

Technological framework for precise management of the system “soil-plants-ground atmosphere”

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Abstract

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Joint remote sensing, synchronous and quasisynchronous ground based studies, combined with GIS technologies for estimation of the state of agricultural lands provide a valuable source of information for precise management of agricultural activities on the field. They constitute a part of the data base used for operation of a number of models for evaluation and forecast of the state of land (soil and vegetation) resources.

Based on satellite images studies from Copernicus Sentinel satellites, simple relations between the water and temperature regimes of soil and vegetation covers and their optic or thermal characteristics are sought. These studies have to be combined with GIS technologies for evaluation of spatial distribution of agricultural land management.

Specialists can be users of continuous flow of satellite imagery and spatial data in the agricultural and the environmental sectors. This requires an active participation of European space-related projects, programmes and initiatives. With their help, the assessment of the status of soil and plant resources is synchronous over time and could provide reliable data and information to Bulgarian ministries and agencies in support of their decision making process, related to the cultivation of the basic agricultural crops on the territory of Bulgaria.

The land tenants, managers of farm associations, agronomists and farmers have to take their responsibility for managing of the technological operations in the system “soil-plant-ground atmosphere”, in order to fulfill the public objective for efficient crop production for obtaining economically viable crop yields, while maintaining and increasing soil fertility.

Keywords: remote sensing; soil; management; GIS and LPIS technologies

Introduction

The search for effective management solutions for the system “soil-plants-ground atmosphere” requires objective information on the soil and crop conditions, the agro-meteorological situation on the field and on the outcomes of the technological operations already carried out. The information needed about the condition of the system – collected through the relevant sensors and measuring devices – includes: (1) evaluation of the condition of some basic soil parameters (humidity, density, temperature, pH, transpiration,

etc.); (2) the state of the crop (togetherness of crop growth, condition and the height of plant cover, evapotranspiration; (3) the state of atmosphere near the surface (temperature, relative humidity, solar radiation, wind speed, radiation balance, etc.), and (4) state of the environment (dew, rime, frost, fires, thermal death of plants, dust storms, radiation pollution, etc.) (Wooding et al., 1993; Ustin et al., 1999; Kolev, 1996; Ilieva-Obretenova, 2015a,b; 2016; Kanev, 2010; Holben et al., 1992; Kolev et al., 2012).

By launching of the constellation of European satellites Sentinel 2 and 3 (ESA-SP-1322/2 and ESA-SP-1322/3,

2012), the Copernicus Programme has provided high-quality images, in the visible and infrared wavelength ranges of the spectrum, as well as data in the microwave range, which allows for the collection of remotely sensed data on agricultural and forest areas. By using crop development models, these images permit the assessment of the condition of crops and plantations at different stages of their development. This technique gives the possibility to estimate the density, humidity and temperature of the soil, as well as the state of the water and nutritional regimes of the plants; and in such a way to predict their development and expected yields well before harvest (Holben & Kimes, 1992 ; Wooding et al., 1993; Mather, 2002; Kolev et al., 2012 ; Kolev & Kozelov, 2015; Karger et al., 2017).

The complexity, diversity and dynamism of the agricultural production system requires the application of different approaches for the evaluation of its properties in the different seasons of the year, for the stages in crop development, and in the different organization of agricultural activity.

The land tenants, managers of farm associations, agronomists and farmers have to take their responsibility for managing of the technological operations in the system “soil-plant-ground atmosphere”, in order to fulfill the public objective for efficient crop production for obtaining economically viable crop yields, while maintaining and increasing soil fertility, as well as meeting the requirements for ecological-friendly plant production and clean environment.

Materials and Methods

Agricultural parcels, subject to agro-physical measurements and technological management, are characterized by the following main features:

- large number of interlinked parameters that characterize the field;
- complexity and cybernetic nature of the system “soil - plants – ground atmosphere”;
- sequential character of the production process during the crop growing season;
- randomness of the stages (pheno-phases) in the crop development and dependence on external influences, including also technological management;
- low pace of conduction of plant development and related technological processes;
- unpredictability of agro-meteorological conditions and plant development factors;
- complexity and implied necessity for correction of the technological management schemes, determined by different number of technological operations;
- simultaneity and continuity of technological processes

- es in the different production areas of the single plot;
- presence of a large number of predictable and unpredictable constraints (organizational, technical, resource-related, production and technological);
- organic link between management regimes in individual production areas due to resource constraints (equipment, people, irrigation water, fertilizers, etc.).

The intuition and experience of farmers and agronomists are not sufficient to assess objectively the state of the system “soil - plants - ground atmosphere” in agricultural parcels. They must obtain quantitative information on a number of its characteristic properties, such as soil moisture and temperature, evapotranspiration, photosynthesis, respiration, etc. The question is not just to measure one or more parameters over a long period of time, but also to perform specific calculation to obtain the values of its constituent properties for the purpose of modeling and the management of the production processes.

However, it is imperative to use computerized agrometeorological systems to perform an integrated assessment of evapotranspiration E from a unit of agricultural area, using the method of energy balance. The following parameters are measured: radiation balance R_n , net solar radiation R_n ; soil heat flux G_g ; gradients of the air humidity and temperature T and the parameter evapotranspiration E is calculated with the formula (1) (Kolev, 1996 ; Kolev et al, 2012):

$$E = \frac{1}{L} * \frac{R_n - G_g}{\Delta_e + 0.64\Delta T} \quad [W .m^{-2}], \quad (1)$$

where L = specific heat of evaporation of water.

Based on the data on the state of the elements of evapotranspiration, decisions can be made to manage the irrigation process in the field and to combat diseases that are dangerous to crop plants.

An experimental model of a computerized agrometeorological system, designed at the Institute of Soil Science, Agrotechnology and Plant Protection “N. Poushkarov ” includes high-technological and widespread precision sensors and integrated sensor blocks, technical solutions with smart grids and systems with architectures distributed in space and time (Dzamiykov, 2018; Ilieva-Obretenova, 2013, 2015a,b; Mutha et al., 2016; Paul et al., 2018 ; Gerard & Meijer, 2018; Iliev, 2018).

For measuring the temperature, four TMP112 digital temperature sensor (semiconductor type) are used, with an integrated 12 digit ADC and a resolution of 0.0625°C (Texas Instruments, SLOS887, 2015). The accuracy of temperature measurement, according to the manufacturer’s specification, is $\pm 1^\circ\text{C}$ for the entire operating temperature range from

–40°C to 125°C. A method for its improvement, by sensor calibration, is proposed. These temperature sensors allowed the conduction of measurements of the ground air temperature, of the plant leaves and of the soil.

The relative air humidity is measured at two levels above the plant surface (Sapundjiev, 2009). The measuring channels represent HDC1080 digital sensors for relative humidity with a resolution of 0.1%, with an integrated 14-bit ADC temperature sensor having precision of $\pm 4\%$ for the whole measuring range from 0% to 100%. According to the manufacturer’s characteristic, it reaches $\pm 4\%$ for the measuring range from 60% to 100%. The sensor calibration function is provided by the manufacturer, but to improve its performance, the sensor can be calibrated based on control point to eliminate the initial inaccuracy and also the error caused by the aging effects of the polymer at operating temperature from -20°C to $+85^{\circ}\text{C}$ (Texas Instruments, SNAS672A, 2015).

The atmospheric pressure of the ambient air is measured with a digital sensor type BMP180 of piezo-resistive type with a resolution of 0.01hPa at maximum error ± 6.0 hPa for the whole measuring range from 300 to 1100 hPa, and at operating temperatures of -20°C to 65°C (Mutha et al., 2015).

Although the wind speed is a vector with three-dimensional components, winds at the surface could be regarded as a vector with two-dimensional components according to the guidelines of the World Meteorological Organization (Iliev et al., 2017). This allows to use the well-known cup anemometer sensor with a digital output.

The solar radiation is a characteristic representing the power, received from the sun on a given area and is measured in watts per square meter (W/m^2). The radiation balance is the net solar radiation, which is measured with two pyranometers connected as a battery. A bolometer with analog output is used to estimate the soil heat flux G (W/mm) (Kolev, 1996).

Many of the described sensors are built as separate measurement channels, ready for connection via a standard interface to a holistic system of data collection.

Depending on the purpose of the measurements and the rate of data collection, the designed field agro-meteorological measurement systems can be divided in two categories - real-time continuous measurement systems and systems for express measurements. Their structures are modular and are organized according to the tasks they need to perform (Kolev et al, 2012; Mutha 2016).

Data from the computerized measuring systems and development models of the main agricultural crops could be used to predict the development of plants and the expected yield, before the end of the crop growing season (Baret et al., 1993; Banari et al., 1995).

Results and Discussion

Aerospace technologies provide images of the objects “fixed” on the ground (fields, orchards, grasslands, forests) and allow the assessment of the individual crops and grass covers through their basic color shades in those cases when they are clearly distinct (from saturated green to yellow). This allows the performance of an accurate detection of the type of crops and plantations and the stage of their development. The images in the visible and infrared spectrums, as well as those in the microwave range allow the discrimination of the different types of crops, planting and conditions, whether they are sown or selfseed (Carter, 1994; Banari et al., 1995). These technologies could support the estimation of soil density, humidity and temperature, as well as the state of the aquatic and nutritional regimes of the plants, and consequently, could predict their development and expected yields, well before harvest (Holben & Kimes, 1986; Banari et al., 1995).

As the observable objects are of complex and mixed nature, including soil, cultivated vegetation (continuous and in rows) and weed vegetation, including trees, thorns and shrubs, it is necessary to carry out synchronous and quasi-synchronous terrestrial agronomic observations and agrophysical measurements on a representative sample of agricultural plots. Then, we can be sure of the reliability of the data from the airborne or spaceborne instruments, including the accuracy of its georeferencing to the relevant plots concerned (Wooding et al., 1993; Kolev & Kozelov, 2015).

Bulgaria has established a national network of test sites for in-situ observations and measurements in agricultural and forest areas, which could be synchronized and quasi-synchronized with the aerospace monitoring technologies. This network is under development and improvement and is aligned with the geographic distribution of the scientific institutes and experimental stations of the Agricultural Academy.

Agrophysical in-situ measurements provide data for the estimation of humidity, temperature, density and heat flux of the soil profile, as well as for the assessment of the microclimatic conditions on the field. These measurements are performed with computerized agrometeorological systems of the type, described above.

The agronomic observations allow the depiction of the landscape situation in the different seasons of the year, the crop growing stages and status, as well as the degree of erosion of agricultural lands. They enable the detection of the nature of weed infestation of agricultural land (annual and perennial weeds), the condition of the soil surface (roughness, structure, density) and the nature of the areas (small,

medium and large agricultural parcels), as well as the condition of the crops.

The use of satellite images and the conduction of synchronous and quasi-synchronous agronomic observations and agrophysical measurements in the test sites located in the agricultural and forest areas is provided by a joint team of the Remote Sensing Application Center (ReSAC) and the Institute of Soil Science, Agrotechnology and Plant Protection. The members of this team:

- Have scientists who are experts in agronomy, phytopathology, agrophysics and agro-ecology and can carry out observations, evaluations and measurements in test sites located in different parts of the country.
- Are owners of databases for the areas within the test sites, containing descriptions of the soil-agrochemical characteristics and vegetative calendars of major crops.
- Have laboratories for soil and agrochemical analysis at the institutes and experimental stations of the Agricultural Academy that are close to the test sites.
- Maintain good research relationships with the teams from the Space Research and Technology Institute at the Bulgarian Academy of Science.
- Have their own mobile laboratories with advanced measuring instruments and trained personnel for carrying out test agrophysical measurements on the field. They comprise parameters of the system “soil-vegetation-ground - atmosphere”, such as: soil humidity and temperature, salinity, pH, density, compactness; temperature of the vegetation cover and leaf area index; components of solar radiation, rain, speed and

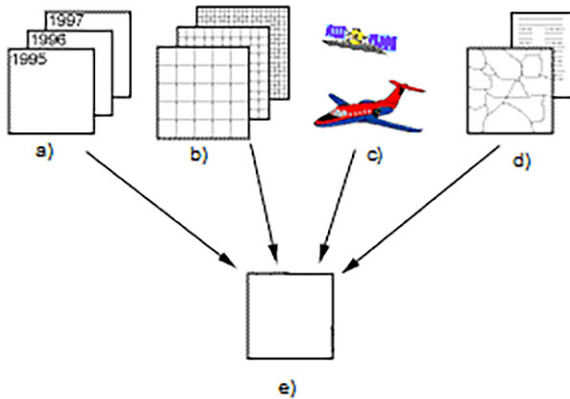


Fig. 1. An integrated system of data flows from various sources: a) land parcels history data; b) field cadastral data; c) remote sensing laboratories; d) land position identification system (LPIS); e) collecting data center

direction of wind, air humidity, soil heat areas and vegetation cover, etc..

Figure 1 shows schematically the structure and technologies to obtain data from aerospace imaging equipment and the supporting GIS infrastructure (hardware and software) for mapping and monitoring of agricultural and forest areas.

In the period from 2018 to 2020, aerial surveying provided orthophoto maps for the needs of the Land Parcel Identification System (LPIS). In addition, the family of Copernicus Sentinel satellites are offering open and free-of-charge multispectral images of high resolution and precedent frequency, with worldwide coverage.

As said before, due to the complex nature of the observable objects, the correct extraction of information from the airborne and spaceborne imagery often requires the provision of in-situ data collected on the field. This data is used for wide range of tasks, such as image calibration, training of classification algorithms and tuning of crop prediction models, and validation of the obtained results.

Figure 2 shows a map with the test sites of Belozem, Bratya Daskalovi and Chirpan from the Plovdiv test polygon, where ground-based agronomic observations of agricultural areas and agro-physical measurements have been carried out with the purpose to verify the spaceborne imagery and data.

Since the soil cover is diverse and the crops are different, and at the different stages of their development, representa-

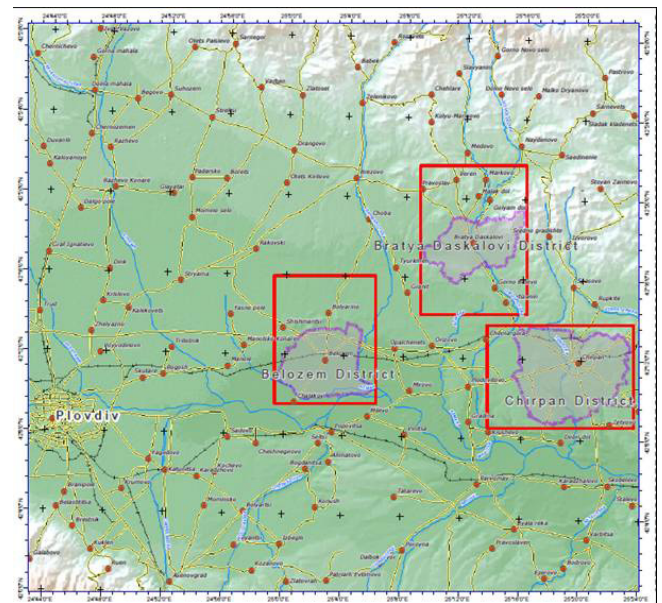


Fig. 2. Map of test sites from Plovdiv polygon



a)



b)



c)

Fig. 3. Mobile measuring equipment for assessment of the basic agrophysical parameters in the agricultural parcels: a) equipment for thermal and radiation measurements; b) complex measuring instrument for soil temperature and humidity and vegetation profiles; c) soil hygrometer and tensiometer

tive locations are selected from the test sites to mount the agro-physical measuring equipment, as shown in Figure 3 for the Belozem test site.

The satellite imagery of the Earth’s surface allows the monitoring of soil moisture and soil temperature on the basis of their spectral reflectance characteristics. In such a way, we could perform an assessment of the current state of crops and plantations in those areas occupied by the main crop types, which will enable a precise control of agricultural production.

Airborne and spaceborne imagery could detect and assess natural disasters related to floods, droughts and fires. Through the use of models, such imagery could allow a holistic assessment of the system “soil - plants - ground atmosphere” (Mather, 2002; Kanev, 2010).

The joint team of ReSAC and ISSAP “N. Poushkarov ” has a state-of-the-art geomatic tools for the organization and integration of the geospatial information: vector data; ortho-photo maps; large-scale topographic and soil maps; maps of agri-ecological areas; maps of the spatial distribution of water sources for irrigation purposes; flood risk maps; maps of soil stock with essential nutrients (nitrogen, phosphorus and potassium); maps of the service transport network between the agricultural parcels.

Using technologies and specialized models, we could assess the risk of flooding of agricultural land and the risk of adverse weather impacts on crops and plantations (frosts, hail, and drought). With their help, the assessment of the state of soil and plant resources is synchronous over time and provides data and information to the relevant users - producers, ministries and agencies - in order to assist them in taking management decisions for precision agriculture applied for the cultivation of major crops, occupying large areas of the Bulgarian territory.

The precise management of agricultural production is achieved when the decisions on:

- management of the production organization are taken on the basis of information from the cadastre of agricultural lands, on the ownership and condition of agricultural lands, on the available human and financial resources, as well as mechanization, on the accessible road network and transport, on the existing water distribution system and water;
- production process management are based on objective data and information on the state of the system “soil- surface – ground atmosphere”;
- environmental assessment, production unit capabilities, and risks are taken on the basis of information and data on climate, natural events and disasters.

There are further important considerations, such as:

- using the experience of advanced agricultural countries with operational systems for precision agriculture and sustainable links between the scientific community and farmers with the capabilities and approach towards the management of agricultural production;
- implementation of a consolidated state policy at national and regional levels and of ‘good practices’ at local level for a balanced management of processes for the benefit of present and future generations;
- development and implementation of possible measures for: limiting and overcoming the adverse effects of degradation of land resources; reducing the impact of climate change; sustainable use of resources through integrated land use planning;
- defined in such a way, the land use provides a direct link between land resources and human activities in the context of the particular environment, with sustainable production management tailored to the specific location;
- production efficiency is achieved with a great soil diversity and with monitoring and suppression of eventual degradation processes;
- the use of agricultural land is socially acceptable and account for elements such as food security, work availability and income in rural areas.

Conclusion

The limited use of fertilizers, irrigation water and chemicals, requires an objective instrumental-based assessment of the basic properties of the system “soil-plant-ground atmosphere” that helps the optimization of technological processes on the field. This justifies the use of hierarchical information-measuring systems, which ensures the improvement of technological management and precision agriculture.

We can be users of continuous flow of satellite imagery and spatial data in the agricultural and the environmental sectors.

Having data from Sentinel satellite images agronomy observations and in situ measurements the specialists can monitor the dynamics of the processes in the fields.

This requires our active participation of European space-related projects, programmes and initiatives. With their help, the assessment of the status of soil and plant resources is synchronous over time and could provide re-

liable data and information to Bulgarian ministries and agencies in support of their decision making process, related to the cultivation of the basic agricultural crops on the territory of Bulgaria.

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