Chapter 8

MONITORING CROP GROWTH AND DEVELOPMENT THROUGH THE USE OF CLIMATE INFORMATION FROM AUTOMATIC WEATHER STATIONS

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1. Introduction

FAO estimates that food production must increase by at least 60 percent to respond to the demand of the 9 billion people that are expected to inhabit the planet by 2050. Today, the agriculture sector is under a continuous pressure to deliver more in order to meet the increasing demand for food production and accessibility to food. Growers are required to increase the agriculture production, with similar or lower inputs for crop production. Ensuring the food security with fewer resources is becoming an even greater challenge for agriculture sector [6].

The agriculture production demand challenges will be exacerbated by projected climate change and an expected increase in extreme weather events. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), rising temperatures and increased frequency of extreme events will have direct and negative impacts on crops, livestock, forestry, fisheries and aquaculture productivity [6].

Monitoring the environmental parameters and their impact on the crop production is the first step of developing a sustainable agricultural productivity and adapted to climate change. The automated phytoclimate monitoring systems presented in the current paper is an efficient tool for farmers to achieve the goal of growing more food with fewer resources. The system presented makes use of most advanced technologies available today and it puts together sensors to collect data about the environment and crops and the power of internet for computing and making the information available from anywhere [1, 2, 3] (Figure 1).

All the data collected by the sensors in the field is then processed centrally and through specialized software, the information is presented into practical solutions that support the farmer in planning and execution of his/her daily operations.

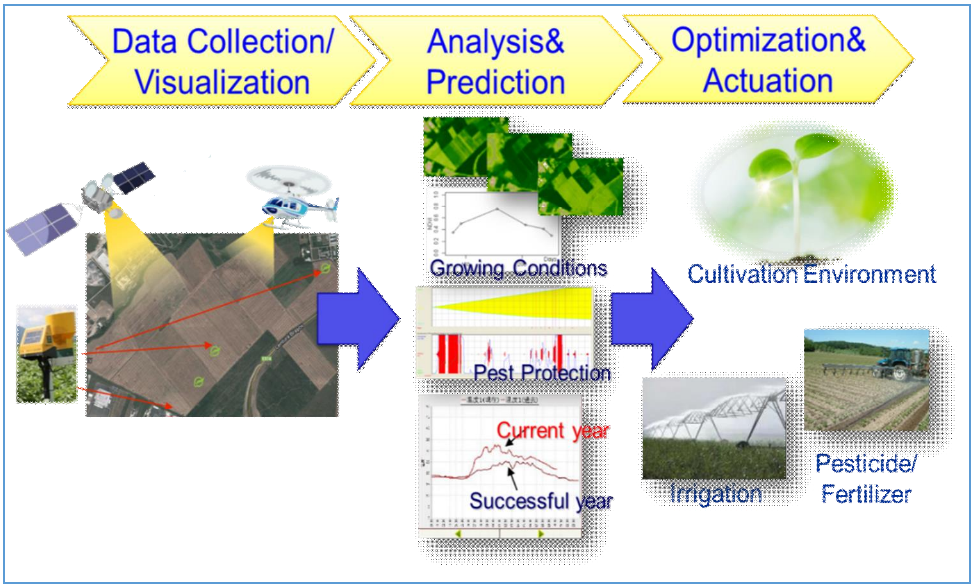


Fig. 1. *Climate information system overview*

It has been proved though the years that for a farming system to reach the economic optimal, precision timing and using the right products is critical. The aim of the system is to integrate multiple aspects of the crop development (e.g. soil, water, chemicals, fertilizer, plant development) into the crop dynamic models to achieve the maximum yield possible.

Continuous tracking of phytoclimate conditions has become very important to areas like improved management of crops and promotion of precision farming. Challenges are the real-time collection of reliable crop environment information and methods for adaptation of these innovative systems by farmers to change from traditional practices to new methods.

2. Material and Methods (System Presentation)

2.1. Sensors

Monitoring the environmental conditions from the fields in real-time are important for an agriculture management system. For the system presented in the current paper, we are collecting data about the weather and soil through weather stations and soil moisture stations. Due to the constant exposure of the sensors to all kinds of climatic conditions, the sensors are implementing a constant validation mechanism to insure that the data collected is accurate.

The system presented in the current paper may handle various data collection points with multiple sensors. Specific for this paper, we are using only two types of sensors, weather station and soil moisture station, and from those sensors we are collecting information from the field regarding: soil moisture content, rainfall, solar radiation, wind speed and wind direction, temperature and relative humidity. Raw data is collected through telemetry (see the sensors specs) and then is sent via a wireless GPRS/3G connection to a central server to be stored and further processed. The central server is hosted in could and it can be accessed from everywhere through a browser or/and dedicated application to visualize the data. Further development of more intelligent sensors and make them available for every farmer (including family farmers) are one of the challenges that lay ahead [4, 5].

WEATHER STATION. The complete Weather Station automatically collect and transmit a multitude of parameters in a flexible setup (Table 1 and Fig. 2). Parameters like; temperature, relative humidity, rain, wind speed, wind direction and solar radiation. The weather stations are solar powered and data is transmitted via GPRS/3G through the integrated Sensor Gateway (DSG).

Table 1. *Main characteristics of Combi Sensor*

Sensor Type	SDI-12 Standard V 1.3
Supply Voltage	6 -16 V
Air temperature	-40°C ... +85°C
Accuracy	+/- 0.2°C @ 5 - 60°C, max +/- 1°C @ -40 - 5°C
Relative Humidity	0 - 100%
Accuracy	+/- 1.8% @ 10 - 90% RH
Rain gauge	
Resolution	0.2mm
Orifice	200cm^2
Accuracy	+/-1%
Capacity	2.4 mm
Pyranometer (Solar Radiation)	
Sensing element	Silicium
Sensitivity	100 εV/Wm²
Spectral range	400 ï 1100 nm
Max. Irradiance	2000 W/m

Temp. dep of sensivity	+/- 0.15%/°C
Operating temp.	-30°C - +70°C
Wind Combi	
Wind Speed	0.6 ï 55.6 m/s (2.2 ï 200 km/h)
Linearity	+/- 0.3m/s & +/- 2% rdg @20°C
Onset speed	0.6 m/s (2.2 km/h)
Operating temp.	-30°C - 65°C
Wind Direction	0° - 360°
Measuring unit	Potentiometer
Linearity	+/- 1%
Dead angle	3° +/- 1°
Switch over point	North
Onset speed	0.6 m/s (2.2 km/h)

Fig. 2: *Weather Station*

Soil Moisture Station. The Soil Moisture Station consists of a measuring unit and a soil moisture sensor that reads at multiple depths (every 10 cm) the amount of water content of the soil (Table 2 and Figure 3). It measures the soil temperature. This information is combined with a rain gauge that measures both rain and/or irrigation. The stations are solar powered and transmit data via GPRS/3G through the integrated Sensor Gateway (DSG).

Table 2. *Characteristics of Soil Moisture Sensor*

Measuring range	
Measuring range	0-100% Vol
Temperature	-20°C ... +60°C
Measuring method	HF Capacitance, 100 MHz
Accuracy when calibrated	+/- 1%
Interface	SDI-12
Lengths	60
Number of sensors	On every 10cm
Number of temp. sensors	2 or 3
Power supply	5.5 ... 12 VDC
Rain gauge	
Resolution	0.2 mm
Orifice	200 cm^2
Accuracy	+/-1%
Capacity	2.4 mm

Fig. 3: *Soil Moisture Station*

SENSOR GATEWAY (DSG). The Sensor Gateway is developed and built in The Netherlands by Dacom using the latest electronic technology (Table 3 and Figure 4). It is a modular system with a highly flexible set up. Communication takes place through the networks that are available locally such as GPRS and RF. The stylish housing is tailor made and exists of durable, waterproof and UV resistant material. An integrated solar panel provides the energy.

Table 3. *Main characteristics of DSG*

Dimensions:	180 x 180 x 105mm (w x h x d)
Weight:	910 g
Protection type:	IP62
Energy supply:	4V 5AH rechargeable lead battery Solar panel External power supply (optional)
Input/Output:	1 or 2 multi-channel I/Oĉs 1 counter input 1 digital channel (SDI-12) 3 analog channels
Connectors:	Waterproof binder connectors
Sampling interval:	Every 15 minutes (adjustable)
Communication	Quad band GPRS module
Temperature range:	-30°C to +60°C

Fig. 4: *Sensor Gateway (DSG)*

2.2. Models and Software Application

All the information gathered and the outcome of the data processed is presented to the farmer by specialized software applications to simple user interface and grouped in functional solutions. On top of data presentation, the application plays another critical role for farms: crop recording. With the crop recording facility, the farmer is able to log information about crops field location (GPS coordinated and boundary), crop variety, activities (e.g. crop protection, fertilization), crop development observations and yield information. Currently, the crop recording data are entered manually, but the application could be extended further and other type of inputs are being sought, like remote sensing techniques (e.g. vegetative state of the crop) and computer vision (e.g. crop growth).

Besides the technology the system presented in the current paper combine their experience in the field of measuring and modelling. We presented above the tools used for measuring, like sensors and manual input. Modelling is a key component of the system presented in the current paper and the models developed on domain specific scientific knowledge. Those complex models are the core of the system and are integrated into the application as algorithms. Based on the farmerȏs input and the models used by the system are permanently evaluated and adjusted in order to provide the best solution for the farmer in an ever changing environment.

The farmer interaction with the system is done through a simple interface, available on multiple devices such as laptop, table or/and smartphone. In this way, the farmers has access to latest scientific knowledge and it shortens adoption of the new discoveries by the farmers (Figure 5).

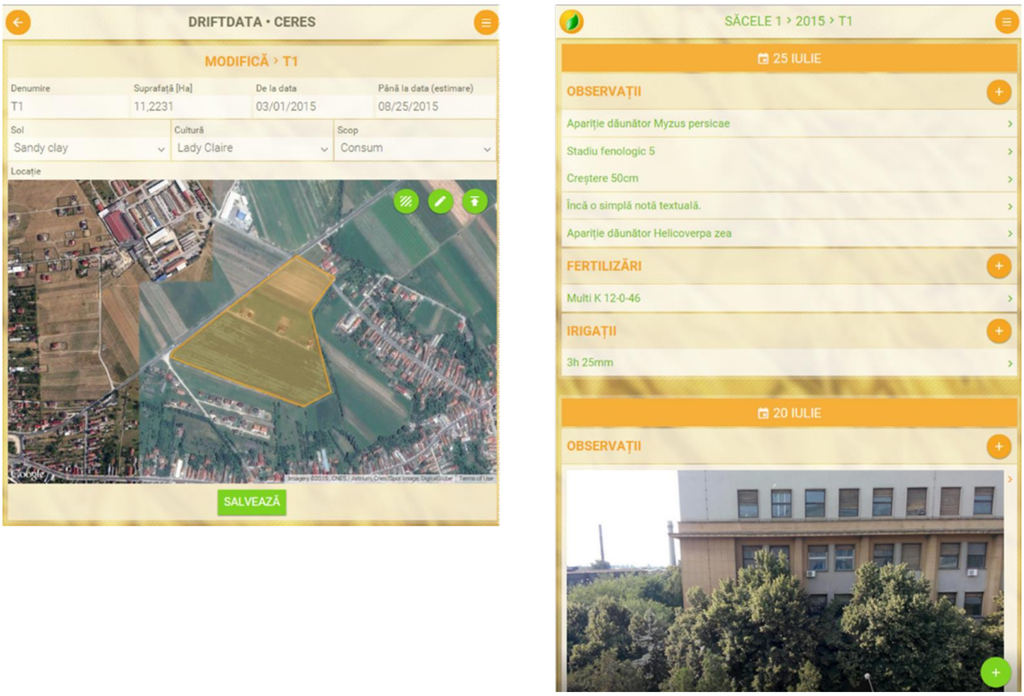


Fig. 5: *Crop recoding application interface*

A computer must be able to connect to the internet. The software shows the data from the stations on your computer. The basic software consists of crop recording which can be extended with the weather forecast for your farm location, disease modeling and irrigation modeling.

2.3. Operating Mode

<u>Weather Data Collection</u>. In the continuously changing climate environment, growers can continuously monitor an adapt production throughout the growing season. With the automated water stations, the grower is able to continuously monitor the vegetation condition and microclimate of plants and, as well as other crop factors (Figure 6).

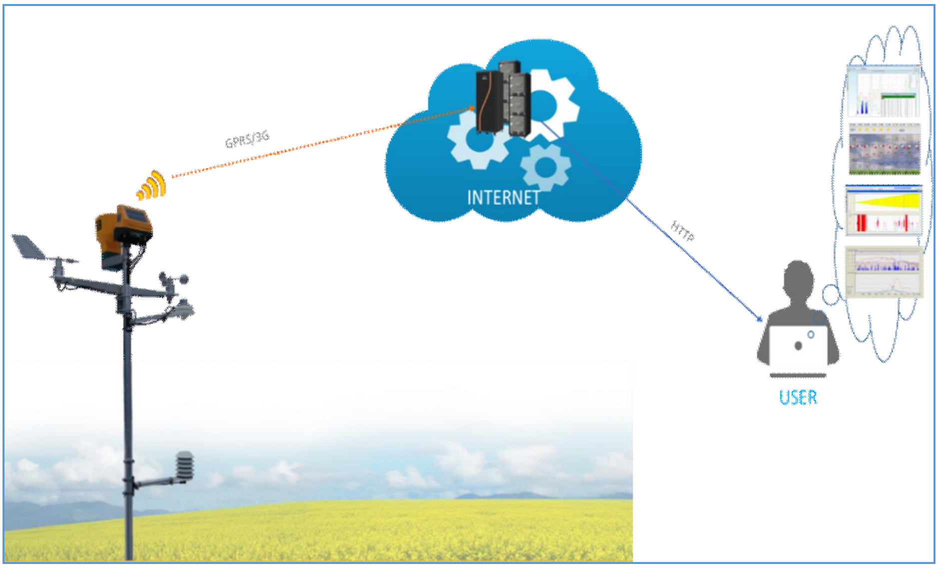


Fig. 6: *A general overview of the automated weather station operation*

The data is collected by each sensor from the weather station continuously and it is sent hourly to the central server via a wireless network (GPRS/3G). The weather data that will be collected are temperature, relative humidity, rain, wind speed and wind direction and solar radiation. This information is available for the grower and/or his consultant or other nominated parties. The software presents the data in convenient format (charts and tables) for easy visualization and further analysis. In addition, the system is informed by and extremely accurate 10 day weather prediction. With these parameters disease models can be calculated and the grower can be advised to treat their crop on the right time with the right product.

IRRIGATION MANAGEMENT. Next to nutrient application, water is one of the most important factors that a farmer may influence during crop growth and it is essential in achieving sustainable increasing yield. Using a soil moisture sensor in the growerǿs field, the Irrigation Management System shows the hour and daily water consumption of the crop in the carious layers of the soil. These data together with the weather forecast help to determine the optimum moment for irrigation. This prevents damage due to both drought and excessive watering. Another advantage of optimum irrigation is crop quality improvement.

This solution is based on the sensors presented above and is a combination of the following features (Figure 7):

- Soil Moisture Station to measure the soil moisture and soil temperature.
- Sensor Gateway (DSG) for data transfer from the sensor.
- Irrigation module with one week irrigation forecast.

- Control system for irrigation systems (e.g. pivot, drip, etc.) and pumps.

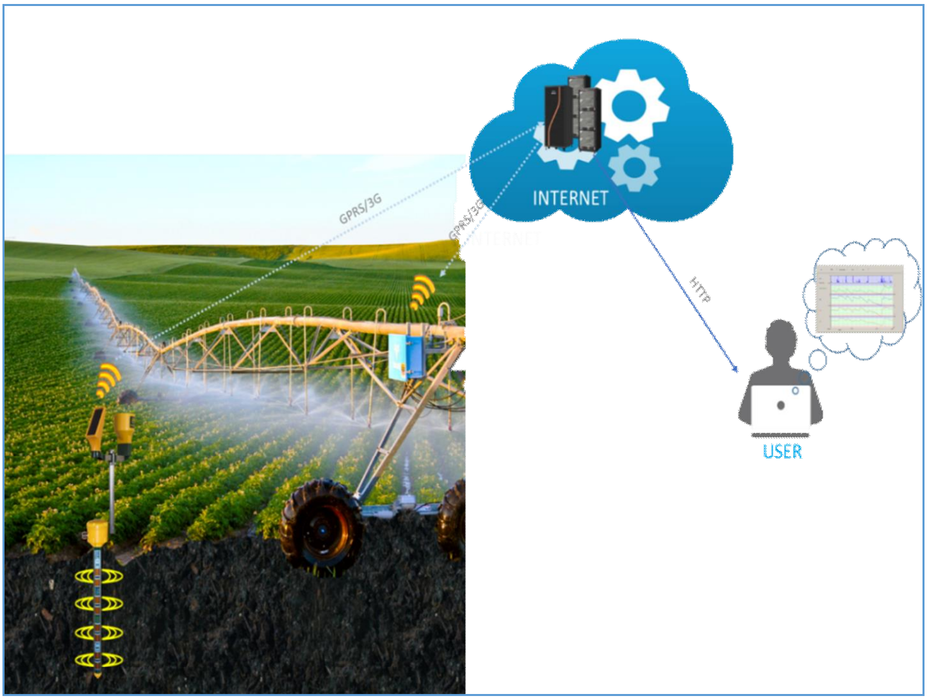


Fig. 7: *A general overview of the system operation*

The data measured by the Soil Moisture Station are sent to the central server via a wireless network (GPRS/3G). This information is available for the grower and/or his consultant or other nominated parties. The software presents the data in convenient format (charts and tables) for easy visualization. Based on the current crop water usage and the weather forecast, the water requirements for the following days are calculated and the irrigation planning is updated.

This irrigation planning will be downloaded to the irrigation system at the next connection to the central server for updates.

3. Results

Progress in quality, reliability and diversification of contact and remote sensing sensors for monitoring soil resources, vegetation condition and microclimate of plants and crop, allow precision management efficiency and environment friendly for:

- phenotype selection of the new varieties adapted to changing conditions (precision breeding) and
- improvement of the crop production management (precision farming)

In the current paper we will cover only aspects related to plats and crop phytoclimate conditions at NIRDPSB, specifically for potato crop. Continuous tracking of microclimate conditions has become very important to areas like improved management of crops and promotion of precision farming. The model is based on monitoring data destined for the phytoclimate (minimum and maximum air temperature, soil temperature, solar radiation, the relative humidity of the air, soil moisture dynamics, wind speed and direction, evapotranspiration potential, etc.) and accumulation over time.

This paper presents a computational model of browsing phenology phases of plant growth and potato crop phytoclimate using data from automatic weather station. Presenting the accumulation growing degree-days dynamics in correlation with the main phenology growth stages for potato plant.

As a general overview, we may notice several differences between the year 2014 and year 2015 (Table 4). It is clear that year 2015 was warmer compared with year 2014 (φ Tmean_Air =1.65°C) and with lower precipitations, both in absolute amount (φ Precipitations =-94.4mm) and water deficit (45.22mm in 2014 and 202.95mm in 2015). A snapshot is presented in Table 4.

Looking at the potato crop growth and development in Brasov based on the phytoclimate data collected from the automated weather station, we may notice some changes related to the duration of the phenology stages for the potato plants and crop (Figure 8 and 9).

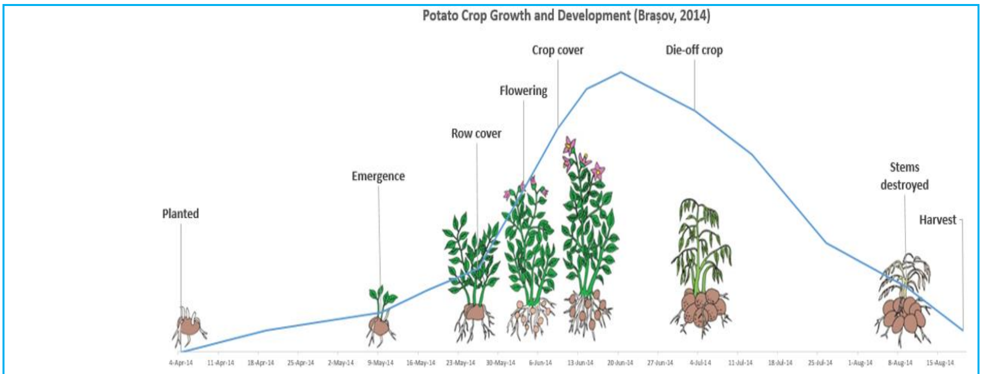
By making a high-level comparison year-over-year for the main growth periods, specific ñPlanted-Emergenceò and ñEmergence ï Stems Destroyedò, in summary we observed that:

A. *Growth period "Planted-Emergence":*

a) From duration perspective, it was with 10% longer in 2015 compared with 2014 (39 days in 2015 vs. 35 days in 2014).

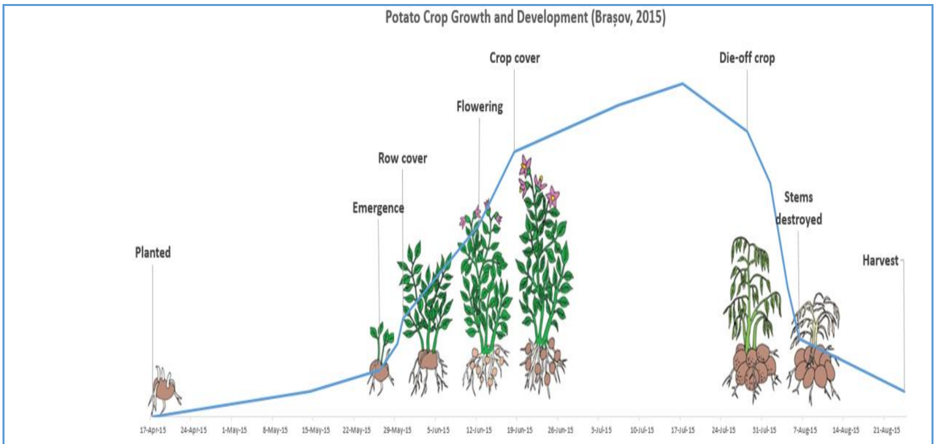
Table 4: Comparison of general climate condition in Brasov in 2014 and 2015

	Year 2014	Year 2015
No of Days	137	129
Tmean_Air (°C)	15.8	17.4
Tmax_Air (°C)	32.8	34.5
Tmin_Air (°C)	0.1	-3.7
Tmean_Soil (°C)	16.25	17.98
Σ Precipitation (mm)	399.10	304.70
Σ Solar Radiation (kW/m2)	891.82	944.60
Σ ET0 (mm)	444.32	507.65
Σ GDD1	1606.30	1364.20
Σ GDD2	870.30	788.20
Σ Solar Radiation Vegetation (kW/m2)	663.08	557.99
No of Dew Points	15	2



Date	4-Apr-14	9-May-14	3-Jun-14	9-Jun-14		3-Jul-14	9-Aug-14	19-Aug-14
Growth Period (cummulative phenological stages)	Planted - Emergence	Emergence - Flowering						
		Emergence - Crop cover						
		Emergence - Die-off crop						
		Emergence - Stems destroyed						
Duration (cummulative days)	35 (Σ=35)	25 (Σ=60)		6 Σ=66)	24 (Σ=90)	37 (Σ=127)		10 (Σ=137)
Tmean_Air (°C)	9.8	17.5						20.5
Tmean_Soil (°C)	10.9	17.9						19.4
No of days with Dew Point	12	3						0
Σ Precipitations (mm)	118.1	255.2						25.8
Σ ET0 (mm)	65.1	332.8						46.5
Σ Solar Radiation (kW/m2)	n/a	663.1						n/a
Σ GDD1	n/a	1606.3						n/a
Σ GDD2	n/a	870.3						n/a
No of days with Tmean_Air < 8°C	32	8						n/a
No of days with Tmean_Air > 28°C	0	10						n/a

Fig. 8: Year 2014 - Potato Crop



Date	17-Apr-15	26-May-15	12-Jun-15	18-Jun-15		28-Jul-15	6-Aug-15	24-Aug-15
Growth Period (cummulative phenological stages)	Planted - Emergence	Emergence - Flowering						
		Emergence - Crop cover						
		Emergence - Die-off crop						
		Emergence - Stems destroyed						
Duration (cummulative days)	39 (Σ=39)	17 (Σ=56)		6 (Σ=62)	40 (Σ=102)	9 (Σ=111)		18 (Σ=129)
Tmean_Air (°C)	13.7	18.9						19.2
Tmean_Soil (°C)	12.6	19.6						22.6
No of days with Dew Point	1	1						0
Σ Precipitations (mm)	53.4	231.8						19.5
Σ ET0 (mm)	132.0	297.1						78.6
Σ Solar Radiation (kW/m2)	n/a	558.0						n/a
Σ GDD1	n/a	1364.2						n/a
Σ GDD2	n/a	788.2						n/a
No of days with Tmean_Air < 8°C	18	10						n/a
No of days with Tmean_Air > 28°C	1	24						n/a

Fig. 9: *Year 2015 - Potato Crop*

b) The mean temperatures for air and soil surface were higher in year 2015 vs. year 2014 with a 3.9°C in air, respectively 1.7°C at the soil surface.

c) The accumulated precipitations were higher in year 2014 compared with 2015 with the amount of 64.7mm.

d) The deficit of water for the crop, calculated as the difference between the accumulated precipitations and potential evapotranspiration (ET0), was negative in 2015 and it was in amount of -78.6mm vs. 53mm in 2014.

B. *Growth period "Emergence – Stems Destroyed":*

a) The duration of the growth period was with 20% shorter in 2015 compared with 2014 (72 days in 2015 vs. 92 days in 2014).

b) The average mean temperatures for the period were higher in 2015 with approximatively 1°C compared with 2014.

c) The accumulated precipitations was slightly higher in year 2014 compared with 2015 with the amount of 23.4mm.

d) The deficit of water for the crop, calculated as the difference between the accumulated precipitations and potential evapotranspiration (ET0), was negative in both years (-77.6mm in2 2014 and -65.3mm in 2015). At the end of the period, the deficit of water for the crop was -24.6mm in 2014, respectively -143.9mm in 2015.

e) Both the accumulated Growing Degree-Day (GDD) and accumulated solar radiation were higher in 2014 and mainly it is due to the longer duration of the period.

f) In 2015 we observed a significant bigger number of days when the plant was in stress due to days with temperature lower than 8°C or higher than 28°C. Specific, in 2015 we observed a number of 34 days when the plant was in thermic stress (vs. 18 day in 2014), 10 days with air temperature lower than 8°C (vs. 8 in 2014) and 24 days with air temperature higher than 28°C (vs. 10 in 2014).

Base on the phytoclimate data collected for the potato crop, we may conclude that:

1. The duration of the growth period ñPlanted - Emergenceò is directly affected by (i) the amount of accumulates precipitations, (ii) deficit of water for the crop has to have a positive and (iii) the mean temperatures (both air and soil) has to be above T_{base} (8°C). The impact that as long as the potato seeds are staying in soil and are not emerging, this may have a negative impact on the future crop development.

2. The vegetation period (growth period ñ*Emergence – Stems Destroyed*ò) is affected negatively by (i) the number of days when the plant is thermic stress, (ii) the amount of accumulates precipitations and (iii) deficit of water for the crop. Due to the factors mentioned above, the length of the period is shorten and accumulation of GDD and solar radiation is lower and may have a negative impact on the crop yield.

Based on the phytoclimate data collected for the crop with the automated weather station, we are able to make an in-depth analysis of the climate condition on the plants and crop. In the figures below we will present side-by-side a set of microclimate data from weather station during the period ñEmergence - Stems destroyedò for years 2014 and 2015 (Figure 10, 11, 12, 13 and 14):

2014 *2015*

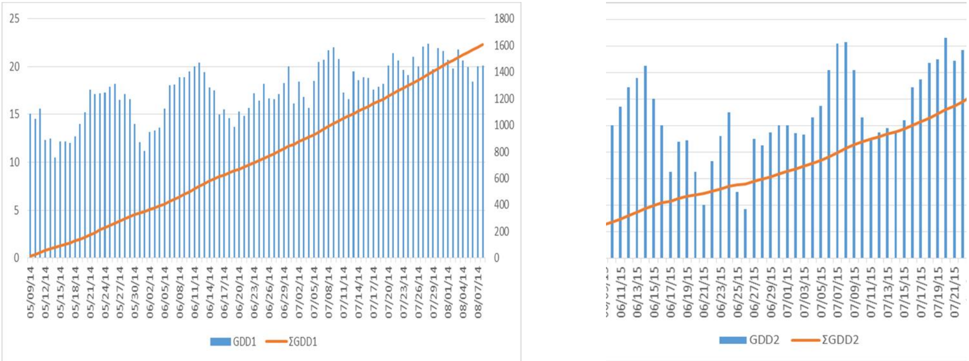


Fig 10. Growing Degree-Day

2014 *2015*

Fig. 11. Solar Radiation

2014 *2015*

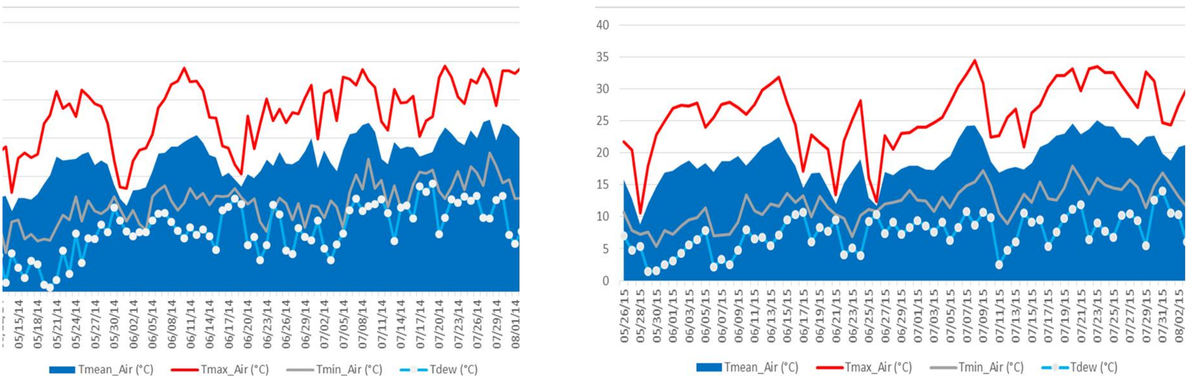


Fig. 12. Air Temperatures: max, min, dew point

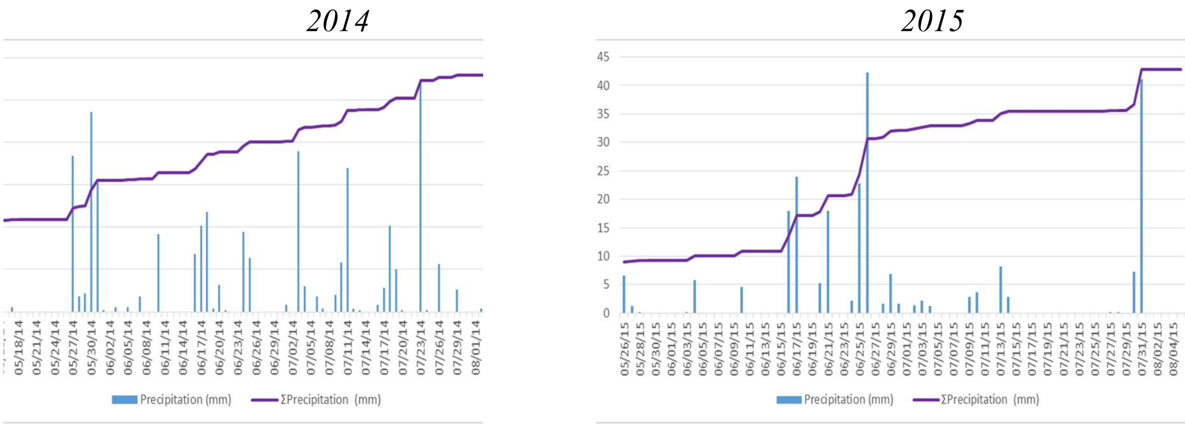


Fig. 13. *Precipitations*

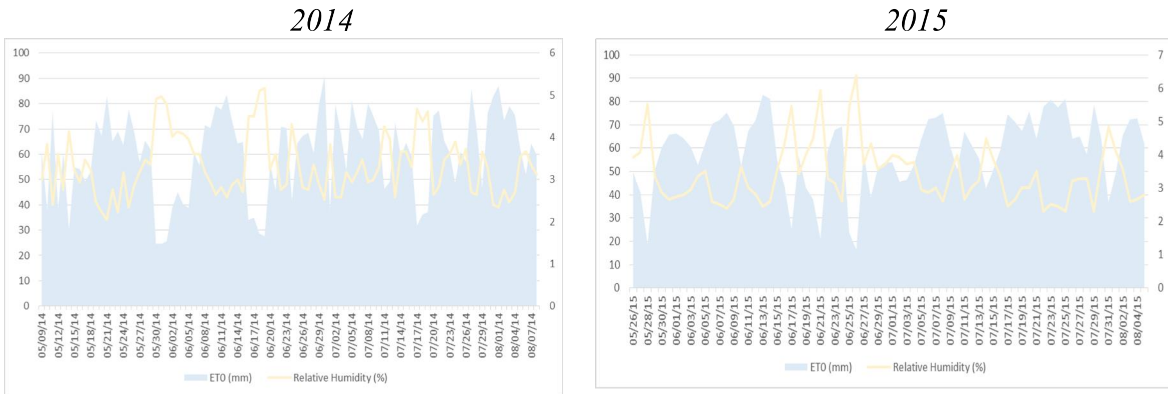


Fig. 14. *Relative Humidity and Evapotranspiration*

The information collected and analyzed could be used further in decision support systems related to precision crop management (phased fertilization, disease and pest control, irrigation, weather and more accurate production optimal timing of harvest).

4. Conclusion: Contribution for Sustainable Agriculture

The challenge for agriculture is to produce more with less and to adapt to the new climate conditions. The system presented in the current paper provides an important contribution towards the future demand for food. Challenges are the real-time collection of reliable crop environment information and methods for adaptation of these innovative systems by farmers to change from traditional practices to new methods.

The system contribution for sustainable agriculture is realized through precision design for the continual farming by continuous analysis of real-time data and providing recommendations:

1. Accurate time and spatial prediction (Figure 15)

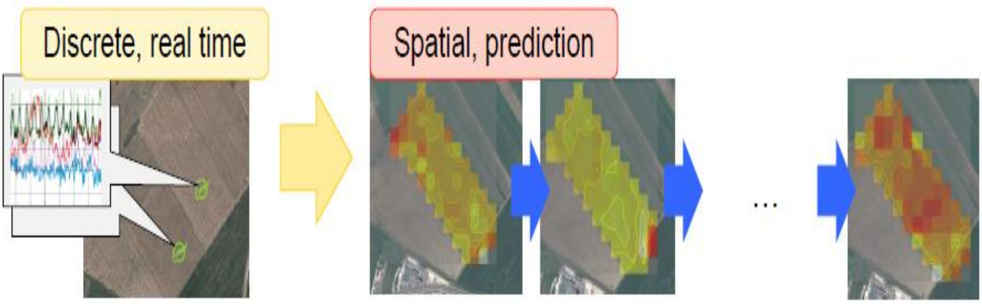


Fig. 15. *Reducing uncertainty by sensed data and sequential validation technique*

2. *Decision support for optimal control (Figure 16)*

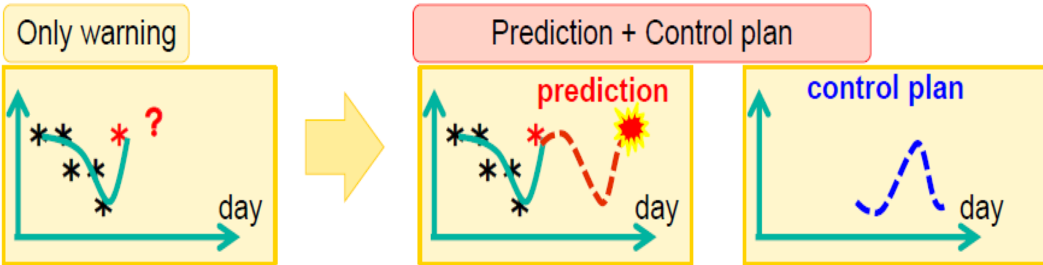


Fig. 16. Estimating and visualizing unobserved factor by theoretical model

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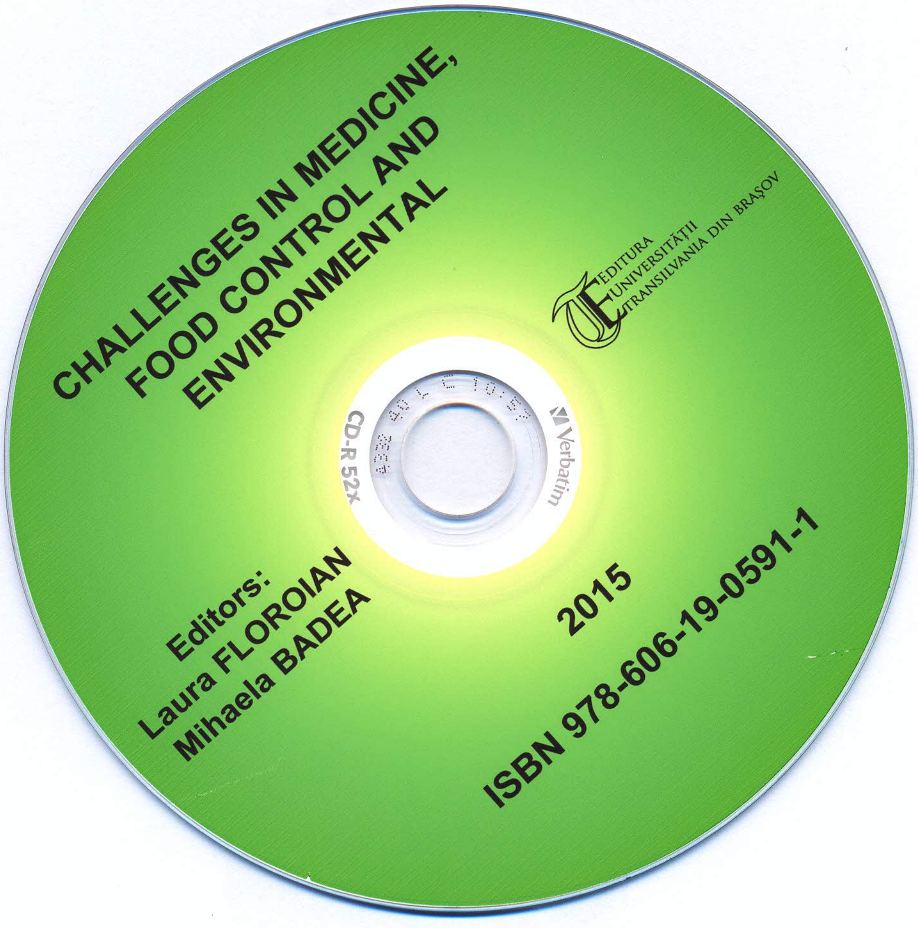
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