (**slide 4 and 5**). Indeed, the high-quality standards imposed by the markets and the limitations of the main factors of production (cost of labour in one of the first positions), impose the use of innovative technologies to maintain high, constant, and durable the orchard sustainability. The technical approaches suggested by POM protocols, in this context, can give back to the grower "precise" indications to improve the management of cultural practices and the use of resources as water, fertilizer, and manpower, in order to maximize the profitability of the orchard. Though in many cases the POM protocols and technologies are similar to those used in other precision approaches (i.e., precision agriculture and viticulture) must take into account that in orchards there are limitations due to several factors. First, the tree habitus and the three-dimensionality of the crops, the complexity constituted of a bimembral plant (made of a scion and rootstock), and the multi-year nature, require in fact the adoption of sampling/monitoring techniques different from those adopted in other areas of intensive cultivation. Moreover, the data related to productivity and fruit growth, if for extensive/wine-growing crops can be mechanized and often collected in one-pick, in orchards, since the maturation occurs often staggered because of the intra-plant/orchard variability (often collected in 2 or 3 picks), data are often collected manually or, to date, not mechanized. Additionally, since the orchard often require the presence of anti-hail nets, diagnostics of physiological parameters is often impeded along the season, requiring, also in this case, the manual collection of data. On the base of what above stated the tools and models dedicated to the POM should therefore be adapted to ensure compliance with the specific characteristics of the crop (from **slides 6 to 13**).

The match of new management practices, technologies and robotics will bring on the market new systems/machines able to perform as "super-human". However, up to now no commercial vehicle able to perform management practices autonomously are available even examples of automatic fruit pickers, sprayers and tree training systems adapted to this practice are already described in the literature (from **slide 14 to 17**).

One of the POM main issues and research topic is related to the use of orchards parameters to the monitoring of the plant status. Fruit diametral variation along the production season and within the day have shown to be an integrated parameter for having back information on the condition of the crop and therefore is functional for the management practices modulation. The fruit, in fact, integrates most of the functionality of the plant variables according to the assumption: if the fruit grows "well" the plant is in optimal conditions. Information on fruit size variability in fact can be connected to yield and quality prediction/information and the economics of the farm, used for scheduling/segmentate future markets, map within orchard variability (and subsequent creation of prescription maps), give feedbacks on management decisions/scheduling as labour logistics at harvest (from **slides 18 to 26**).

Statistical and geostatistical analysis of fruit load and production parameters have been shaped according to the discrete distributions and by the planting distances of tree crops. Sampling methods and data collection take into account the development and the complexity of the foliage/fruit distribution within the canopy. Also, sensors or sensor systems, which should be costless for a greater implementation, needs to be capable of measuring the desired parameters (e.g., the diameter and number of the fruit, the volume of the foliage, the presence of pathogen, the plant water status, etc.). Moreover, the models used in the analysis of the monitored data, must take into account the individual species characteristics: the physiology of the growth of an apple fruit, for example, is very different from that of the peach or pear. Moreover, studies carried out on a single apple orchard showed that within the same orchard can co-exist zones with different production characteristics and these are potentially manageable with different approaches to maximize the production (from **slides 27 to 36**).

The techniques to detect fruit and their diametral/volumetric displacement con be divided in two macro areas: Plant based and vision systems. The first take into account sensors touching the fruit employing linear variable displacement transducer sensors and strain gauges or potentiometers which, despite being highly accurate, are limited by a usually very small measurable range. Therefore, in order to keep on with the measurement process, frequent repositioning of the sensor on the fruit is required. This time and labor consuming activity has a cost, and therefore an impact on farmer's income. There are alternative solutions that do not require relocation over time, such as those employing optical sensors directly on the fruit, but they are usually affected by low accuracy and the inability to detect fruit shrinkage. Currently, systems capable of horticultural analysis have been developed using computer vision and artificial intelligence methodologies. In particular, techniques to estimate the number of fruits and their size have been introduced and implemented at orchard level. However, the accuracy achievable by these devices is still low compared to traditional techniques (from **slide 33 to 43**).

Fruit detection and growth monitoring present several advantages and opportunities for growers, thus justifying the continued development of monitoring approaches to generate reliable support systems. The advent of digital agriculture, which relies on crop management, environment, and production data to optimize the use of resources is highly dependent on reliable yield monitoring technologies will enable fruit crop production to fully embrace this new paradigm. The choice of the right yield monitoring approach is linked to the different context of each crop and should consider multiple factors such as adaptability, reliability, precision, and accuracy. In general, despite the numerous papers published on fruit monitoring approaches, several stones remain unturned. Machine vision and sensor fusion appear as a promising approach for monitoring crop yield on-the-go. The digital agriculture revolution for fruit crops remains contingent upon the development of reliable and ubiquitous monitoring systems (**slide 44**).

Michela Janni | IMEM-CNR

Bioristor, an in vivo biosensor for plant sap monitoring

Michela Janni is a researcher of the Institute of Materials for Electronics and Magnetism (IMEM). IMEM is part of the National Research Council (CNR). (**slide 2**)

This section provides new information on a new approach developed in IMEM to monitor continuously and in vivo the plant health and development (https://youtu.be/69Ffr6EbblA e https://youtu.be/l8zeN82uL50 (**slide 3**).

The agricultural sector is going to face enormous challenges in order to feed the 9.6 billion people that the FAO predicts are going to inhabit the planet by 2050: food production must increase by 60% by 2050 (**slide 4**), and this has to be achieved in spite of the limited availability of arable lands, the increasing need for fresh water (agriculture consumes 70 per cent of the world's fresh water supply) and the severe impact of climate change (**slide 5**) . About 40%of total agricultural production relies on irrigation with the demand of water that is going to increase by 50% by 2030 (**slide 6**). Yield losses, drought and fertilizers have a strong impact on food security and environmental safety.

In this scenario, a possible approach is the use of sensing technology to make farms more intelligent and more connected with the environment. Innovation is thus a key to mitigate the effects of climate change, preserve food security and ensure farmers' incomes (**slides 7,8,9**).

Remotes and proximal sensors have been increasingly used in farm management and are becoming main drivers of automation in the agriculture domain to optimize productivity and sustainability (**slides 9, 10**).

When plant experience the drought stress a series of defence mechanisms are triggered with a strong impact on physiological process crucial for plant growth and development such as reduced photosynthesis, stomatal closure thus block of transpiration, accumulation of phytohormones and solutes accumulation (**slide 12**).

Drought response is a complex phenomenon diverse, dynamic, rapid and that can involve different mechanisms during time. Drought tolerance is often associated with the maintenance of the plant water status that can be achieved by reducing the water loss either decreasing the rate of transpiration or by improving the accumulation of osmoregulators (ions, soluble sugars, and small organic molecules).

Ions, thus, play a key role in promoting drought tolerance. In this scenario the in vivo sensor bioristor, brings novelty to the field, being directly inserted in the plant stem and providing information on the plant health continuously, in real time for the entire plant lifecycle.

What is bioristor?

Bioristor is an Organic Electrochemical Transistor (OECT) composed by a channel and a gate both functionalized through an organic polymer named (PEDOT:PSS, **slide 14**) and controlled by an IoT control system.

The channel current can be modulated by the gate voltage that push the ions contained in the electrolyte solution in the channel changing its conductivity. The output is the sensor response R an index proportional to concentration of positive ions present in the plant sap (**slide 16**).

In principle, bioristor is capable of detecting changes in the concentration of ions in the plant sap upon abiotic stresses.

Bioristor is highly biocompatible, it can measure for the entire length of the plant cycle, operates in realtime and acquired data every 15 minutes continuously (**slide 17,** [1]).

Bioristor was firstly implemented in plants in 2017, and so far by means on experiments conducted in controlled environments we have learned several features of bioristor.

It is biocompatible since does not affect the function of the vascular plant tissues (**slide 19**). It's effectiveness in early detecting drought stress in tomato was proved already 30hours from the stress beginning (**slide 20**). Through the analysis of the sensor response (R) [2]a high correaltion was observed with stomatal conductance and plant biomass both indicated as good phenotypic proxy of the plant health status.

In field, bioristor was used to monitor tomato plants in different plots with a different irrigation recipe (100%, 80%, 60%) and allowed the continuous monitoring for 64 days of growth (**slide 26**).

The sensor response highlights the presence of one only week in which the absence of rainy events allowed to distinguish between theses. When the sensor response, in this timeline, was compared with the achieved yield, was possible to hypothesize that if bioristor would have used to control irrigation, 36% of water savings could be achieved (**slides 27, 28**).

In a nutshell, the application of bioristor in the irrigation management, coupled also with conventional sensors, can significantly improve the water use efficiency in farm management, by giving to the plants the exact amount of water when is really needed.

When compared with agricultural index conventionally achieved, a strong correlation was achieved with the Crop Water Stress Index (CSWI, **slide 29**).

Bioristor was used to also monitored fruit species as kiwifruit, differently irrigated, revealing the ability of bioristor to monitor kiwi fruit for 4 months detecting drought events physiopathology (**slides 30, 31**).

The possibility to improve nitrogen use efficiency, thus reducing losses of fertilizers in the environment, is mandatory to improve agriculture sustainability. A trial with this focus was conducted implementing bioristor in apple fruits. Bioristor succeeded in detecting small variation of the R immediately after the input of specific classes of fertilizers (**slides 32**, **33**).

Moreover, in collaboration with the University of Bologna, a case of study on the translocation of potassium from soil to the apple fruit was performed. 8 sensors (4 per plants) were installed in two apple trees, on two branches each plant and on the apple bags to trac a possible migration of k+ during fruit development (**slides 35, 36, 37**). The sensor response highlights a unique difference in trend of R few days from the first potassium fertilization in the soil, paving the way for the use of bioristor in fertirrigation, although needs further experiments.

Significant improvements in the sensor development, were also made toward the achievement of increased detection specificity of bioristor. Different approaches have been used: i) ion selective membranes in the sensor preparation, or ii) MIP (molecular imprinted polymer) approach to improve the sensitivity of bioristor toward more complex molecules as for example glucose). The glucose specific sensor was already tested in field to monitor kiwifruits up to 6 months continuously. Interestingly, the sensor response trend observed plotting the day/night trend was extremely diverse from the previous R recorded with non-specific bioristor (**slide 36**).

Artificial intelligence is now applied to develop new algorithm to predict the real plant needs in terms of irrigation recipe and plant health status (**slides 40, 41**).

Concluding, bioristor is the first in vivo sensor implantable in the plant stem allowing for the real time continuous monitoring of the changes occurring in the plant sap composition addressing the need of a dynamic measurement of plant defence response to drought (**slide 42**). Its application can concretely optimize the water inputs in agriculture reducing the crops water footprint and preserving the environment.

Francesca Ventura | DISTAL UNIBO

Digital water management for sustainable irrigation: a case study on agronomic crops, validation of positive models

This case study presents the results of a project financed by POR-FESR 2014-2020, Rural Development Programs of European Union (European Commission, 2013).

POSITIVE (Scalable Operational Protocols for precision agriculture) is a precision agriculture project for variable rate irrigation, designed to improve the functionality of the IRRIFRAME system, the irrigation advice service of the Emilia-Romagna region. The strategic objective was to downscale the technological potential of precision irrigation into **concrete management techniques**, by defining appropriate operational protocols. In fact the meaning of the name referred to **scalable** solutions, i.e. not limited to a single company or a single experiment, but able to be replicated in a vast context without technological limitations. They had to be **operational,** which means concretely applicable, not reserved for contexts that require specialist skills, and had to produce **protocols**, i.e. standard and well-defined executive procedures or interfacing methods, for the final users.

The idea was to give **positive** solutions, capable of producing significant economic and environmental impacts in a short time, at least on a regional scale, to the challenges posed by climate change.

In order to obtain these results, we make use of satellite remote sensing, the use of vegetation indices for crops, IoT (Internet of Things) technologies, Big Data and 4.0 irrigation machinery. A central server manages the information flow, and provides variable rate irrigation maps for farmers as final users. The public support system for precision irrigation and fertirrigation at variable rate is an evolution of IRRIFRAME regional irrigation service developed by CER. The service architecture is schematized in figure 1. The ARPAE (Agenzia regionale per la prevenzione, l'ambiente e l'energia dell'Emilia-Romagna) server Sat Service downloads and processes the data of Sentinel-2 satellite, generating digital maps of NDVI and EVI vegetation indices. POSITIVE SERVER receives the indices maps, processes them and sends them to the IRRIFRAME/IRRINET subsystem, which integrates the value of the indices and, based on them, generates a new enhanced Kc. This new value of crop coefficient is assimilated within the calculation of the water balance, to produce variable rate irrigation prescription maps. Specifically, the average EVI value calculated for the plot is used to adjust the Kc generated by IRRIFRAME for that plot, while the NDVI map is used for spatialization, i.e. to generate the variable rate irrigation within the same plot. The maps are time-dynamic, because updated at every satellite overflight. In this way soil and crop inhomogeneity are taken into account. Figure 2 and 3 show respectively soil inhomogeneity and index of vegetative vigor inhomogeneity in three dates during the project experimentation.

Figure 3 shows the NDVI at two experimental plot observed during the project experimentation, and is one of the more common vegetation index. We would like to underline that Sentinel 2 data are freely available and downloadable from the Copernicus web-site.

One of the aims of the project was to search if, among the many available, there was an index that gave more satisfactory results in representing the vegetational characteristics of crops. In order to find an index with a better performance three crops were studied: tomato, onion and maize, at CER "Acqua Campus" experimental farm (Mezzolara di Budrio (BO). For each crop, two plots were evaluated: one not irrigated and one irrigated according to the calculation performed by IRRIFRAME. For each plot, based on the Sentinel-2 grid, an Elementary Surface Unit (ESU) was identified corresponding to a pixel of 20x20m. Within each ESU, at four Sentinel-2 flight during the season, the following biophysical parameters were measured/calculated: phenological phases (aimed at calibrating the Kc of IRRIFRAME model), crop height, LAI, SPAD (Soil and Plant Analyzer Development), measurements for Life Cycle Calculation (LCC) estimation (Fig. 4). For each survey date, satellite images were downloaded and pre-processed. Through the algebraic combination of Sentinel-2 multispectral bands, more than 100 vegetation indices have been calculated, and among these, were selected those able to better estimate the chosen parameters. DISTAL (Dipartimento di Scienze e Tecnologie Agro-Alimentari - Università di Bologna) performed the measurements of the biophysical parameters under study (Ventura et al., 2021), while CRAST (Centro di Ricerca Analisi geoSpaziale e Telerilevamento, Università Cattolica del Sacro Cuore) performed the calculation and validation of the VIs (Amaducci et al., 2020, Croci et al., 2022**).** The indices with the best performances resulting from the experiment, regardless of the crop, were the Enhanced Vegetation Index (EVI) and the Normalized Difference Vegetation Index (NDVI). They are then used to adjust the crops Kc in the water balance performed by the IRRIFRAME system, and consequently make it possible to calculate a

precision irrigation recipe at the field level. The $Kc_{(NDVI/EVI)}$ obtained for each plot must be multiplied by the average irrigation advice (VA) of the plot as calculated by Water Balance by the IRRIFRAME system, thus obtaining a higher or lower VA depending on the vigor of the vegetation (Fig. 5). The spatial variability step is defined by the step of the irrigation machine. The water savings for each irrigation seem to be negligible, but it is interesting to calculate their total amount at the Emilia-Romagna region level. In this calculation we only considered the two main irrigated open field crops, which are maize and tomato. The surfaces for these two crops are, as an average for 2020, respectively 90k ha for corn and 23k ha for tomato. Considering a reduction of irrigation of around 150-200 m^3 ha^{-1}, water savings that would have been achieved for 2020 in Emilia-Romagna for maize and tomato crops by applying irrigation with integration of satellite data are estimated as 19,665,320 m^3 (Fig. 6). We must not forget that, together with the actual water saving, there is a great saving of energy, the one used for pumping water for irrigation.
Summarizing:

- We presented here the Positive Project, a precision agriculture project for variable rate irrigation, designed to improve the functionality of the IRRIFRAME system, the irrigation advice service of the Emilia-Romagna region. As a first result a method to refine crops Kc, and calculate more precise water balance at field level, was achieved, using vegetation indices downloaded from Sentinel 2.
- As a second result the EVI index was selected among about 100 indices, as the one with better performances when tested on the ground (ground truth)
- Precision irrigation with irrigation recipes corrected by vegetation variability was put into a Protocol, i.e. standard and well-defined executive procedure for the final users, and down to the irrigation equipment level. Some manufacturers of irrigation machines were part of the project, making it possible to activate this procedure directly on the sprinklers.
- Water savings! If farmers activate these procedures, even if only with the refining of Kc using satellite data, there will be an important saving of water, and consequently of energy, regarding field crops largely cultivate in Emilia-Romagna (corn, tomato).

Amaducci S., Croci M., Impollonia G., Colauzzi M., 2020. Project report "*validazione correlazioni tra indici di vegetazione e parametri biofisici*".
Michele Croci, Giorgio Impollonia, Andrea Marcone, Giulia Antonucci, Tommaso Letterio, Michele Colauzzi, Marco Vignudelli, Francesca Ventura, Stefano Anconelli and Stefano Amaducci, Agronomy 2022, 12(11), 2835.
Francesca Ventura, Marco Vignudelli, Giovanni Maria Poggi, Tommaso Letterio, Stefano Anconelli, 2021. *POSITIVE: A SMART IRRIGATION PROJECT FOR AGRICULTURE 4.0, Proceedings of the XXIII Convegno Nazionale di Agrometeorologia "Agricoltura 4.0 e cambiamento climatico: il ruolo dell'Agrometeorologia*", Bologna, Dipartimento di Scienze e Tecnologie Agro-Alimentari Università di Bologna, AMSActa, 2021, pp. 26 – 29. 10.6092/unibo/amsacta/6713.

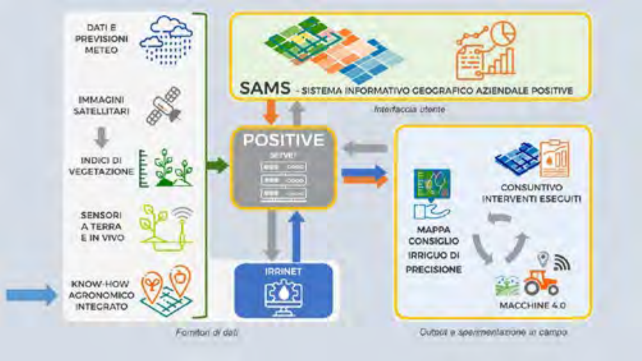


Figure 1 – scheme of the architecture of the POSITIVE service.

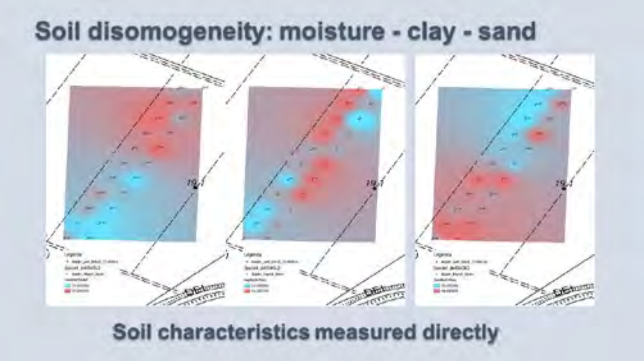


Figure 2 - Soil inhomogeneity and soil moisture variation in the POSITIVE experimentation plots.

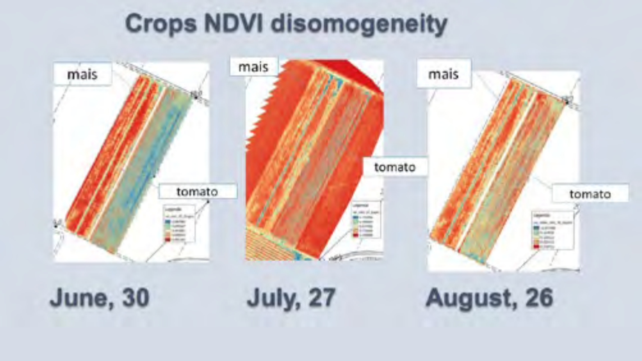


Figure 3 - Index of vegetative vigor (NDVI) inhomogeneity in three dates during the project experimentation.

Figure 4 – Working to assess the “ground truth”: phenological phases (aimed at calibrating the Kc of IRRIFRAME model), crop height, LAI, SPAD (Soil and Plant Analyzer Development), measurements for LCC estimation.

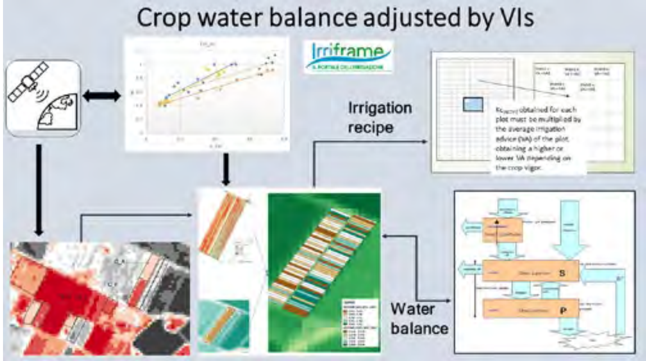


Figure 5 – Concept of the adjustment of crop water balance using satellite data.

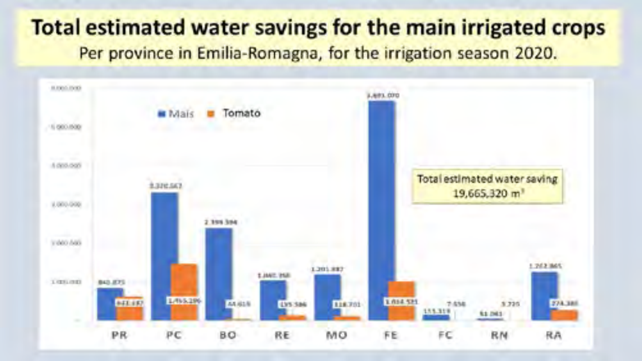
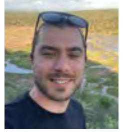


Figure 6 – Estimation of water savings that would have been achieved for 2020 in Emilia-Romagna for maize and tomato crops, by applying irrigation with integration of Sentinel 2 data.

Gianmarco Bortolotti | DISTAL UNIBO



Alessandro Bonora | DISTAL UNIBO

▶ Case study fruit growing: image analysis for crop load estimation, fruit skin blemishes

[slides 2 -3] Images are multidimensional matrix of data (w, h, ch), that can be analyzed.
The Image analysis can consist in:

- Basic statistical analysis to extract “appearance” information (Color, lightness, etc.)
- Advanced statistical analysis for Image features extraction (object shapes, relative dimensions, etc.)
- Artificial intelligence (AI) to move forward and reach an image “understanding”.

Computer Vision (CV) is an interdisciplinary subject that deals with using computers to automatically obtain high-level understanding of images (or videos). Its goal is to replicate / automate / improve the human ability of rapidly obtain “difficult-to-extract” information from images. It can use AI approaches, where math models mime the structure, and the way human brain works, to solve complex problems such as detection or segmentation or tracking of objects in images or videos.

Fruit for fresh consumption need to match market/consumers requirements in term of size, appearance, and quality to maintain production remunerative for growers. One of the main parameters affecting fruit size/ quality is the tree crop load (CL), due to sink/source balance. CL evaluation is complex, time consuming and require human operators.

The advantage of utilizing CV, is that CNN based solution can carry out those (e.g., CL estimation) operation requiring a high level of understanding, in an automated and fast way, enabling then wide scale operation (to better represent orchard variability). **[slide 4]** Another great advantage of CNN CV solution is their self-learning process, thanks to an iterative process (called “training”) where the algorithm learns from a bunch of given examples, correctly annotated. The drawback is that a correct and large dataset is needed, and its creation is time consuming due to manual labeling work.

[slide 5] We report an example of a CV application using a CNN (YOLOv3) to estimate CL in apple trees. The goal was to evaluate the improvement, induced by 2D training systems architecture, of computer vision field application for fruit detection. Two different architectures were considered: 2D and 3D. **[slides 6-7]** 90 images were collected, per each training system, creating 2D_DS and 3D_DS datasets (DSs). All the fruit visible in the images were manually labelled. Then the two DSs were merged, to have a mixed architecture dataset (MX_DX). Each DS was then split into “train”, “validation” and test “set” (70%, 20%, 10%). The “Train set” is used as information source, where the model “learns” how to perform a correct detection, adapting its internal parameters, while the “validation set” is used to dynamically evaluate the results of what learned. The process of “learning” how to tune its parameters, followed by the “validation” of this tuning, is called “epoch”. A YOLOv3 CNN object detection algorithm was trained per each dataset obtaining three specialized detection algorithms (Y_2D, Y_3D, Y_MX). **[slide 8]** Y_2D, Y_3D, Y_MX was then cross validated on all the test sets available (2D, 3D, MX) where per each picture was known the tree CL. Performances were evaluated with Precision (P, false positive related error – I.e, erroneous detected fruit), Recall (R, false negative related error- miss detection) and F1-score (Harmonic mean of P and R) metrics; estimated CL was compared with actual CL. **[slides 9-10]** Results showed the possibility to estimate tree CL by mean of a CNN algorithm image analysis, also if performances resulted not satisfactory for field application (F1-score max < 0.9 and real CL estimation error >60%). Despite this, the 2D system improved CL estimation results for all the models tested (+2.4, +9.9, +11.5% respectively for Y_3D, Y_MX, Y_2D), not considering the fruit occlusion induced by each training system.

[slide 11] Following this study, we tried to improve detection performances moving to state of the art object detection algorithm (YOLOv5, 2022 Q1), obtaining a result increase of 10-15% (F1= 0.74). Occlusion level remained a main factor to consider in CL estimation. **[slide 12]** This was underlined again when testing the same algorithm for grape cluster detection; excellent detection performances were obtained (F1 = 0.96), but CL estimation resulted hard due to vine habitus: without defoliation most of clusters result occluded making the detection model useless. **[slide 13]** Changing specie, we tried to account for fruit occlusion in CL estimation. Many models were trained for green apricot detection and then, the detection results were corrected with a coefficient accounting for fruit occlusion level. Results varied widely with 17-80% of actual CL. This experiment showed that a site-specific calibration of CV system is needed to improve CL estimation results by image analysis, due to plant status*training*system*management*environment. **[slide 14]** The take home messages from the presented studies are that CV can automate and improve CL estimation; it is “easy to use” but requires time for creating datasets and acquiring minimum coding

skills; CL estimation through CV requires a site-specific calibration for best results.
[slide 15] Another study from our group investigated fruit quality and production estimation of peach fruit directly in field. In this case a depth camera (RGB-D) collecting also depth information was utilized. From a top view of a fruit bin, it was possible to detect the most visible fruit, on which to estimate fruit size exploiting a trigonometric approach and depth information. The goal was to develop a cheap plug-and-play tool for harvest platform, enabling production mapping directly in filed. Results reported an error (>10mm) not matching the growers' requirements (1-2mm). **[slide 16]** In a different study, we utilized the same approach and camera to size apple fruit on the tree, adding a circle detection step and different methodologies for depth/sizing estimation. The error was reduced up to 7-9 mm for fruit, and to 2-4mm if applied on regular shape objects**. [slide 17]** CV can be used also in case of sensor fusion, in the European SHEET project we exploited RGB-D and thermal cameras to create a low-cost system for mapping fruit temperature and position in the orchard. **[slide 18]** Many other are possibilities of CV application, as example we are trying to improve the presented system for in field image analysis for color estimation as well as fruit defect detection such as sunburn browning symptoms.

Moreover, CV could be applied also during fruit post-harvest handling to detect storage disorders and fruit maturity. We tested this possibility on different species such as pears, apples and kiwifruit.

[slides 19-20-21] Using a YOLOv3 CCN, we tried to detect superficial scald, a physiological disorders which affect pear fruit after some months of cold storage. This issue is caused by oxidative stress and cold injury followed by the production of toxic volatile compounds, leading to skin tissue necrosis. This Disease is difficult to recognize and estimate even by a human expert.
Preliminary statistics showed that the first trained model reached low accuracy (up to 20 % of true positives) but maintained a good average precision (60 %) with different confidence thresholds (40 % and 20 %). We noted an increase of the F1 score by adding images in our dataset (symptoms instances) while training different models.
[slides 22-23-24-25] Afterwards, we tested CV to estimate the starch pattern index (SPI) value of pears and apples assessed using the Lugol solution. Our efforts aim to provide an objective tool for SPI since different operators can give different scores depending on their subjectivity. The models with YOLOv3 and 300 pear box images had good performances compared to the CTIFL and Laimburg scales, with an F1 score of 0.36 and 0.59, respectively. Regarding apples we imposed different resolution using the Laimburg scale (from 0.1 to 1) and the updated YOLOv5. The F1 increased considerably reaching 0.76 with five classes and 500 pictures. The effectiveness of the transfer learning method was demonstrated by using a larger dataset (1000 images / 10.000 fruit approx..). We showed an interesting result with 0.2 of imposed class resolution obtaining 0.46 of F1 score.
[slides 26-27-28] Another study regarded CV application, in kiwifruit, for red flesh surface area estimation which can be difficult to standardize due to the fruit variability. In particular, the interest in CV application could be important for fruit whose red coloration is only partial such as the new red cultivars where red surface area might have same dimension, but color intensity that affect human red flesh area estimation. An integrated methods was applied using different techniques (image light correction, CNN application for object detection, single fruit extraction, HSV color filtering for red flesh and fruit pixels counting). We obtained a general small RMSE of 10.57% with the best results in a range between 20% and 40% of actual red flesh estimation.
[slide 29] CV systems can estimate crop load and fruit quality in pre- and post-harvest, using image analysis based on state-of-the art algorithm as CNN. Thus, fruit number and their color, size and defects in field can be detected. In a near future, incomes of farmer can be improved, and products losses can be avoided by applying different orchard management strategies in advance or with an in-field sorting for the direct marketing. Internal and external storage disorders and fruit maturity parameters objectively and rapidly can be assessed to improve storability and consumer acceptance.

Dario Mengoli | UNIBO

▶ Case study autonomous, electric vehicles: the Dedalus Rover

The presentation aims to show the concept and the features behind the development of our autonomous electric vehicle for precision agriculture called Dedalo.

Starting with adaptability and flexibility, the prototype relies on two tracked cores that provide electrical-powered locomotion to the platform. Each core is self-contained and uses a standard CANBus interface to give commands to the unit and provide appropriate telemetry data as feedback. We also believe that electric-based locomotion is optimal in terms of flexibility as it will operate with good performances on open fields/orchards and at the same time it can be used with no risk also inside greenhouses. The implement interface has been designed to be as much «plug and play» as possible, by using a simple mechanical connection and exploiting the CANBus protocol to manage the implement itself. This will allow a quick tool change operation and exploit tool recognition capabilities by the rover control unit.

In terms of scalability, instead of relying on a bigger unit, our concept aims to exploit redundancy and replication of smaller units to not distort the characteristics described in terms of soil compaction and versatility in on-field applications. This will also introduce fault tolerance on the whole system, because more single autonomous units can overcome a failure of one of the agents by re-assigning tasks. Furthermore, when the correct time windows to perform a treatment is narrow, the multi-agent system can be exploited to reduce overall execution time.

With respect to versatility, the prototype is conceived to act in a full autonomous way, to perform repetitive and basic operations such as spraying or thinning. The same platform can also be exploited to help human labor in more complex tasks (such as harvesting) where autonomous navigation capabilities can help farmers to focus on the task itself, while leaving logistics or easier jobs to the machine.

The idea of a «motorized implement», where the implement itself is the focus of the platform and not the locomotion by itself, has been declined into two tools, namely a prayer and a mower. The ultimate goal here will be to specifically design the implement as a relevant part of the whole system, with a special focus on power requirements and efficiency. Since we can't rely on the conventional big and powerful engine of commercial tractors, the implements may be optimized to reduce weight and energy consumption as much as the platform itself had undergo these kind of optimizations. (**slides 1-9**)

Static stability testing has been performed of the platform that highlighted a maximum inclination of more than 45 degrees. The sensor and computational units are composed of two parts: high level and low level. The high-level systems are in charge of performing high level control tasks such as autonomous navigation and mission planning. Here all the available sensors are used and fused together to maximize localization capabilities inside the orchard and perform obstacle avoidance maneuvers. The computational unit is a powerful Intel i5 mini-PC that focus more on data processing power. The low-level systems are adopted to ensure system stability and reliability both in terms of locomotion and safety emergency stop. A rugged computer has been used to maximize system stability. This is directly connected to motors drivers using industrial-proven protocols like CANBus. Furthermore, a suite of relay is in charge to control all the physical systems installed on the rover, such as water pumps, implement power on/off, implement height, etc. In the low-level environment, hardware is minimized to ensure the most simple and reliable connections towards the locomotion cores, thus minimizing points of failure. All the safety circuits are isolated and self-contained by means of physical switches that cut-off main power in case of emergency. The autonomous navigation system features both open-field path following and in-orchard task execution. (**slides 10-18**)

To enter a bit more into detail of what is implemented for the open field navigation scenario, we may assume that the rover is somehow parked or stored in the garage, then autonomous spraying task is requested on the orchard and the robotic platform must autonomously navigate to the correct row entry point to start in-field operations. This requires GNSS positioning and a quite reliable map to the surroundings to be able to reach the target waypoint without issues. For this purpose, we've used the existing ROS navigation stack capabilities that provides 2D path planning and mapping features by means of a bidimensional occupancy map. Obstacle distance is sensed using the lidar installed onboard that is capable to give environmental awareness to the robot. Trajectories are used to give always a suitable and trackable set-point to our robot, to ensure smoothness of operation and have a guarantee to be free of discontinuities in the set-point that may harm the regulator stability. The use of polynomial trajectories has a desirable effect of simplify derivative computation, and the input-output linearization technique is achieved by regulating an external point in front of the robot to simplify the controller and better relate the output position to the input given by the motors. The trajectory computation aims to minimize acceleration and execution time, thus optimize the locomotion efficiency. (**slides 19-25**)

The orchard in-row navigation relies mainly into detect tree rows using Hough Transform algorithms. Hough Transform is a computer vision algorithm able to detect geometric shapes hidden inside an image (or in our case a point cloud image equivalent). Point distances coming from the lidar are therefore flattened to build a 2d representation of the surroundings in which search for lines patterns that will describe the tree lines. This can be done as orchards are mainly a semi-structured environment where trees are planted on a regular basis by forming a clear grid that can be traversed by means of rows. The algorithm has been optimized by exploiting the fact that subsequent point clouds are not so different from the previous ones in term of tree lines estimation (because trees remain in place), therefore reducing the search pattern for lines detection. The algorithm features automatic rows recognition and row-end detection to trigger the row-change maneuver. Experimental testing shows that the row following task is correctly performed as the robot is able to maintain a 2 meter distance from the trees while traversing the orchard (given a 4 meters row width). (**slides 26-32**)

Upon reaching the end of the row, the prototype automatically enters the row-change maneuver, that tries to estimate the next lane to enter and the orchard's tree boundary to compute a pivot point around of which performing the turning maneuver. These further estimations are still computed using the same Hough Transform algorithm described before. Experimental testing showed the precision of the pivot point computation, and the videos give evidence on the maneuvers performed by the prototype in our testing orchard. Further system improvements will focus on creating an integrated ecosystem that can be sustainable also from both energy and environmental perspectives. (**slides 33-38**)

The developed platform can be used also to enable Precision Agriculture applications, such as precision spraying and thinning, crop monitoring, and autonomous harvesting. Our research group has investigated some of the monitoring applications that aimed to produce a reliable estimation in terms of crop load by counting and sizing fruit on the trees during the whole growth season. (**slides 39-48**)

Efthymia Chatzidaki | UNIBO

▶ Arpae's climate services and open data supporting climate change mitigation and adaptation

In date 15th of September 2022, in the framework of the summer school "Digital Water Management", Efthymia Chatzidaki on behalf of the Regional Agency for Prevention, Environment and Energy of Emilia-Romagna (Arpae) presented the agency and the part it held at the Positive project. During this presentation the agency has been presented briefly with a main focus on the Hydro-Meteo-Climate Service and the Climate Observatory. The Climate Observatory, established in 2017 by a regional law, is in charge of studying the climate both past, present and future, by elaborating the data collected and downscaling the global climate projections into a regional and sub-regional scale. It also tests the efficiency of proposed mitigation measures. In addition, it contributes to the maintenance of Arpae's weather stations, to the quality control of the collected data and uses them to produce seasonal meteorological forecasts. The main products and data available have been shown, and two case-studies have been analysed through the data that Arpae collects from various sources (weather stations, satellite imagery, models and so on): the drought that characterised North Italy during this summer period and the differences between the current climate with regard to the one of the past decades. The two databases, constructed and maintained by Arpae and populated with in-situ measurements, the meteorological database ERG5 (https://dati. arpae.it/dataset/erg5-interpolazione-su-griglia-di-dati-meteo) and the climatic database Eraclito (https://dati.arpae.it/dataset/erg5-eraclito), have also been presented so that new scientists and researchers could learn about the information they hold and use this big amount of regional open data for their studies. In the following slides, the main publications of Arpae-Simc, focused mainly on the publications of the Climate Observatory, both periodical and occasional, have been illustrated. In these publications (Climatic Atlas of the Emilia-Romagna region, HydroMeteoClimate Report, monthly bullettin, weekly Agrometeorological bulletin, Nitrate and Air quality bulletin, Snow bulletin etc. or occasional ones like for example the bulletin of the freezing conditions or that on a specific meteorological event that took place in the Region), the principal aspects of the current state of the weather have been collected, analysed statistically and presented through maps, graphs and tables. In some cases, seasonal weather predictions, future climate projections for the Emilia-Romagna region and predictions of seasonal plant's irrigation needs have been documented too.

The future climate projections shown in this presentation, highlight the probable increase of the temperature range, the overall decrease in precipitation in the spring and summer months as well as a small increase in the autumn and the probability of higher frequency of extreme events all year round. From the comparison of the maps and graphs regarding the air temperature, it becomes evident how the mean annual temperature has increased in the last two decades, especially in the lower altitudes, with respect to the reference period 1961 - 1990. Both maximum and minimum temperatures increase too although not by the same amount, leading to a greater temperature range. The precipitation pattern was not so homogeneous. In most of the Emilia-Romagna's valley, precipitation has decreased, although a seasonal variation has become evident. Data regarding the hydro-climatic balance (BIC) have been presented too, from which it becomes obvious how in the last thirty years, most of the years end up with a negative BIC resulting in drought conditions of variable severity. As with the other variables, most variations are concentrated in the Po valley area. The second example presented, regarded this summer's drought as it has been measured at the weather stations of Emilia-Romagna. From the graphs it is derived that this summer's drought has been the result of a prolonged period of precipitation deficit that began almost at the beginning of the year. The prolonged period of relatively high and anomalous temperatures, starting at May and continuing during the summer, only worsened the situation. The summer precipitation of 2022 has been much lower than the average of the past thirty years and the Romagna has been the area most affected by the precipitation scarcity. All these, contributed to create the severe drought conditions experienced this summer. The following part of the presentation regarded Arpae Simc's participation to the Positive project. Positive (http://www.progettopositive.it/nqcontent.cfm?a_id=19491&tt=t_bt_app1_www), whose main partners were: CIDEA (Interdepartmental centre for Energy and Environment, University of Parma) along with CER (Consortium of the Emilia-Romagna's Canal), CRAST (Research centre for Geospatial Analysis and Remote sensing, Catholic Efthymia Chatzidaki | DISTAL University of Bologna training manual 9 University of Sacro Cuore), T&A Tech (Terra&AcquaTech, University of Ferrara), CRPA Lab (CRPA Lab, Research centre for animal production – C.R.P.A. S.p.A.) had the objective to provide at regional scale agronomic indices derived from Copernicus satellite data and to design an IT infrastructure promoting precision irrigation and fertigation as a feasible approach throughout the region. This has been done briefly by studying, either experimentally or by scientific literature, the vegetation indices that best describe the well-being of the plants. An archive of maps of the vegetation indices selected has been created and is hosted on an account on the Lepida virtual server. Partners of the project have access to that archive and, through procedures developed in the project and well documented in the protocols developed, download the latest maps available in order to insert them into models (IRRINET and FERTIRRINET service) that elaborate weather and environmental variables and come up with irrigation advice for the EmiliaRomagna's farmers. Arpae Simc was in charge of the satellite part of this project. For the precision, a service has been developed, called SatService, that every day downloads automatically from the ESA site (https://scihub.copernicus.eu/dhus/#/home), updated Sentinel-2 satellite images of level two (atmospherically corrected) over the Emilia-Romagna region. The bands of interest for the calculation of the indices have been extracted, downscaled at ten meters, transformed into reflectance, grouped together into a single archive and then maps of the vegetation indices have been produced. These maps, after being masked by the cloud mask that comes along with the data from ESA (Scene classification mask), are saved automatically into the dedicated Lepida account, and remain available for the end users (models or people) for several months. A secondary structure has been developed, always by Arpae, that deals with the communication of external to Arpae users with this archive. The communication, that consists of making a request of data (maps) through a GeoJSON, elaborating the product by cutting it around the area requested, changing the projection and so on and send it back to the machine that requested it (as a group of georeferenced polygons accompanied by the value of the index), has been developed in Node.js and remains available for interrogation on the apposite account of the cloud Lepida.

Stefano Amaducci | CRAST — UNICATT

Michele Croci | CRAST — UNICATT

▶ Vegetation indices for open field crops: from synthetic indices to biophysical parameters

Precision agriculture is an agricultural management concept based on observing, measuring and responding to inter- and intra-field variability of crops. Specifically, it is based on the introduction into production processes of technologies and principles to manage the spatial and temporal variability associated with all aspects of agricultural production at different scales, from the individual plot to an entire territory (Pierce and Nowak, 1999). A classic example of precision agriculture is the variable-rate application of agronomic inputs such as fertilisers, water and pesticides according to the actual needs of the crop and the bio-chemical-physical characteristics of the soil in order to make spatially and temporally appropriate decisions. To make decisions, it is important to know the main causes of spatial and temporal variability within and between plots. Generally, spatio-temporal variability is due to: i) Morphology and hydro-geological conditions; ii) Soil chemical-physical characteristics (pH, SO, Texture, Salinity, EC); iii) Adverse climatic conditions (drought, hail); iv) Phytosanitary conditions, presence of pests and plant diseases; Agronomic management (sowing density, input application methods, tillage); v) Anthropic action (merging and levelling of plots)

In the study of variability, satellite data play a fundamental role, especially those provided by the twin Sentinel-2 satellites, which, thanks to their low revisit time (only 3-5 days) and high spatial resolution (10 and 20 m, depending on the different spectral bands), make it possible to adequately analyse both the variability in time (temporal variability) and space (spatial variability) of the area observed (from an entire territory to a single plot). In particular, the use of satellite data is useful not only to identify variability but also to interpret that variability. In fact, for each observed pixel, it will be possible to obtain a specific spectral signature from specific chemical and physical characteristics. Knowing the behaviour of the regions of the electromagnetic spectrum as the chemical and structural composition of the vegetation varies, it is possible to infer these properties from the information observed at different wavelengths. The regions of the electromagnetic spectrum of greatest interest for studying vegetation are the visible (VIS), near-infrared (NIR) and short infrared (SWIR) regions.

Each region of the electromagnetic spectrum is related to specific aspects of vegetation. The first observable region of the spectrum in terms of wavelength is the visible region (VIS, 400-700 nm). For example, the reflectance in the VIS region correlates strongly with the concentration of leaf pigments such as chlorophyll, carotenoids and anthocyanins. In the VIS, most of the light in the blue and red wavelengths that strikes vegetation is absorbed by chlorophyll for photosynthesis (low reflectances), with pigment absorption maxima at 470 nm and 670 nm. While a small reflection peak can be observed in green. Thus, as the chlorophyll content increases, there is a reduction in reflectance in the blue and red regions. Leaf chlorophyll concentration being correlated with nitrogen content is important for precision fertilisation.

At wavelengths above 700 nm, we find the near-infrared region (NIR, 700-1300 nm). In this region of the electromagnetic spectrum, leaf pigments such as chlorophyll are transparent and therefore the foliar absorbance in this region is very low; on the contrary, it is characterised by a high reflectance at both leaf and canopy levels, reaching very high values (even above 60%). This behaviour is caused by multiple reflections between the hydrated cell walls and the leaf spaces between the air-filled cells of the cell tissue.

Other factors that have a great influence on this region of the spectrum are leaf inclination (erectile plants let more light through, while planophiles reflect more light) and the leaf area index (LAI). As the LAI increases, there is an increase in reflectance in the NIR region. Another very important region of the spectrum is the region located between VIS and NIR, called the Red Edge. This region, which straddles 700nm, is very important for obtaining information about the health of vegetation. In the presence of stress in this region of the spectrum, a phenomenon called blue-shift occurs, i.e. a leftward shift of the reflectance inflexion point. The last region of the electromagnetic spectrum that I am going to show you is the SWIR region, which is often associated with water stress. With the same levels of green biomass present, the reflectance in this region of the spectrum increases as the relative water content (RWC) of the vegetation decreases, making this region of the electromagnetic spectrum the reference for determining the water status of crops. The reflectance in the SWIR is inversely proportional to the total liquid water content of the canopy. As the water content decreases, we have an increase in reflectance, approaching the spectral signatures of totally dry vegetation.

However, it is not always possible to analyse the entire spectral signature and it is, necessary to summarise the values in parameters of agronomic interest related to crop health (biophysical parameters).

The types of variables that can be derived from satellite data can be classified into i) primary, those variables or characteristics that are directly involved in the radiative processes observed through spectral data such as leaf area index - LAI, leaf chlorophyll content, temperature or certain soil properties and ii) secondary, not directly involved in radiative processes but derived from the combination of several primary variables or correlated with one of them such as crop production or evapotranspiration.

From a methodological point of view, the estimation of biophysical parameters can be carried out using two approaches. The first is referred to as the ‘statistical approach’ and is suitable for the estimation of both primary and secondary variables. It consists of the construction of linear or non-linear empirical relationships between vegetation indices (algebraic combination of bands) and the biophysical parameters measured in the field. Over the years, various vegetation indices have been developed for this purpose. Starting with the NDVI, one of the most widely used indices, several indices have been developed to reduce the main shortcomings of the NDVI such as saturation problems, sensitivity to soil effect and weathering. The pros of this approach are simplicity of use, reduced knowledge required for its use and speed of processing, on the other hand, this approach is generally site-specific. The second approach is only suitable for primary parameters and is instead based on radiative transfer models (RTMs) that simulate spectral behaviour as the biochemical and structural characteristics of leaves and canopy change, including leaf area index and leaf chlorophyll concentration. RTM inversion is characterised by lower site-specificity than techniques based on vegetation indices but requires a high development time.

Once the most suitable methodology for estimating biophysical parameters has been identified, it will be possible to identify and characterise the differences present in the field, for example by analysing the biophysical parameters in the different homogeneous areas (MZs). After characterising the variability, it will then be possible to carry out differentiated agronomic management for each area. For example, by distributing different irrigation volumes or different amounts of nitrogen.

The POSITIVE project aimed to promote the use of satellite images in precision agriculture, in particular through the provision of maps of biophysical parameters. Within this project, several data collection campaigns were carried out on different crops to have a sufficiently large dataset to validate both approaches for leaf area index estimation. The results showed that some empirical relationships derived from the statistical approach performed well and that the best indices were those that included the red-edgered edge band.

Another important result from the POSITIVE project was to identify the best vegetation index for estimating the crop coefficient (Kc) to integrate this information into the IRRINET decision support system.

The possible spin-offs of a spatially and temporally variable estimation of biophysical parameters are not limited to variable-rate irrigation alone but can be applied on a regional scale to make estimates of water consumption useful for the management and distribution of water on the territory.

Stefano Caselli | University of Parma, Center for Energy and Environment (CIDEA)

▶ Toward impactful irrigation advisory services

The POSITIVE project, funded by Regione Emilia-Romagna, has been tasked with the goal of enabling precision irrigation and variable rate irrigation across the whole irrigated area of the region. Indeed, several obstacles have been deterring farmers from application of precision irrigation. These obstacles include:

- the lack of widespread, easy access sensor-based information about the vegetation vigor of the crop and about the soil moisture available to the crop,
- the limited farmers' confidence in current irrigation advisory services,
- the complexity and lack of interoperability among equipment, sensors, decision support systems, farm information systems, and communication network, which are all involved in the irrigation process.

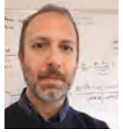
If applying precision irrigation is complicated and expensive, many farmers will stay away from it.

POSITIVE has confronted with the goal described above by developing a set of open standard protocols to connect and make interoperable all components involved in irrigation. In order to ensure coverage of the whole Emilia-Romagna region (as well as the extendibility to other regions), POSITIVE has built information flows to exchange data with the free, widespread IRRINET irrigation advisory service, which already encompasses fundamental soil, crop, and weather knowledge.

POSITIVE computes maps of vegetation indices (NDVI, EVI) from satellite data every 5 days (based on satellite revisit period), with 10m x 10m resolution. These maps are fed to IRRIFRAME for the registered plots thereby enabling a periodic recalibration of the IRRIFRAME advice for the specific crop. Moreover, if variable rate (VR) irrigation equipment is available and has been associated to the plot by the farmer, a VR irrigation prescription map is computed at the same resolution of the NDVI or EVI map. This map is also aligned with the plot coordinates used by the advisory service and the equipment (which are different from the satellite coordinates for the same plot) and finally adapted to the actual capabilities of the irrigation machines.

Additional protocols developed by POSITIVE deal with the acquisition of data from many different types of soil, plant and environmental sensors, for which standard protocols and acquisition procedures have been built, and with the interfacing to a farm-specific geographic information system (GIS) where all the data related to irrigation can be properly managed and preserved (e.g. history of VI maps for each plot, history of irrigation prescription and actual irrigation performed, map of yields, etc.). These protocols are fully described in subsequent lectures.

In this lecture, **slides up to n. 8** discuss the project context and goals. **slides from 9 to 13** summarize the multiple information flows managed by the POSITIVE server. **slides from 14 to 17** report experiments that exemplify the direct, machine-to-machine actuation of VR irrigation prescriptions with a rain wing commanded by hose reel, with a large pivot irrigator, and with a rain gun sprinkler whose angle limits are controlled in real-time. The final section of the lecture discusses the priorities perceived by stakeholders for widespread adoption of precision and VR irrigation.



Michele Amoretti | University of Parma, Center for Energy and Environment (CIDEA)

▶ Acquisition of satellite-based vegetation maps for VR irrigation

The POSITIVE Information System (**slide 3**) is a distributed, service-oriented, and Big Data-oriented information system, whose purpose is to enable Scalable Operating Protocols (POS) using heterogeneous data sources and standard exchange formats.

The heart of the POSITIVE Information System is the POSITIVE Server (**slide 4**), written in Go Language for high scalability. The POSITIVE Server collects and processes satellite and sensor data and orchestrates the irrigation process by handling requests from farmers and interacting with irrigation machines. Its current architecture (**slide 5**) is based on three layers: Web APIs, Business Logic, and Persistence. However, it is evolving towards a MicroService architecture (**slide 6**), to improve its modularity, maintainability, independent deployability. The POSITIVE Server enables several information flows (**slide 8**), namely: satellite data flow, interaction with IRRINET (a service provided by CER), sensor data flow, and irrigation recipe flow to the machine.

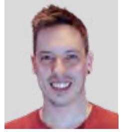
In the satellite data flow (**slide 9**), four main actors are involved: Sentinel-2 satellites that provide radiation maps in various bands, observing the same plot every 3-5 days; the Sat Service (provided by ARPAE) that processes Sentinel-2 data and produces vegetation vigor maps (NDVI, EVI) for the whole Emilia-Romagna plain; and the POSITIVE Server that periodically queries the Sat Service (**slide 12**) to obtain vegetation vigour maps for plots registered to IRRINET and corrects border factors and outliers (**slide 13**). The interaction between the POSITIVE Server and IRRINET (**slide 14**) is as follows: IRRINET receives improved vegetation vigour maps from the POSITIVE Server and integrates them into the model that is used to generate VR irrigation advice.

The sensor data flow (**slide 15**) involves both field sensors and in vivo sensors. In general, sensors have limited coverage, reason why several of them must be deployed to cover one or more plots. The POSITIVE Server may directly collect sensor data, or instead other intermediate server may perform some filtering or local processing. For example, the Sensor Server (**slide 16**) (provided by Terra&Acqua Tech) is periodically queried to provide soil moisture and crop water stress data. Conversely, bioristor data (**slide 16**) are directly uploaded to the POSITIVE Server. A relevant IoT long-range technology that has been explored during the implementation of the POSITIVE project is LoRaWAN (**slide 17**). The Regional company Lepida is deploying public gateways all over the territory, allowing citizens to connect their devices to provide any kind of useful data. In the context of the POSITIVE project, we experimented LoRaWAN protocols with soil moisture and temperature sensors. To minimize human intervention in the configuration phase of new sensor nodes, we designed and implemented SEAMDAP (SEAMless Data Acquisition Protocol) (**slide 18**), enabling automatic data aggregation from Edge to Cloud.

Finally, the irrigation flow to the machine (**slide 19**) consists in the POSITIVE Server that adapts the irrigation advice produced by IRRINET to the specific machine type, sends commands to the machine (directly or through cloud services) based on its specific features, and receives irrigation data once the process is completed. Supported machine types are linear irrigation machines with nozzle cart or water ranger, and pivots. Experimental activities have been carried out in collaboration with OCMIS and SIME (**slide 20**).

Further research activities concerned NDVI forecasting (**slide 22**) based on daily observation (from satellite data), using machine learning techniques. More precisely, we proposed a multivariate multi-step NDVI forecasting method based on LSTM networks (**slide 23**).

Another research direction is dealing with missing data. We are currently working on a problem of over-irrigation detection (**slide 24**). The irrigation dataset we are using has several unreliable data items and several missing data. To repair it, we are considering other datasets that are assumed to be reliable, e.g., the precipitation history.



Matteo Francia | PhD - DISI UNIBO

▶ Data platform and AI for precision farming: soil moisture modeling and assessment as a case study

This talk is the result of joint work with Prof. Matteo Golfarelli, Prof. Moreno Toselli, and Dott. Joseph Giovanelli.

Today we are witnessing a process of data-driven innovation (**slides 6-8**), where companies use data and analytics to foster new products, processes, and markets as well as to create new services with a business value. Digitalization is a multi-year journey made of intermediate goals, each of which must be feasible: it should solve a company's pain and bring value, it should be accomplished in a limited time range, and its costs should be economically related to gains. Companies are investing in data platforms, i.e. ecosystems capable to fulfill end-to-end data needs (**slides 9-14**).

The synergy of the internet of things (IoT) and precision farming is producing valuable applications in the AgriTech domain, i.e. the use of technology for farming to improve efficiency and profitability (**slide 15**). In this context, the Business Intelligence Group has expertise spanning many years, projects, and applications, such as: smart watering management to produce Kiwifruit with higher quality while saving water, and sustainable weed management with laser-based autonomous tools. Henceforth, we describe our experience with soil moisture monitoring as a case study.

Optimizing soil moisture is crucial for watering and crop performance (**slide 16**). The goal is to save water while improving fruit quality (i.e., provide a recommendation of the amount of necessary water). However, crop fields have many differences such as: soils with different water retention, watering systems, plant types with different water demand (e.g., Kiwi vs Grapes), and sensors producing measurements with different precisions. Our reference scenario is an orchard where Kiwi plants are aligned along rows, each row has many drippers, and drippers can water a limited soil volume (**slide 17**). Our goal is to move towards an autonomous decision support system that uses sensor data, learns the watering optimization process, and controls the watering system (**slides 18-19**). To do so, we need to understand how the soil behaves (**slides 20-21**). Unfortunately, soil simulators require knowing and manually tuning lots of parameters, and still simulators are not representative of all the phenomena that can incur in a certain volume of soil.

In our approach, '*Francia, Matteo, et al. "Multi-sensor profiling for precision soil-moisture monitoring." Computers and Electronics in Agriculture 197 (2022): 106924.*', we exploit sensor data to learn how the soil behaves (**slides 22-24**). Given our reference orchard, where plants follow a regular layout, we can make symmetry assumptions about the irrigation, so that a 2D (or 3D) grid can be representative of a bigger field. Then, given coarse-grained sensor data and the learned behavior of the soil, our goal is to produce a finer soil profile describing soil moisture.

Henceforth, we restrict to a 2D grid for the sake of conciseness. We use a grid of 12 gypsum-block soil-moisture sensors (**slides 25-26**); 4 columns are located across the rows of kiwi plants at increasing distance from the dripper (e.g., 0/30/60/90cm) and each column has 3 sensors located at 3 depths (e.g., 20/40/60cm). With this setting, we collected almost three million samples in two years.

Given these data, we apply two processing strategies to approximate/learn the soil behavior (**slide 27**). The "feature unaware" (**slides 28-29**) is plug-and-play since it can be used as soon as the sensors are deployed on the field; it approximates the soil behavior with a bi-linear interpolation. The "feature aware" (**slides 30-35**) learns an interpolation of the real-time sensor data through machine learning. This is a (multi-output) regression problem. Given the soil texture as input, it simulates different patterns of soil moisture to produce a dataset to train a neural network. We use CRITERIA 3D to simulate the hydrological fluxes in the soil following Richard's equations; we produced two datasets with 35 thousand samples each for training and validation. Then, we tested the results on 4 months of real data from the field. Noticeably, the soil profiles returned by the FU and FA strategies are different (**slide 36**). On the one hand, FA is more precise (**slide 37**) and produce better results than FU even with fewer sensors. On the other hand, it requires real data to be tested before its actual application.

Once the system is up and running, we need to make this data accessible through user-friendly dashboards and analytics for knowledge dissemination (**slides 41-47**). Starting from the profile, we derive meaningful visualizations/analyses for instance to (i) identify what is the watered volume, (ii) identify over-watering, and (iii) identify where the root suction higher. Also, we can provide an empirical rule for watering recommendations (**slides 44-46**). We tested the watering recommendation as follows (**slide 47**). We deployed two irrigation setups during the 2021 campaign (i.e., may/october) within the same orchard. The first is Managed Row, where irrigation is *automatically* controlled using our 2D installation of 12 sensors. The second is the Control Row, where irrigation is *manually* controlled by the farmer. The MR saved 44% of water during the whole campaign, with the maximum saving being in June and September (for the farmer is harder to estimate the water requirement in the months). The productivity of vines was unaffected by the irrigation and ranged from 32 to 39 kg/vine (35-44 t/ha). Fruits from CR appeared greener (hue angle of 105) than fruits from MR (hue angle of 102). Finally, fruits from CR had lower soluble solid concentration at harvest (12.7 brix) than fruits from MR (15.3 brix) and the gap has been maintained after 2 months of storage (and 1 day of shelf life).

Of course, there is much more to do to reach autonomous watering (**slides 48-50**), such as:

- improving the training of FA through continual learning to overcome the limitations of the soil simulator and to fit unforeseen field conditions;
- handling “water needs” of different plants, the phenological growth stages, and water availability;
- forecasting soil moisture following different watering patterns;
- integrating these modules into a data platform for precision farming that enables a unifying data collection, access, and analysis.

Matteo Albéri | UNIFE

▶ Proximal nuclear sensors for soil water monitoring

To achieve optimal agricultural management for sustainable water usage, one of the key challenges is to implement continuous and accurate soil moisture monitoring at the field scale using non-destructive and real-time techniques. To this end, the Laboratory for Nuclear Technologies Applied to the Environment of University of Ferrara has developed an automated gamma spectroscopy station that allows for real-time and continuous measurement of soil moisture at the field scale (0.2 hectares). The device was successfully validated in the context of the ALADIN project (Agroalimentare Idrointelligente) and has been further improved during the Positive project (Protocolli operativi scalabili per l'agricoltura di precisione).

The Proximal Gamma-Ray Spectrometry (PGRS) method is based on the detection of terrestrial radioactivity caused by naturally occurring radioactive elements that have half-lives comparable to the age of the Earth. Potassium-40 (^{40}K) and some radioisotopes in the uranium and thorium decay chains emit γ-rays with energies on the order of MeV, which can be readily detected via γ-ray spectroscopy. Potassium is one of the most abundant elements in nature, and soils (especially clay soils) are generally rich in this nutritional element, which is primarily present in oxide form (**slide 4**).

Radiation can be detected through a scintillator detector, which consists of a sodium iodide (NaI) coupled to a photomultiplier tube base. The output of the photomultiplier tube is processed by a digital multi-channel analyzer. The detector measures the photon radiation produced by the decays of naturally occurring radionuclides and records a spectrum, which is a histogram representing the energy distribution of photons emitted by the source. Since each gamma decay has a specific emission energy, a gamma spectrum is characterized by the presence of distinctive structures (photopeaks) that allow for the identification and quantification of ^{40}K. The integrated number of events within the energy ranges associated with ^{40}K's main photopeaks is used to determine the counts per second (cps) (**slides 5-6**).

PGRS is a method that is particularly sensitive to Soil Water Content (SWC), as the mass attenuation coefficient of water is significantly higher than that of the typical minerals commonly present in the soil. This means that a small increase in SWC can be indirectly estimated by measuring the attenuation in the gamma. The detection of the ^{40}K gamma signal photopeak (1.46 MeV) is useful in agricultural lands, as it is homogeneously distributed in space and time. Since water distributed in the terrain shields the terrestrial gamma flux, an inverse relationship between SWC and the gamma signal measured by the spectrometric station is used for a quantitative estimation of SWC (**slides 7-10**).

The gamma spectroscopy station, welded on top of a 2.25 m pole, receives the radiation emitted by the top 25 cm of soil from a circular area with a radius of 25 meters (0.2 hectares). The developed prototype is energy-independent thanks to a solar panel and a buffer battery and can operate autonomously. The system is equipped with a microcomputer with 4G connection that allows remote control of the device and real-time transmission of data acquired by the detector. The data is processed to obtain hourly gravimetric (kg/kg) and volumetric (m^3/m^3) SWC, and a system developed for the Positive project transmits them to the IRRINET platform. The data is then integrated into the IRRIFRAME water balance model for irrigation management. The data on SWC are acquired during two different crop cycles: between April and November 2017 (tomato) and between March and August 2020 (maize), respectively, as part of the ALADIN and Positive projects. Both data takings refer to the agricultural test field of Acqua Campus, a research center of the Emiliano-Romagnolo Canal (CER) irrigation district in the Emilia-Romagna region of Italy. During the first measurement campaign, the instrument was calibrated using gravimetric measurements of water content on soil samples collected uniformly around the detector (**slides 11-15**).

To extract SWC values from PGRS measurements, it is necessary to consider a non-constant correction due to the presence of growing vegetation beneath the detector position, namely Biomass Water Content (BWC). As the plants mature, the gamma spectrometer receives a progressively reduced gamma flux due to the shielding effect produced by the crop system. The BWC refers to the amount of water contained in the entire plant, and the effect of the BWC on the signal is indistinguishable from that generated by an increase in the SWC. The BWC can be modeled as a layer of a few millimeters of water covering the ground. The quantification of the gamma signal attenuation as a function of the modeled water layer thickness is studied through Monte Carlo simulations. Since the temporal evolution of BWC is tightly related to the crop's growth stage, the overall BWC is estimated based on gravimetric measurements on stem, leaf, and fruit samples collected at different stages of tomato and maize maturity. The evolution of the entire organism is modeled by means of a Gompertz sigmoid function to calculate the time-dependent correction to be applied to the measured gamma signal (**slides 16-19**).

The temporal trend of the SWC acquired during the two periods reveals the station's ability to reliably record the wetting and drying phases of the soil following rainfall and irrigation events. PGRS gives a satisfactory description of SWC content over time also when compared to simulation data, showing that the combination of accurate soil water content measurements and water budget computation with crop models can be effective tools for water resources and irrigation planning. The SWC measured with the gamma sensor is compatible at 1σ level with gravimetric measurements, and the BWC correction function is effective for both corn and tomatoes. During drying phases, it allows, thanks to the water balance models of IRRIFRAME, the prompt elaboration of irrigation intervention recommendations, with adequate volumes, contributing to quality production while saving water resources (**slides 20-26**).

The Positive project demonstrates the maturity of this technology: PGRS is an effective tool for estimating soil water content at a field-scale, making it a promising ground truthing technique for satellite data calibration (**slide 27**).

Barbara Fabbri | UNIFE

▶ From sensor technology to true olfactory systems for agriculture

Slide 3: Water resource scarcity is a global concern. We can touch the problem firsthand even by looking at it over a short period of analysis. Indeed, just in one year, one can observe the impressive variation of Po river path and of adjacent lands, due to a strong reduction of water flow rate that was 10 times lower than the average one of the period.
Slide 5: Here, Agriculture 4.0 comes into play, it is an evolution of precision farming based on a precise and accurate analysis of data from advanced tools and technologies.
Slide 6: The aim of these technologies is to offer the most extensive and precise support to farmers in the decision-making process related to their activity, e.g. in water management, and the relationship with other parties in the supply chain. The ultimate goal is to increase economic, environmental, and social sustainability – as well as profitability – of agricultural processes.
Slide 7: The report of The World Government Summit (2018) has identified four main developments placing pressure on agriculture: Demographics, Scarcity of natural resources, Climate change, and Food waste. In particular, agriculture highly contributes to greenhouse emissions, such as methane and nitrous oxides, and to temperature increase.
Slide 8: Moreover, one of the key elements for agriculture is water, the most important and at the same time the most limiting resource for agricultural production. Indeed, for each gram of organic matter produced by a plant, approximately 500 g of water are absorbed by the roots and transpired, and water typically makes up 80-95% of the plant tissue.
Slide 9: The food-water double pyramid highlights the importance of water footprint of most common foods, included in our diet.
Slide 10: Then, water management in agri-food production requires particular attention to avoid and solve significant problems, such as waste of water resources and lack of efficiency of the traditional monitoring based direct human intervention. In these perspectives, we need a systematic and continuous monitoring of soil moisture conditions, a method to identify the water retention capacity of the soil and its real needs for a rational use of water resources.
Slide 12: Nowadays, technologies and methods have gained a huge development to reach the expectations of the water management, and to support a deep understanding about the mechanisms that regulate water stress plays a fundamental role in the water balance determination and that represents a great challenge for the agri-food panorama, in particular for an efficient irrigation scheduling. The crop-coefficient reference, defined as EvapoTranspiration (Kc), evaluates how and how much the soil-plant atmosphere transfer processes affect the crops water use. It is a robust method to estimate water requirements from crop, but it is difficult to measure since it is mainly based on experience. There is also a wide range of remote sensing systems that can support such computational methods, i.e. lab-based and on-field analyses. The first are invasive and expensive, e.g. gas-chromatography, while spectroscopy or olfactory systems result non-invasive and cheaper. Indeed, optical analyses are commonly used to assess crops status, for example by the definition of vegetative indexes.
Slide 13: On the contrary, there is not a robust technology that allows the parallel evaluation of the soil moisture and the monitoring of crop gaseous emissions. In fact, until now the majority of the studies on volatile gas profile have been addressed to the metabolic activity of soil and crops as a function or disease or insects' affection. Volatile Organic Compounds (VOCs) emission represent only the 3% of the total carbon exchanged between the biosphere and the atmosphere, but their high reactivity can influence the chemical and physical properties of the last. Besides, VOCs emissions are affected by internal and external factors, such as biochemical issues or temperature and radiation. However, until now the role of water stress has not been identified, probably because it affects them in different ways. Therefore, it is necessary to clarify the relationship between the water availability and variability and the potential water need of crops.
Slide 14: So,which olfactory system we can use to address this issue? For the estimation of VOCs emitted from soil and plants, equipment should be cheap and not bulky, whereas analysis techniques should be easy to perform and non-invasive.
Slide 15: Electronic noses, composed of an array of gas sensors and a signal deconvolution system, are tools that allow a direct real-time acquisition, but usually are quite complex and expensive.
Slide 17: Starting from the concept of this technology, and thanks to the funding of two POR-FESR 2014-2020 research projects, we have tried to approach the issue designing a

sort of simplified e-nose based on chemical gas sensors.

Slide 18-19: These are mainly composed of a mechanical support and a sensing material, which aims to result highly sensitive with an operating low power consumption in order to address the IoT paradigma.

Slide 20-21: Among the wide palette of chemical gas sensors, chemoresistive ones are commercially widespread. They transduce modifications of environmental chemical conditions in a variation of electric resistance/conductance.

Slide 26-27: The goal was to provide a system based on these devices that, after collecting and proper calibrating gas emission data from field, returns directly to the agricultural operator an information on the crop water status, easy to access and to use, in the perspective of decision support system. In the first project, named ALADIN, we developed gas-sensing units to monitor tomato and maize crops. These systems were based on 4 chemoresistive gas sensors, properly selected and calibrated as a function of the potential compounds secreted from the crops, allowed to monitor the whole growth season.

Slide 28: The comparison between gaseous emissions, meteo and irrigation data allowed defining a correlation to gas sensors response, rainfalls and irrigations. The further comparison of on-field measurements and lab calibration supported the refinement of the suitable sensing materials for this type of application.

Slide 29: The study proceeded with a second project, named POSITIVE, in which the attention was focused on tomato.

Slide 30: We improved the monitoring system by an automatization of the sensors signal processing and data transfer towards dedicated servers. The sensing unit allows a continuous, geolocated, and real-time acquisition of the 4 gas sensors signals together with humidity and temperature values.

Slide 31: The research activity was supported by IRRIFRAME platform, a large-scale decision support system for irrigation scheduling that provides a day-by-day information on how much and when irrigating crops. This water balance system is based on pedofunctions, which take into account the type of irrigation, the texture of the soil, the type of the crop and the relative phenophases and roots. The intervention and the higher thresholds are defined on the hydric capacity and the drying point of the field, on soil moisture and plant roots. These thresholds identify the minimum and the maximum water content at which it is necessary to start and to finish the irrigation.

Slide 32: Analysing the response of sensor based on tin dioxide decorated with platinum, one can observe that its response became flatten in August when the irrigation was stopped and tomato started the last ripening phase, then confirming the correlation between emissions and water status.

Slide 35: During the last experimentation, an additional tool has been included in the sensing unit to also monitor the vegetative status. We inserted a camera equipped with and infrared filter to acquire pictures directly in tomato crop both in the visible and in NIR region. Then, now we can correlate three information: water balance from Irriframe, gas sensor response and NDVI index.

Slide 36: There are different vegetative indicators correlated to the live green content in the plant, we selected the NDVI (Normalized Difference Vegetation Index) that is based on the different reflection of red component of the light between healthy and stressed leaf.

Slide 38-39: Definitively, chemoresistive gas sensors represent a potential technology for the agriculture water management: it is possible to identify a palette of sensing materials, which feature to recognize, at a macroscopic level, variations of gaseous emissions correlated to water stress suffered by crops. The gas detection system proposed is a non-invasive technology, easier to use and more cost-effective than computational methods and lab-based analyses, and more usable and sustainable than an eNose. From a technological point of view, the highlighted information may provide irrigation advices about the time of intervention and the volumes to be used in order to obtain a quality product. Now, on one side, the research will be addressed to limit the number of gas sensors towards a stand-alone and more compact monitoring system. On the other side, the data sharing with the Servers, also in Open IoT mode, opens the doors to a machine learning approach for the definition of a more effective water balance model than crop-coefficient reference (Kc).


Michele Amoretti | UNIPR


Gabriele Penzotti | UNIPR

Scalable protocols for sensor data acquisition in precision agriculture

This presentation consists of:
- an introduction to the main concept of this work;
- *incremental examples to explain the ways of thinking used during the design of SEAMDAP*;
- a discussion about SEAMDAP features and the main challenges of data acquisition in Precision Agriculture (PA).

Protocols. A protocol is a set of rules to establish communication between parties. Informatic communications are structured in levels and the level of abstraction of this discussion is *high application level*.

Sensors. We refer to sensor any device that is composed of 4 components. The most limiting aspect is the energy availability, very limited in almost all battery-powered devices. This affects the operation of the other parts, especially the communication unit (energy intensive).

The information **scenario** that is emerging in PA is made up of two elements very relevant: data and applications.

Regarding **data**, the trend that can be hinted is configured in an enormous growth in quantity, in agreement with other sectors (e.g. industry), and an increase in heterogeneity in terms of semantics and representation. Data exchange will take place at different levels of abstraction, with the presence of raw, filtered, aggregated information, etc. Data privacy is obviously very relevant also in agriculture.

Applications are also expanding both in number and in type. PA Applications can operate at different levels of abstraction, sometimes even on multiple levels, dealing with raw and/or high-level data. There are distributed applications or centralized applications with an increasing use of AI.

SEAMDAP is a protocol for the acquisition of sensors data, designed to work at different network levels, so with devices having different processing capabilities. Its design has been guided by some features, such as scalability and lightness. To pursue these features, we had to make some design choices. In the following slides we will see the reasoning behind these choices, by examples.

Let us start with a simple example.

We have a sensor that samples moisture and air temperature, installed in an agricultural plot. To proceed with data collection, we need to identify the data produced by this sensor and how an application could deal with those data.

A very simple description can be like: <temperature>;<humidity>. It is very concise, but it could lead to confusion problems between the two measures. A better description is done by using keywords to add meaning to the values. We need also to add the time instant.

Another improvement regards the transmission: we could accumulate a series of measurements and send them in a unique package. In the SEAMDAP protocol this is done via the SenML format.

Let's consider a new example that considers two sensors installed in the same plot. We can use the format seen above and send the data separately for each sensor. The problem now is the inability to figure out which sensor a message belongs to. One solution is to assign an ID (a name) to the sensors.

Expanding the problem, other information can better describe and identify each sensor.

First, we can indicate the associated plot (by an ID), the installation position (to know in which area of the plot the sensor is) and the area of validity (the area where sensor data are reliable). This is a concept useful in a different situation. For example, consider a local weather station, which allows public access to the data and that provides atmospheric data associated with its position. Knowing its area of validity is essential to associate weather data to a plot. Moreover, this information could be much more sophisticated, using not fixed areas (avoiding microclimates incongruences).

The full message we have is now very complete, but the payload has increased significantly. However, we can observe that the information we are sending is not all the usual type, *some are mutable data, others are very static. We can differ the methods of sending individual data: static data are sent once, and a lighter payload with mutable data are sent at will. For this, it is necessary to provide some sort of identification of the sensor (through a registration). Data Acquisition is then simplified.*

The future PA scenario foresees applications with that need additional information on the data itself (produced by the sensor), to be able to know how to process them. So, we want to provide a further layer of information i.e., a description useful for the applications that collect the data (e.g., unit of measure, limits and constraints of validity). These are certainly static data.

Let us scale the example one last time. Now we have a lot of sensors transmitting data (via messages) and many applications that need to process the data. In such a situation, all quantities increase rapidly. All the small additions we have put in the messages are inefficiencies which help in the description of the data, but their increased weight could cause congestion in the network, high latency times and greater energy consumption, leading to fast draining of sensors battery.

In the example we must register the instance (the single physical sensor) for each single application that uses that sensor. As before, we can see if there is any data that repeats across the various instances. Indeed, the type of data that the sensor generates, and their description does not vary on different instances, because it is related to the construction technology of the sensors class. So, we can decide to record the sensor interface, so how the sensor presents the data and related information. In SEAMDAP, W3C Thing Description format is used to register the interface. Doing so, if we have 100 sensors of one type, it is only necessary to register the interface once. Instance registration is then simplified.

This is what happens in SEAMDAP protocol: we are dividing the information load into different phases (Data Interface Registration, Instance Registration, and Data Acquisition), so that repetitions are reduced to a minimum, but it still is possible to obtain a high descriptive content of each sensor message.

In the context of PA, protocols such this will be essential to integrate data from different sources, with different semantics and technologies, to deal with this complex and heterogeneous scenario.

Now let us analyze whether the choices made in SEAMDAP can satisfy the main desired features.

Lightweight. This it is intended in terms of a single message, achieved using protocols with light payloads. Phases are introduced, and message size is lighter in phases with more occurrence (more messages) and vice versa.

Simplicity and autonomy of integration. The formats are human-readable, especially in the phases with fewer messages. Phase 1 can be delegated to the sensor manufacturer who has the technical knowledge.

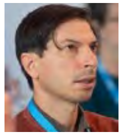
Customization. In SEAMDAP, the implementation of phase 2 is left to the user, because there may be different needs based on the use case. Phase 1 uses a protocol with extensible vocabularies.

Privacy and security. SEAMDAP does not provide other security mechanisms but allows the use of the classic security techniques and messages descriptor obfuscation.

Scalability. This is achieved thanks to all previous features and the use of asynchronous phases.

Several advantages can be outlined in the use of protocols such as SEAMDAP, both for manufacturers, users, and developers of systems.

In conclusion, the computing scenario of the PA is evolving. Modern applications can support agricultural activities, but they need a lot of data to work effectively. The individual farmer can benefit from his own data, but if those data are shared, will gain greater value, bringing advantages to the whole sector and further benefits also to the owner of the data. (e.g., geographical related phenomena as spread of diseases, weather forecast, …). In this context, data sharing should rely on protocols such as SEAMDAP.



Paolo Mantovi | Centro Ricerche Produzioni Animali – CRPA

Giuseppe Veneri | Centro Ricerche Produzioni Animali – CRPA

▶ The SAMS platform - Validation of scalable operating protocols via Positive SAMS in partner farms

The collection and analysis of data coming directly from the fields is becoming increasingly automated, thanks to sensors and other sources; and for the management of farm data we use GIS: geographic information systems.

With POSITIVE, a farmer can now manage and monitor variable rate precision irrigation to supply crops with the correct amounts of water, following freely accessible operating protocols.

Smart Agronomic Management System – SAMS, a specific GIS that connects to the POSITIVE project server, proves it. SAMS allows, via the POSITIVE protocols, the farmer to:

- describe the crop plan;
- monitor the vegetative state of crops;
- derive and use a precision irrigation advice;
- perform irrigation by interpreting the irrigation advice data.

It is prepared to transmit the irrigation prescription to the 4 0 machines and to acquire/record/communicate to IRRINET+ the performed irrigation.

Plot polygons are stored on the IRRINET+ server and read by Positive SAMS, plot centroids are stored on the SAMS server, calculated and kept up-to-date by Positive SAMS.

The SAMS operational dashboard has a list of functions that can be called up on the selected plots (tick box).

The visualization of the Vegetation Indexes (NDVI or EVI) developed from satellite data allows to evaluate the state of the crops in real time through a map divided into 10m x 10m squares.

The resulting Irrigation Advice is expressed in a map of the same type, where the values represent the recommended amounts of water, expressed in millimeters. Each mesh has a colour proportional to the value in mm of recommended administration of water.

The map of the precision irrigation advice, transformed into a Prescription Map, is transmitted to the irrigation machines, which can vary the longitudinal and transversal flow.

And to come full circle, each irrigation machine returns the values actually delivered, always in the form of a map which, acquired by the POSITIVE system, allows to recalculate the next irrigation advice, corrected on the basis of the data from sensors in the field, if necessary.

Maps are transferable, storable and usable over time. GeoJSON is an open international standard format containing objects described with geometry and properties. It is readable by various systems (GIS and statistical analysis).

This is how POSITIVE puts Agriculture 4.0 into action! Through variable rate precision irrigation based on operational protocols fully available to the production world. Tools and skills to enable sustainability!

Gabriele Baroni | DISTAL UNIBO

State-of-the-art of cosmic-ray neutron sensing for soil moisture monitoring and precision agriculture

In this contribution, the cosmic ray neutron sensing technique for soil moisture estimation is presented and discussed. A specific focus is paid on the recent advancements and applications in the context of precision agriculture.

After a short biography of the Author and his research activities (**slides 3 - 4**), the presentation introduces the importance of soil moisture observations in many applications, ranging from weather forecasting to agricultural practices (**slides 5 - 6**). An overview of the techniques currently available for monitoring soil moisture are then described (**slides 7 - 8**). On the one hand, there are point scale soil moisture sensors that are invasive detectors that can be installed into the soil, in principle, at any soil depth. They produce soil moisture values with high accuracy and precision, and they have been used successfully in many applications. However, the signal represents soil moisture over a small soil volume (of about 1000 cm^3) and the use of these techniques is limited if large areas need to be studied. Moreover, the installation could be difficult in some places for the presence of gravel or when soil is managed (e.g., tillage activities). On the other hand, remote sensing methods are non invasive approaches and they cover large areas. For these reasons, they overcome the aforementioned limitations and they have been successfully adopted in some applications. Currently, however, spatial resolution is about 1 km^2, temporal resolution is within days, and the signal is very shallow (i.e., few centimetres into the soil) and strongly disturbed by the presence of vegetation. Therefore, the use of remote sensing for soil moisture estimation is still debated in some applications like in agriculture. More recently, a third group of so-called proximal soil sensing techniques have been the focus by many research groups. In this case, the sensors are installed above ground and the detected volume is around hectares, an intermediate scale between point-scale sensors and remote methods. For these reasons, they have been considered to fill the gap of more traditional technologies providing a new prospective for soil moisture estimation.

The contribution moves further by presenting in more detail the cosmic-ray neutron sensing technique for soil moisture estimation, currently known in literature with the acronyms of CRNS. This technique belongs to the proximal soil moisture techniques, and it is showing promising results also in the context of precision agriculture. The main theoretical basis and characteristics of this technique is first presented (**slides 9 - 11**). Specifically, the sensor measures natural environmental neutrons at a specific energy range produced by cosmic rays. These neutrons interact with the amount of hydrogen at the land surface. Since the changes in the amount of hydrogen is mainly driven by soil moisture dynamic, an inverse correlation between the detected signal and soil moisture can be established. Neutrons are also travelling relatively long distances in the air and down to the soil. For this reason, the signal measured by a detector placed above ground is proportional to the soil moisture over a relatively large area of about five hectares, without any strong topography effect. Moreover, the signal represents in many cases the soil moisture in the plant root system overcoming some of the limitations of other techniques.

It is then discussed how cosmic-ray neutron sensing has emerged, after a long way from the first studies conducted in 1960s, as a promising non invasive soil moisture sensor that can be integrated in many applications (**slides 12-16**). Specifically, nowadays, CRNS technique is used by many research groups all around the World and soil moisture networks are also emerging at different levels. Some specific contributions for snow and biomass estimation are also shortly discussed. In the context of precision agriculture, some preliminary studies have been presented for supporting irrigation scheduling and for soil mapping. For these reasons, CRNS has also been promoted by the International Atomic Energy Agency (IAEA-FAO) in many countries by distributing equipment and organizing technical training (**slides 17 - 18**).

More recently, effort is put to move the use of this technology further from academy and research. Two main needs have been identified: (i) to reduce the costs of the sensors and (ii) to simplify the post-processing of the signal (**slides 19 - 27**). While several initiatives are conducted by many scientific groups, in this presentation special focus is paid to the activities of the Author and his research team.

In the first case (**slides 27 - 28**), new technical developments have been promoted by new groups and private companies. Part of the research activities of the team of the Author focus on the assessment of these new prototypes. Among others, the experiments conducted in 2021 to assess the new FINAPP detector (https://www.finapptech.com/en) are shown and discussed. Specifically, four sites in Northern Italy have been identified. During the monitoring period of about six months, from April to October, three intensive independent soil sampling campaigns have been conducted for comparison at each site. At each field campaign, 72 soil samples have been collected within the CRNS footprint. Based on these samples, gravimetric soil moisture measurements have been performed in the laboratory by oven-dry method (24 hours at 105 °C). Soil organic carbon and lattice water have also been assessed on a mixed soil sample. The results have shown that the new FINAPP sensor well reproduced soil moisture dynamic at the different locations. Absolute values were also in very good agreements but with some differences that can be attributed to the contribution of the biomass on the signal. All these activities have been conducted in collaboration with the Italian regional environmental agencies (ARPA) to promote the technologies and to evaluate the integration of these sensors with current weather stations. At the time when this report is written, a manuscript where these experiments and results are presented and discussed is under review and the possibility of establishing a CRNS network for soil moisture observation over the different Italian regions is under discussion.

In the second case (**slide 29**), it has been recognized that the analysis of the signal requires relatively advanced technical skills. Moreover, despite some general guidelines about the use of this technology have been developed, data processing steps are still not fully standardized and traceable. For this reason, additional activities of the team of the Author are focused on developing and sharing standard processing tools towards relatively simple graphical user interface for end users. Specifically, a decision support system for agricultural practices integrating soil moisture estimation with additional data like weather data is envisaged to better capture the environmental conditions and the abiotic factors that could affect plant stress. These activities are currently under development based on the data collected at the walnut orchard in collaboration with Aretè.srl (https://www.areteagrifood.com/en/) at Ferrara, Italy (data not shown).

The contribution is concluded with a short summary of the main achievements and further plans of the research team (**slides 30 - 31**). Specifically, despite it is acknowledged that some developments are still welcome and a fully technology transfer from academy to practitioners will still take some time, it is highlighted that CRNS can be considered a reliable soil moisture sensor for many applications. One of the main challenges is to understand how and where to integrate these observations to boost our monitoring systems and to achieve a better support to our management strategies.

Raffaella Zucaro | Canale Emiliano Romagnolo

Consorzio Canale Emiliano Romagnolo and Acqua Campus

Consorzio CER is a second-degree reclamation consortium, established - according to art. 57 of the Italian Royal Decree of February 13, 1933, n. 215 with Royal Decree of 28 September 1939, n. 8288 - for the study, execution and exercise of irrigation infrastructures in the common interest of the associated Consortia. According to the statute of the Consortium between its activity, there can be found the objective to carry out field studies, research, communication and dissemination, technical assistance and training activities on irrigation, water saving and water quality in agriculture, in favor of other reclamation consortia and public bodies and private individuals within the limits of institutional purposes and in compliance with the rules on service procurement. Consorzio CER's activities also include the promotion of initiatives aimed at saving water, the correct use of water, safeguarding its quality and reducing land subsidence. In this field, Consorzio CER is at the same time the main local agricultural water stakeholder (Emilia-Romagna) and a private institute undertaking research on agricultural water management and governance, offering extension services support to farmers and other water stakeholders.

Like all second-degree consortia, it was born following the existence of common interests in several first-degree consortia which, therefore, are associated with it:

- the Burana reclamation consortium;
- the Ferrara plain reclamation consortium;
- the Renana reclamation consortium;
- the Western Romagna reclamation consortium;
- the Romagna reclamation consortium.
- Ravenna Servizi Industriali S.C.P.A., the only non-agricultural member of the consortium.

These entities are assignees of a water supply, within the resources available to CER. In particular, the associated consortia are entrusted with the irrigation distribution of the resource in the area. In fact, in art. 3 of the Statute of the Consortium lists its tasks and functions, carried out "for the purpose of rational use of water resources in agriculture and in other water-demanding sectors". In particular, the consortium provides:

- the study, design and execution of derivation works from the Po river, from other rivers and reservoirs, as well as from the adductor canals of common interest to the territories of • the provinces of Ferrara, Modena, Ravenna, Forlì-Cesena, Rimini and the metropolitan city from Bologna;
- the maintenance and operation of the intake works, the lifting systems, the governance of the aforesaid adductor channels and the artefacts related to them;
- the distribution of water to members;
- the pre-financing of the costs for the construction of the aforesaid works;
- the coordination of the activities of the associated consortia for the execution of the irrigation works and for the integration of these with the works of the second-level consortium, in order to make better use of the water resources of the CER;
- the reorganization of its utilities and water uses;
- the use of the water resource for multiple use of water pursuant to and for the purposes of current legislation;
- the promotion of initiatives for the adaptation of agriculture to drought and climate change, for the mitigation of the related effects, for the protection of production and for the economic valorisation of the area;
- to carry out study, research, experimentation, dissemination, technical assistance and training activities on irrigation, water saving and the quality and protection of water in agriculture, in favor of reclamation consortia and other public and private entities and subjects in the limits of the institutional purposes and in compliance with the rules on service contracts.

The water supply to the system is ensured by a right-hand diversion of the Po, in Salvatonica di Bondeno (Ferrara), near the Cavo Napoleonico, an unlined earth channel also known as the actuator of the floods of the Reno and the first vector of the Emilia-Romagna canal system. Water supply of the Canal is 68 m^3/s from the river Po in the months from May to

September, and 25 m^3/s in the remaining months; it also has the possibility of withdrawing 1.5 m^3/s from the Reno river from April to September, and 2 m^3/s in the rest of the year. The water flow inside the canal is ensured by a series of lifting systems placed along the channel to overcome the unfavorable altimetry, all thanks to a complex system which, based on the levels of the various sections of the canal, ensures the optimal water supply to facilitate its outflow. In fact, the CER is an uphill river: it passes from a free surface water level of 4 meters above sea level. at the point of derivation from the Po up to 18 m.s.l.m. subsequent to the lifting of the Pieve di Cento plant, to then proceed on very low slopes and with decreasing flow rates up to a free surface level of 14 meters above sea level, to finally be raised by about 2 meters above sea level and end up in the province of Rimini.

Across years, CER has experienced an increase in volumes that are distributed annually. This is also confirmed by the latest climatic trends. If overall annual rainfall does not deviate significantly from the average in the historical reference period, it is the distribution of rainfall that is of concern. It is now a characteristic revealed by Arpae data in the regional territory, that of extreme meteoric events alternating with less and less rainy springs and summers. This changing climate has both managerial consequences, creating complications for the management and maintenance of irrigation infrastructures, and productive consequences, especially for agriculture which sees a constantly growing demand for water from crops. In an area such as that of the CER characterized by a reduced capacity to invade rainwater, this changed distribution of rainfall together with hot irrigation seasons highlights the need for increasingly targeted and effective infrastructural and management interventions.

As mentioned before, CER has a long experience in research, experimentation and communication in precision irrigation, water resources monitoring, development of irrigation water balance and water governance. Three are the location where such activities are carried out and where each year citizens, stakeholders and farmers visit:

- Acqua Campus – Demonstrative area: an open-aire showroom where innovations and new technologies are open to be visited and studied. Each year hundreds of farmers and stakeholders participate at open days and visits.
- Acqua Campus – Natura: this is a natural wetland located in the province of Ravenna, in the regional parc Parco del Delta del Po and acts as a rich source of rural biodiversity and strongly contributes to contrast the salinization of surface and subsurface water bodies affecting crop cultivation in nearby cultivated fields.
- Acqua Campus – Experimental farm: real scale (12.5 hectares) experimental farm where crops are cultivated to carry out numerous field trials. The farm is equipped with full scale meteo-station, groundwater monitoring pits, soil sensors, etc. Here, there is also an internal laboratory for the analysis of the major soil and water parameters.

ANBI Emilia-Romagna is the regional section of the National Association of the Agricultural Water Board in charge of the management of the agricultural water networks (“ Consortia”). Through the associated Consortia, ANBI ER operates water supply for irrigation and hydraulic risk management of the Emilia Romagna territory. The main roles of ANBI-ER are the following:

- act for the Consortia at Regional, local State offices and local authorities;
- participate in the regional working groups for economic and social development programs, water use and risk management plans;
- identify and studiy general technical, economic and social problems concerning land reclamation, irrigation and land potential enhancements;
- promote the development of initiatives for reclamation, irrigation, hydraulic risk management and land resilience improvement.

Finally, ANBI-ER is the natural interface with River basin Authorities and Regional Government, in charge for the safeguard of water and soils against pollutions and over-exploitation and climate change.

Pasquale Campi | Council for Agricultural Research and Economics
- Agriculture and Environment Research Center, Bari

▶ Precision Irrigation: new water saving approaches

In the Mediterranean basin, the limited availability of water implies the need to seek agronomic solutions aiming at mitigating the consequences of water deficits while increasing water productivity (**slide 3**). Over the years irrigation technology has been improved: from simply water supplying to the spatial application of irrigation water (Variable Rate Irrigation, VRI) to meet the site-specific plant needs (**slide 4**). VRI aims to: ensure favorable conditions of water content; absence of stress or controlled water deficit in any site within the plot (**slide 5**). This is very important because using irrigation it is now possible to obtain, worldwide, about 40% of agricultural production from about 20% of the cultivated area (**slide 6**). In particular, precision irrigation (PI) take into account the variability over time and space and use of water balance management tools and several sensors IOT (**slide 7**). In the word, the research for PI incoming from 90s years and for the future a strong increase in the use of this technology is expected (**slides 8-9**). France, Germany and the United Kingdom, where farms that have already adopted precision farming techniques exceed 20%, while in the USA they are now widely and commonly used practices. The diffusion in Italy of Precision Irrigation is very limited for small size of farms, the high average age of farmers and the lack of internet connections in rural areas (**slides 10-11**). The IP modify the agro-management for multiple objectives: (i) increase in the efficiency of use of agronomic inputs; (ii) reduction of environmental impacts; (iii) increase in the farmer's profits; (iv) improvement of product quality (**slide s12-13**).

The stage of PI are:

1. Data acquisition. An IP system requires the presence of a spatial and/or temporal variable of the characteristics of the soil and of the conditions of the crop within a field and the ability to identify and quantify such variability (**slide 14**). This is possible thanks to:
   a) remote sensing: tools that allow the remote shooting of crops and soils through the capture of radiation emitted or reflected by them. The presence of Sentinel-2 currently allows to identify variability with high spatial and temporal resolutions. (**slide 15**);
   b) proximal sensing: a set of measurement technologies, in which the sensor is in direct contact with the object to be measured, the soil or the crop, or is at a distance of less than 2 m (**slide 16**);
   c) production maps: sensors mounted on harvesting machines capable of Site-specific registration of productions (**slide 17**);
   d) stationary sensors: fixed sensors, well calibrated, measure variations of a certain magnitude even over time (**slide 18-20**).
2. Identifying the Management Zones by geostatistical technologies (**slide 21**).
3. Scheduling Irrigation for each homogeneous zone. In this case, the water balance model is applied (**slides 22-24**) and the possibility of applying saving water strategies (**slide 25**) is identified through the coefficient of productive response (**slide 26**). The three methods of saving water are Deficit irrigation (**slides 28-30**); Regulated Deficit irrigation (**slides 31-34**); Partial root drying (**slide 35**).
4. Applying specific volumes of water with irrigation systems suitable for IP. Irrigation systems for PI are:
   a) sprinkler Irrigation (**slides 36-54**) by rangers and pivot. They can also be used for tree crops (**slide 40**) and be used for precision fertirrigation and e precise pathogen control (slide 44). In addition, Pivots can also be programmed to automatically close dispensers to avoid inefficient overlaps of watered surfaces, irrigation not required for some crops (**slides 47-48**) and application in soils with different topography (slide 53). Another method of Sprinkler Irrigation is HYDRO SAT system. The objective of the system is to distribute the amount of water required according to specific irrigation prescription maps, obtained through satellite, aerial or proximity sensor images and processed using appropriate algorithms (**slide 51**)
   b) microirrigation (**slides 54- 65**) has many agronomic advantages (**slides 55-57**) and with sub-irrigation (**slides 58-60**) represents an irrigation system easily adaptable with P.I. with elettrovalvole and automatic site-specific irrigation control systems that adjust the flow based on maps (**slide 64**);
5. control: monitoring and verification (**slides 67-70**). The ability to reallocate inputs and to adapt irrigation management to appropriate spatial and temporal scales are essential

features of a PI system. The application of differential water volumes will depend on the type of irrigation system and can be implemented in two different ways: by varying the intensity of the flow or the application time. Automatic controllers, which work in real time with data from mobile sensors (on-the-go), are the most reliable and accurate tools for irrigation management.

Benefits and Development of P.I (**slides 72-75**). The published literature contains little on the benefits of precision irrigation and what has been published tends to focus on the single aspect of spatially varied applications. In the last decade there has been an increase in the number of papers on P.I. (**slide 72**) In the short term, research and development in the field of VRI will have to focus on plant elements to improve the localized control of rain intensity; guidelines to guide technicians and farmers in the choice of the VRI plant also according to the characteristics of the farm and the pedo-climatic context; tools to identify the best positioning of the sensor network for monitoring the water status of the soil; development of easy-to-use decision support systems (DSS) for irrigation programming (**slides 73-74**). The future success of VRI will depend above all on the economic benefits that can be achieved by farmers. New studies are therefore needed to define the thresholds of economic convenience of VRI. The analysis will also have to consider the environmental advantages, such as the possibility of carrying out site-specific fertigation with positive effects on the nitrogen balance, the lower danger of attacks by mycotoxygenic fungi **(slide 75)**.

Tommaso Letterio | Canale Emiliano Romagnolo

▶ Satellite and sensors: new tools for in-farm irrigation management

Slide 2: Irriframe (IF) service applies a 1D tipping bucket water flow model to soil-water-plant continuous in order to calculate the irrigation amount and the timing for water application. The model considers all variables involved in soil water balance using different available public data sources as meteorological station and soil type when it is possible.
Slide 3: for in-farm irrigation scheduling IF service integrates the meteorological forecast for the further 3 days in order to define the right time for water application. The irrigation volume is calculated according to irrigation method and it is possible to considerate the yield and revenue related to single irrigation water application. The last result is obtained with algorithmic adaptation of yield-water response model of FAO 33 at daily step and considering the fixed and variable cost of water application.
Slide 4: IF service is applied all along the Italian country mainly in north-east regions with a total number of plot of 36296 and a surface served by service of about 7 millions of hectares.
Slide 5: The new advances in irrigation scheduling application have been developed by CER in order to integrate the IOT systems available in field, in order to increase the effectiveness and reliability of the DSS advice. Sensors for monitoring of micro-meteorological parameters, plant, soil-water and others are spreading-out among farmers but it is not always easy to obtain simple and sure advice suitable for the application at different field scale. The integration in IF service allows to reduce the uncertainty related to the measurements and related to the spatial variability. The IF service obtains information from field in order to adjust the irrigation advice to the real field condition. Nowadays the IOT it is not only gathering data but it controls as well actuators.
Slide 6: About soil moisture sensor in IF a web-interface is available for adding data as water percentage in volume or as weight as well as with tension unit (cbar). In order to integrate the IOT system in IF a webapi system was developed to automate the assimilation of data. The integration using an assimilation algorithm was developed with the analysis of common data-assimilation model as Kalman Filter, Ensable Kalman Filter and 4DVAR.
Slide 7: The integration into IF model of fruit growth rate data from field sensor was obtained with integration of web service PERFRUTTO. The growth rate of fruits is used for calculation of harvesting diameter and weight. These data are compared with final objective diameters and according to empirical model between irrigation water and final diameter an adjustment to irrigation volume was applied in order to achieve the objective results.
Slide 8: The pressure transducer and irrigation gauge in field can measure the applied water in field with drip or sprinkler irrigation. The feedback of real amount of water applied coming from IOT can simplify the irrigation scheduling service management and it can improve the quality of service due to an adjustment to the real field management activities. The web-service for IOT system are available in most case but really strong efforts are needed for raw data post-process adaptation: for every case we need a ETL customer service *ad-hoc*.
Slide 9: Every irrigation manufactures area selling technologies that can manage wireless network for interaction with remote valves or unit; the cost is always more accessible, more complex systems can be designed and installed but more complex data processors we need for systems integration in DSS IF.
Slide 10: The last advance in irrigation scheduling with IOT system is the integration with irrigation and fertigation control unit that can be controlled by M2M protocols. The IF service integrates data from field in order to improve the quality of irrigation advice and then it transfers the irrigation length of run directly to the irrigation unit: the farmer has only to verify the adequacy to his need. The autonomous control of irrigation system with DSS IF.
Slide 11: From 2020 the irrigation scheduling is supplied with fertigation scheduling advice as well. The DSS calculates the nutrient balance in soil according to specific uptake from roots system related to crop phenology and than supply to the farmers a nutrient advice for fertigation.
Slide 12: The last developments are focusing on transferring the fertigation advice to fertigation unit: the IF DSS control directly the irrigation and fertigation in field controlling valves and actuators.
Slide 13: The application of anti-hail/shadow net in orchards is increasing and the effects on crop evapostranspiration are strong. Micro-climatological studies have been done by CER in order to integrate into IF DSS service an adjustment algorithm for reduce ET0 form open field network as function of type of net installed.
Slides 14-15: The fine tuning of crop parameters for modelling of crop evapotraspiration in IF was realized applying most advanced measuring technologies such as eddy covariance

as for Kiwifruit and Juglans.

Slide 16: The integration with remote sensing data from satellite and drone was realized with field monitoring and modelling following two main routes: 1) assimilation of data from vegetative and physiological condition of crop into model, 2) integrate the spatial variability of crop in field to develop a VRI map.

Slide 17: About crop condition monitoring from VI remote sensing we calibrated a statistical model with identification of possible biomass stress condition of crop with field monitoring for each crop.

Slide 18: An algorithm of data assimilation was developed in order define a likelyhood criteria for integration into IF. The Kc parametrizations developed into IF is considering agronomic constraints that define practical management strategies. From satellite of course we obtain a signature from crop that can be affected by various typical phenological condition for each crop e.g.: red berry from tomato close to harvesting, flowers for maize and others. That condition affects the spectrum signal so a crop specific calibration function is needed.

Slide 19: The spatial variability of biomass as monitored from satellite was used for calculating of variable irrigation rate map. The VRI map is transferred directly to the irrigation unit into the machinery. The farmer can find into machine the prescription map already available for star irrigation.

Slides 20-25: For specific produces of irrigation machines are available a web service interfaces for the interaction with IF DSS system that can easily be managed by technical and farmers. The management zone defined for VRI map calculation are defined by irrigation machine capabilities. The resolution of satellite used is 10 meters, so it is no possible the reduce the size of area for water application below that threshold. But the main constraints is related to operating capacity of the irrigation machine: with irrigation bar machinery system is possible to rate the retreat velocity so only rectangular area with side length as bar length can be defined.

Slide 26: The automation of gate in surface irrigation system has been developed in order to improve the efficiency of surface irrigation method and avoiding waste of time for water control.

Francesco Cavazza | Canale Emiliano Romagnolo

▶ The use of big data to improve decisions for sustainable water management at the territorial level

Agriculture has always been affected by uncertainty. This is mainly due to the open-air characteristic of production processes carried out in complex agroecosystems with highly variable driving elements such as pests, climate and soil. To face uncertainty, the development of agriculture has been characterized by farmers' effort to control environmental variables. The result of this development process is in distributions of outputs which have lower variability and higher averages. water management and irrigation are a clear example of this. By collecting water in reservoirs before the cultivating season, water management allows to diminish the share of production processes subjected to the variability of unknown and upcoming rainfalls. By moving water from where it is abundant to the field, irrigation allows a more suitable environment for crops. Overall, the irrigation system lowers climate-vulnerability while it increases the average crop productivity. Examples of this kind are available all along the development of agriculture from food gathering to hi-tech greenhouses. This is especially true during *Green Revolution,* which is widely recognized as one the periods where agriculture has been more effective in implementing innovations for the control of agroecosystem's processes.

Nowadays, Climate Change (CC) is exacerbating uncertainty issues by making forecasts more difficult and by increasing the variability of weather events. At the same time, as in everyday life we have seen the proliferation of ICT contributing to support many decisions, also agriculture is taking part to this digitalization process. Decision Support Systems, IoT, Climate Services and GIS are exponentially growing in the agricultural sector and offer decision makers a wide variety of support. Because of the great potential of such ICTs, many authors call this period *Digital agriculture revolution* and believe it is the answer to the challenges the sector is facing due to CC.

New approaches are required combining adaptation and mitigation strategies to realize the goal of sustainable development. With mitigation, the International Panel on Climate Change refers to "options and strategies for reducing GHG (Green House Gases) emissions and increasing GHG uptakes by the Earth system", whereas adaptation is considered as the "process of adjustment to actual or expected climate and its effects". Adaptation and mitigation are the two pillars facing CC. In this regard, weather and climate services can help decision-makers in making informed decisions to improve adaptation capacity by assessing and forecasting existing and emerging risk.

For the management of water resources, Water Authorities and Reclamation boards have to make decisions before knowing the weather conditions they are going to face. The high variability of weather patterns increases the level of uncertainty regarding future weather conditions, causing a moving-target problem. Given these settings, Consorzio CER developed a series of ICT tools to monitor environmental parameters connected with water, soil and atmosphere to provide stakeholders fruitful solutions.

Precision agriculture is a management strategy that aims to meet the actual crop needs, managing their spatial and temporal variability with differentiated agronomic interventions within individual plots according to the particularities of the targeted area. "Doing the right thing, in the right place, at the right time": promptly intervening only when and where necessary and with the correct strategy for managing inputs (**slides 3-4**).

The creation of a digital infrastructure is a fundamental step to take advantage of precision agriculture as this approach is based on the collection and analysis of data during the entire crop cycle from different sources. An open platform can make collected data and their processing usable and, at the same time, hosting, implementing, and developing models, systems, and other external platforms (**slide 5**).

Precision agriculture is based on the study of field variability, which is performed through soil mapping by using different tools like geoelectrical sensors and/or with statistical analysis of crop vigour with satellite imagery. These activities are preparatory to the identification of areas with different characteristics, on which soil sampling will be done to characterize those areas.

The study of field variability can be carried out with proximal sensing, for example with the use of geoelectrical sensors. These are specific tools that measure soil electrical resistivity as a proxy of the main soil properties (**slide 6**).

The study of field variability can also be conducted by multi-temporal analysis of yield maps. This is possible thanks to grain flow sensors installed on the combine harvester, which can measure the amount of product harvested in real time within the field. The following step is processing and analysis of data using specific software to generate yield maps. These maps can be realized for one single year, multiyear or other time scales. The result is the generation of maps indicating zones characterized by specific productivity classes (for example: high, mean and low) (**slide 7**).

One of the most important methods to study field variability is remote sensing, which is based on measuring the reflected or emitted electromagnetic radiation from a sensor placed at a certain distance. In precision agriculture, remote sensing is mainly carried out using sensors installed on satellites, which can provide information on crop vigor by detecting specific vegetative index like NDVI (Normalized Difference Vegetation Index) or MSAVI (Modified Soil-Adjusted Vegetation Index) at 10 m spatial resolution. There also indexes that can provide information from soil like the SOCI (Soil Organic Carbon Index) as this index is highly correlated with important characteristics like organic matter content and texture (**slide 8**).

Field variability can be examined on a smaller scale using drones equipped with sensors to detect information at 2-3 cm spatial resolution. Drones are commonly used in arboriculture and in all situations where canopy is not continuous, as well as in case data must be acquired in small areas or plots (**slide 9**).

Regardless of the methods to be used, the study of field variability has the purpose of identifying homogeneous zones, i.e. sub-regions of the field in which the effects on the crop induced by seasonal differences in the climate, soil and agronomic management can be considered uniform. The definition of homogeneous areas is the basis of the methodological approach of precision agriculture, which is based on site-specific practices to be implemented to optimize agronomic management. Once homogeneous areas are identified, selective soil sampling is carried out according to field variability to characterize those areas in terms of chemical-physical characteristics (i.e: texture, organic matter content, pH, cation exchange capacity, electrical conductivity, etc.). The result of such characterization is the generation of Management Unit Zones (MUZ), which are field areas that will be managed in different ways in terms of agronomic operations (i.e: sowing, irrigation, fertilization, etc.) (**slide 10**).

Water management is essential for agricultural production as its increasing scarcity represents a major concern in the last few decades. In this context, precision agriculture can contribute to the optimization of this important resource through Decision Support Systems (DSS) for irrigation management. These DSS are fed by data from different sources like real weather station, virtual weather stations and soil moisture sensors. Real weather station are instruments generally composed by a single module integrating all sensors for measuring atmospheric parameters. The standard type stations integrate sensors for air temperature, air humidity, rainfall and leaf wetness. Precipitation and temperature data can be used to remotely monitor climatic conditions for planning interventions in the field, especially in case the company is in several estates.

Weather stations data and soil sensors are useful to feed Decision Support Systems, or DSS, for optimizing irrigation management. Such DSS are based on two models: the models based on soil water deficit by soil moisture sensors and models based on water balance:

Models based on soil water deficit by soil moisture sensors are based on the evidence that water movement in soil depends on several forces that plants must overcome by spending energy. The sum of this forces is the water potential, and it has three components:

- Matrix component: defined by colloidal adsorption and soil micropores.
- Osmotic component: defined by salts dissolved in soil water.
- Gravitational component: defined by water weight.

For a better definition of an irrigation practice it is useful to know the soil moisture constants, which are constants able to identify water content in a specific soil type:

- Saturation point: it is the amount of soil water at saturation.
- Field capacity: It is the capacity of the soil to retain water against the downward pull of gravity force. It represents the ideal situation for plants.
- Wilting point: It represents the point where soil is unable to supply water to the plant.

The water fraction contained between the saturation point and the field water capacity is defined as gravitational water (GW). The fraction contained between the field water capacity and the wilting point is called available capillary water (ACW). The fraction contained between the field water capacity and 50% of the available water is the readily usable water (RAW)

Models based on water balance model: it defines the amount of water to be distributed by calculating the difference between water inputs and outputs from soil. Inputs are rainfall, groundwater and irrigation, while outputs are run-off, percolation and evapotranspiration. This concept is expressed in the following formula:

$$I = ET + RO + P - R - G$$

Where:
I= Irrigation
ET= Evapotranspiration. It is the amount of water transferred into the atmosphere due to evaporation from soil and transpiration from vegetation.
RO= Run-off. It is the surface water flow after rainfall. It depends on the amount of precipitation and soil type.
P= Percolation. It is the downward water movement by gravity through soil.
R=Rainfall. It is the amount of water that enters the soil through precipitation from the atmosphere.
G= Groundwater. Inputs from water stored into the soil.
(**Slides 11-12**)
Thanks to precision irrigation and its remote and proximal sensing tools it is possible to optimize water management in a wide range of contexts, rendering the process scalable from small to large companies (**slide 13**).

A. Mambelli | Consorzio di Bonifica della Romagna

▶ Digital water management: examples from reclamation and irrigation boards

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Title: Automated water gates and remote control: how precision irrigation management can help water savings at the district level

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Description of Consorzio di Bonifica activities

3. Irrigation canals
Description of irrigation canals and their characteristics

4. Irrigation canals
Way to reduce the waste of water

5. FSC Tender
Description of The Law nr. 147 of the 27th of December 2013 (2014 Stability Law) and its resources for Development and Cohesion Fund (FSC) fund

6. FSC Tender
Ministerial Decree nr. 39288 of the 6th of December 2019 (The Ministry of Agricultural, Food and Forestry Policies – in Italian MIPAAF) that approved an Announcement of Selection called:
FSC 2014-2020 POA subplan 2 “interventions in irrigation infrastructure, hydraulic drainage, flood protection, storage reservoir and programs of technical assistance and consultancy”

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State of the art about water gates which take water from the CER into irrigation canals

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General map of the 11 water gates

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Water gates’ names

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Michele Solmi | Consorzio della Bonifica Renana

▶ New paradigms for reaching out farmers, save water and provide ecosystem services

The land reclamation and drainage consortium authority of RENANA is a local public organization based on functional autonomy and users' self-government. All the individuals who own land or buildings within the territory managed by Renana and who receive benefits from our activities are required to pay a contribution in proportion to the benefit. The contribution is quantified by a technical document called "Classification Plan".

The area where Consorzio della Bonifica Renana operates is defined by Reno river catchment.

The entire area measures 3,419 km2 (41% plain; 59% mountain), with 2.000 km of irrigation canals and 1.600 hectares of protected areas with wetlands.

The area has about 259.000 associated, owners of properties, united in 63 municipalities in the area of Bologna, Firenze, Pistoia, Modena, Prato, Ferrara and Ravenna.

The roles and functions of Bonifica Renana are:

- Hydraulic facilities management in order to ensure drainage of water and prevent floods;
- Water providing for irrigation;
- hydrogeological instability management within the mountain area;
- Environmental management and improvement.

One of the most important activities of the consortium is irrigation. We distribute each year 70 million cubic meters of water for irrigation and production purposes and we have almost 20.000 hectares irrigated, principally maize and tree crops. Our complex irrigation distribution system is composed by;

- about 2.000 km of hydrographic network
- 272 km of pipes/culverts
- 6 Irrigated reservoirs
- 49 Pumping plants- 95 pumps
- 866 Artifacts for irrigation control

To move water throughout all our areas we use 47 pumping plants but we promote water-saving strategies. Indeed, the vision of the consortium is projected toward sustainable goals such as water reuse and resource saving, which is made possible by intense interaction with farmers, and integrated planning targeted at system efficiency and environmental sustainability.

Water surface sources are different:

- rainwater;
- 46 Treatment plants, 7 of which constitute the only source during the irrigation period. Through these we distribute 45 M cubic meters in the irrigation season;
- Po river that fills the C.E.R with 76 M cubic meters;
- Reno River with 7,3 M cubic meters;
- stream Quaderna, Sillaro, ghironda and Lavino with 0,7 M cubic meters.

To achieve our main goal and be as efficient as possible in water distribution we carried out the project "Acqua Virtuosa". The project aims to create a channel of dialogue with local farms in order to be even more efficient in meeting the needs of irrigators.

Also, rationalize water distribution and improve its use by farmers (Irrinet + water balances per district).

This project gives us the possibility to create an internal call center that allows us to receive and make over 1.500 calls per year. In addition, thanks to this project we send 150

messages per year on average for a total of 20.000 messages sent for:extraordinary maintenances:
- irrigation service interruptions
- shifts
- environmental issues
- invitations to events and meetings

in addition an accurate knowledge of irrigation needs allows the creation of district water balances and a water saving system estimated close to 30%.
We are constantly in contact with the farmers to respond to new irrigation development needs. 7 local meetings have already been held (November 2021-March 2022), with over 300 farmers involved, and a telephone survey was launched with over 1.500 owners.
Another important element of sustainability for us is the optimization of water use.
water reuse is of paramount importance, especially in the current water emergency situation, where water is becoming increasingly scarce.
For this reason, we are engaged in Monitoring the quantity and quality of water treated by 8 treatment plants Sharing flow and volume data, and Sharing an alert system on plant failures.

We are also engaged in environmental activities. We operate for sustainable agricultural production, wetlands management and tourist promotion and biodiversity protection in direct farming and manage protected areas.
The effects of the environmental activities of the consortium are:
- The exercise of better quality agriculture;
- The return of water resources to the natural cycle, without purification costs;
- The continuous and widespread recharge of the water table
- The dilution and phytodepuration, through the passage of water in grassed canals, of any effluent from urban sewage and first rainwater;
- The maintenance of the natural agro-ecosystem: flora and fauna connected to the canals and reservoirs;
- The preservation of the historical rural landscape, with the permanence of traditional irrigated crops;
- The presence of vital agriculture in the territory, a fundamental element of social stability and soil conservation;
- Combating the phenomenon of subsidence through the presence of a network of permanently replenished canals;
- Regulation of the local microclimate and reduction of the urban heat island effect.