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Abstract. The article deals with the questions of application and functioning of automated weather stations in agriculture. Digitalization of agriculture can significantly increase the efficiency of production and reduce the cost of manufacturing products by obtaining and accumulating information about the ongoing technological processes and making appropriate management decisions. A huge role is given to the possibility of obtaining operational data on the level of soil moisture reserves, the prevailing meteorological conditions, etc. in real time. The use of automated meteorological stations makes it possible to obtain data that can be used in the management of operations, requiring control and monitoring. This paper discusses the application and operation of automated meteorological stations in agriculture, and provides an analysis of the operation of the Davis Vantage Pro 2, Sokol-M and Meteobot® Pro weather stations in Krasnogvardeisky, Belogorsky and Saky regions. The analysis of weather station configurations, sensor installation methods, measurement accuracy, and more is made. The measured data was evaluated with the data, obtained from the weather stations of the WMO network. The prospects of further use of automated weather stations in agricultural monitoring tasks are considered.

1. Introduction

Currently there are state programs for agriculture digitalization. Digitalization is a key factor in improving productivity and reducing costs in agricultural production [1-3]. One of the most important factors of digitalization, according to scientists, is obtaining meteorological data from automated local stations [4]. The possibilities of such meteorological systems include measuring a number of indicators, which issue information about the possible development of harmful organisms at specific plot [5].

Weather data are relevant to all agricultural producers. Working with data allows to plan sowing and harvesting, fertilization, measures to protect against insects and weed plants, etc. These data can be obtained online when installing automated meteorological station in the fields.

For example, in the Republic of Kazakhstan, meteorological stations are actively used within the framework of the State Program on the Agro-industrial complex Digitalization in demonstration agricultural parks. The use of digital technologies allows increasing productivity several times [6]. The authors describe the experience of using Sokol-M weather station at demonstration plots of the North Kazakhstan Agricultural Experimental Station. Therefore, they note an increase in the yield predictability through the introduction of innovative technologies in the economy [7].

In the research institutions of the Russian Federation automated meteorological stations are tested and used for various purposes. Therefore, the employees of the Siberian Research Institute of Mechanization and Electrification of Agriculture use automatic meteorological station as part of technical system that controls the provision of plants with mineral nutrition and water. It is installed on the territory of the institute greenhouse complex and transmits data on the environment and soil state, so, it is integral part of grown vegetable crops phytomonitoring [8].

Automated meteorological station Davis Vantage Pro 2 was installed on the territory of production base «Krasnaya Slavyanka» of the Institute of Agroengineering and Environmental Problems of Agricultural Production, which allows analyzing meteorological processes and determining the patterns of weather influence on plants growth [9]. At the experimental fields of FSBI «ASC Donskoy» in the Rostov region, the Watch Dog weather station with remote sensors was used for the purposes of determining and comparing the effect of soil processing techniques on the soil temperature at various levels [10].

Employees of SSU AIM of RAS offer to use automated meteorological stations in combination with phytomonitors in the system of automated control of growing garden crops production processes. Such a system issues forecast data on the future crop, produces management decisions on the agricultural activities, etc. [11].

At the Energy Faculty of Irkutsk SAU, a prototype of automatic field agro meteostation, measuring the main parameters of soil and environment, for the purposes of meteorological phenomena forecast. Meteorological station was established in the fields of the Irkutsk district and receive data on the «People's Monitoring» service, where, due to analysis result, identify the probability of frost occurrence [12]. Based on the Samara State Agricultural Academy, «System of Intellectual Monitoring and Forecasting» has been developed. The complex includes an automated meteorological station, connected to it wireless sensors and web-platform, accumulating all data. Such complex allows predicting the emergence and development of diseases and pests, determine the most favorable time to make fertilizers, predict the best time of sowing and harvesting [13].

Employees Julius Kyun Institute of the Federal Research Center of Cultural Plants in Germany for 10 years collected data from automated meteorological station, located on experimental fields, after which they compared them with the nearest meteorological service of the Meteorological service of Germany. Comparison showed the advantage of automated meteorological stations in the output of data at an hour interval, which allows agricultural producers to more accurately planning field activities [14]. University of Kisaiy staff uses 2 automated PRO AcuRite meteorological stations to track wind gusts in the Mountain Terrain of Kisaiy district, Kenya, at different heights. Weather station transmit hourly data to the server, where they are processed and output the average daily values of the wind speed [15].

Scientists from the University of Covenanta, Nigeria, solved the problem of access of African farmers to short-term meteorological data by creating an automated meteorological station with connected sensors. Meteorological station reduced the cost of obtaining weather information, providing information to users via mobile communications. Such approach can effectively provide food security in arid and semi-sore African countries [16].

Employees of Indian Autonomous Engineering College at the University of Rashtrasanta Tukadodji Maharaja Nagpur developed a similar system. Such system focuses on monitoring and clarifying meteorological parameters using sensors and provides farmers with all necessary recommendations for agricultural planning in accordance with weather conditions by SMS-informing [17].

In Joint International University of Bangladesh a portable meteorological station was developed for reading data on temperature and humidity, UV radiation, atmospheric pressure, soil moisture, etc. The weather station, taking into account the different seasonal weather in the country, accurately measures all the parameters, based on the local weather condition [18]. Their colleagues from the State Engineering University of Khulna have developed a similar weather station for farmers with the possibility of accumulating and exchanging data between the station and the end user through Web-service and Internet [19].

Thus, the use of automated meteorological stations for agricultural purposes is studied in various countries, both technological means for collecting information and informational data processing systems and visualization are developed.

2. Materials and Methods

FSBSI «RIA of Crimea» collects and processes data of automated meteorological stations: 1. «Sokol-M», manufacturer the Escort Group (Russia) [https: //www.fmeter. RU]; 2. Vantage Pro, manufacturer the company Davis Instruments (USA) [https://www.davisinstruments.com]; 3. Meteobot® Pro (Bulgaria) [https://meteobot.com] for research works, and for agrarian services provision.

Within the framework of scientific research, automated meteorological stations are tested, using the data of which will allow deepening the study of meteorological parameters influence on development of agricultural crops.

Socol-M weather stations were installed on April 25, 2019 on the territory of the estate of CF «Dragmi» in v. Elizavenovo of Saksky district and on May 15, 2019 on the territory of LLC «First Crimean Agricultural Company» in the Orekhovsky rural settlement of the Saksky district (Figure 1). Sokol-M meteorological station measures the air temperature, pressure, air humidity, direction and wind speed. All sensors are grouped into a compact «head» of meteorological station. Meteorological station allows getting the operational data of the meteorological situation of the area and, based on them, gives 3-day forecast. The ability to unload data is implemented both by wired laptop connection to the station unit, and wirelessly, by reading data from the server (https://sokolmeteo.com).

Meteobot® Pro meteorological station was installed on May 25, 2019 on the lands of the Field culture department of the RIA of Crimea in v. Klepinino of Krasnogvardeisky region (Figure 1). Professional meteorological station includes temperature, air humidity and atmospheric pressure sensors; rain sensor; soil temperature sensor; soil humidity sensor; wind speed sensor, as well as solar panel and battery, providing its uninterrupted operation. Data access is carried out by means of the Meteobot® App, which provides 10-day forecast and archive data.

Meteorological station Davis Vantage Pro 2 operates in the Department of essential oil and medicinal crops of the RIA of Crimea in v. Crimean Rosa of the Belogorsky district from December 2017 (Figure 1). With the help of meteorological station, it is possible to obtain such data as temperature and humidity, atmospheric pressure, speed and direction of wind, amount of precipitation. The data wirelessly is transmitted to console, which is placed in the room, because it works from electrical network. If you need to receive archive data, the console is connected to computer with cable.

Figure 1. Map of meteorological stations location.

The purpose of the work is to study the reliability and representativeness of automated meteorological stations data in agricultural production.

3. Results and Discussions

Selection of meteorological station and its configuration (sensor equipment) depends on the necessary data and accuracy of their measurement. Number of meteorological station sensors is calculated individually, depending on the farm area, topography of fields and soil type.

Basic configuration of the meteorological station is equipped with the following set of sensors:

a) thermometer - air temperature sensor;
b) hygrometer - air humidity sensor;
c) vane - direction sensor and wind speed;
d) rain gauge - precipitation sensor.

In the aggregate, sensors, based on the received information, may predict the weather data, soil moisture, risks of plant disease and occurrence of pests, dates of preventive treatment with pest control, as well as the time and intensity of irrigation.

One of the important parameters in agriculture is soil temperature and humidity. Soil temperature and humidity sensors measure and show the tendency to parameters change. Leaf humidity sensors imitate the sheet surface, which allows identifying the periods, most favorable for plant diseases development.

When choosing a meteorological station, it should be noted that not all rain gauges are equipped with heating function. This may affect the data on the amount of precipitation dropped, because amount of precipitations in solid form (by type of hail or snow) the sensor will show after their melting. Therefore, when choosing a gauge bucket, the basic requirements should be taken into account:

a) collector's rim must have a sharp edge and be strictly vertical inside and gentle outside; design of precipitation gauges to measure the amount of snow should be such that the narrowing of the receiving opening due to the accumulation of wet snow around the rim could not be significant;
b) area of the receiving hole must be known with accuracy of 0,5%, and design of the rain gauge should be such that this area remains constant with the usual use of it;
c) collector must be designed in such way that the precipitations cannot be sprayed from inside to outside, and so that splashes do not fall inside. This can be achieved if the vertical wall is sufficiently high and the funnel slope is quite gently (at least 45%);
d) design should be such as to minimize losses for wetting. This can be achieved by choosing a suitable material and minimizing the collector total internal surface;
e) inlet of container must be narrow, and container must be sufficiently protected from sunlight to minimize the loss of evaporation. Rain gauges, used in places, where it is advisable to remove the instrument's readings once a week or a month, should be similar to the design of

ones, used for daily measurements, but with container of greater capacity and stronger construction.

Note that the size of collector reservoir does not have a significant effect on the measurement of liquid precipitation, but if significant amount of solid precipitation is expected, the opening area should be at least 200 cm^2. Area from 200 to 500 cm^2 will probably be the most suitable.

Technology of precipitation measurement is also different. Accumulated water is either assembled in the measuring vessel, or overflow from the container to the measuring vessel, or its level in the container is measured directly using graduated rail. There is also weight method, in which precipitates pass through a gauge bucket, where they fall on the scales, installed inside, after which the scales measure the weight of water and translate the data to the standard value (mm/m^2).

Laser sensor is a high-precision measurement device, measuring accuracy, intensity and precipitation type. The principle of its work is to generate a laser beam of light through which the precipitates pass, then the values are processed by the signal reception system.

Soil moisture sensors setting technology. Depending on the selected type of sensor, the installation occurs as follows:

a) Plate or bifurcate sensor. When installing in a well: well is made, using a soil drill. Sensor is placed in the hole vertically, mechanism of the tool perpendicularly fixes the sensor in the soil, and then smoothly releases. When installing in a trench: trench is dug to the necessary depth and sensor is inserted into untouched soil surface (Figure 3).
b) Rod sensor. To install sensor, well is made to a depth, equal to its length. Then sensor is installed in the well and connects to the meteorological station.

Figure 2. Installing the rod sensor in the soil.

For soil moisture sensors installation, a special tool is offered, which is not always suitable for all soil types (gravel and stony). It should also be noted that sensor must enter the soil as thick as possible, without damaging the soil horizons and mixing them, as well as without the formation of air cavities. Otherwise, the parameter measurement error may occur.

When choosing a meteorological station and, accordingly, sensors, you should pay attention to their accuracy of measurement. For example, an optimal error in measuring temperature testimony is ± 0.1° C, air humidity - ± 2%, atmospheric pressure - ± 1 mbar.

Meteorological station is equipment, which requires a power source. The power source can be as a solar panel (if any) and the AC network. The solar panel allows installing an automated meteorological station in the fields away from communications, while a weather station that is not equipped with such a panel must be located near sources of electric current. Therefore, it is desirable to choose meteorological station that has a solar panel. But it should also be taken into account that solar panels are effective in the spring-summer period with a sufficient number of sunny days. In the autumn-winter period, the panels are not as effective and, therefore, reliable. Without enough sunlight, the battery will drain quickly, the station will go into hibernation mode and stop transmitting data to the server. Accordingly, to resume data transmission and read hibernation data, it is necessary to charge the battery from external power source.

When choosing, it is worth considering the integrity and tightness of weather station, as well as build quality. If there are ports for connecting sensors, a prerequisite will be high-quality rubberized or plastic plugs. Plastic of the case should not bend from pressing on it; it should be dense enough, resistant to scratches and accidental impacts.

Technical support. When choosing, it is advisable to rely on meteorological stations, whose manufacturers' offices are located in territorial availability. Or choose manufacturers with high-quality technical support that can promptly respond to identified problems. Problems can arise both in the operation of the station itself and in the operation of the server. The server may stop responding or be restricted from access. Because data transmission from the station to the server is carried out via the mobile network, the signal level of the network should be monitored in order to avoid loss of communication with the station. In this case, it is necessary to go to the area and try to read data from the station in manual mode through a wired laptop connection.

When choosing a location for weather station installing, the areas under observation should be choosing to ensure the safety of the weather station. This can be the territory viewed from external surveillance camera, the installation of the station in close proximity to the security point, or in fenced area, which significantly reduces the potential number of installation sites.

Installation of meteorological station at the place of operation must be carried out in accordance with the instructions and recommendations set out in the “Guidelines for Meteorological Devices and Observation Methods” [20]. At the same time, it is necessary to take into account the operation peculiarities of automated meteorological stations in the winter period [21].

Note that one of the main functions, performed by the meteorological station in the farm, is accumulation of historical data. Thanks to this function, you can determine which technologies have given good results in certain conditions and seasons.

Table 1 shows a comparison of precipitation data, measured at the weather station of the stationary network of Roshydromet and the automated weather station Meteobot® Pro (located at a distance of 760 m from each other).

Data correlation coefficient is 0.86 which indicates that there is a relationship between the data sets. The difference in the absolute values of precipitation may be due to both the uneven distribution of precipitation over the territory, and the error in measuring precipitation at automated weather station.

Due to the fact that access to the data of Roshydromet is paid (about 1 euro for 1 measured precipitation value), and for agricultural purposes, information is required during the growing season for at least a decade, it is possible to obtain this data, using automated weather stations or using satellite data, provided that they are representative of the territory [22].
Example of storage and processing of automated meteorological data is shown in Figure 3.

1	Date	UV	PCP, mm	P, gPa	T, deg C	Tmax, deg C	Tmin, deg C	W, deg	W	Hmean, %	Hmax, %	Hmin, %	WV, m/s	WV2,m/s	Note
275	22.01.2020	66,00	0,00	1014,90	3,72	6,91	-0,61	6	N	99,54	100,0	85,0	3,01	1,78	
276	23.01.2020	50,80	0,00	1012,63	1,22	5,36	-5,65	137	SE	100,00	100,0	100,0	2,09	1,78	
277	24.01.2020	73,45	0,00	1021,68	-0,40	5,17	-4,97	20	NNE	100,00	100,0	100,0	0,92	1,78	
278	25.01.2020	133,20	0,00	1015,02	3,76	8,22	-0,59	5	N	100,00	100,0	100,0	2,60	1,78	
279	26.01.2020	152,95	0,00	1017,26	0,65	8,43	-5,94	4	N	100,00	100,0	100,0	0,14	1,78	
280	27.01.2020	95,65	0,00	1015,21	1,62	8,88	-7,74	314	NW	100,00	100,0	100,0	0,39	1,78	
281	28.01.2020	29,00	4,40	1006,89	5,60	7,48	3,85	292	WNW	100,00	100,0	100,0	1,49	1,78	
282	29.01.2020	70,65	1,40	1002,96	5,90	8,97	0,80	337	NNW	76,13	100,0	41,0	4,11	1,78	
283	30.01.2020	60,55	0,00	1006,66	2,21	6,18	-0,53	291	WNW	81,85	100,0	37,0	0,99	1,78	
284	31.01.2020	135,00	0,30	1007,25	2,35	7,11	-2,28	2	N	80,94	100,0	32,0	0,77	1,78	
285	01.02.2020	75,75	0,00	1005,11	4,96	8,31	1,56	20	NNE	72,09	100,0	35,0	1,15	1,78	
286	02.02.2020	113,90	0,70	1005,83	8,23	12,02	5,69	313	NW	60,48	100,0	24,0	2,91	1,78	
287	03.02.2020	35,70	2,60	1000,19	6,48	9,63	2,42	3	N	48,04	100,0	20,0	3,22	0,94	

Figure 3. Screenshot of DB file of the automated station Sokol-M, located in the Saky district of the Republic of Crimea.

Table 1. Comparison of precipitation data, measured at the weather station of the stationary network of Roshydromet and the automated weather station Meteobot® Pro.

Date	Precipitation, mm	
	WMO 33939	Meteobot® Pro
02.05.2020	5,0	2,75
03.05.2020		
04.05.2020		0,25
05.05.2020	0,4	0,25
***		
21.05.2020	3,0	3,75
22.05.2020	0	
23.05.2020		
24.05.2020		
26.05.2020	2,0	1,25
27.05.2020		1,25
28.05.2020	4,0	3,00
29.05.2020		4,5
***		
20.07.2020		17,75
21.07.2020	29,0	16,25
22.07.2020		
23.07.2020		
24.07.2020		
25.07.2020		
26.07.2020		2,25
27.07.2020	3,0	3,00
***		
14.10.2020	0,7	0,25
15.10.2020		
16.10.2020		
17.10.2020		1,50
18.10.2020	2,0	0,25
19.10.2020	3,0	3,25
***		
16.03.2020	5,0	5,0
17.03.2020	2,0	1,75
18.03.2020	3,0	3
19.03.2020	3,0	3
20.03.2020	0	0

When processing, it is necessary to take into account that the parameters are measured at a certain time interval, and in the future for convenience of analysis it is necessary to carry out processing and forming a database with the storage option in a daily and hourly format, if it not provided by the manufacturer.

4. Conclusion

As a result, it should be noted that an automatic weather station should be installed, if possible, in the visible area or in protected areas. When installing, it is necessary to take into account the terrain and give preference when it is heterogeneous to heights in order to avoid signal loss and, as a result, the impossibility of transmitting data to the server. It is also necessary to keep in touch with the developer's technical support for quick troubleshooting when working with the server. It should be noted that the automated meteorological station is quite effective for agricultural producers, since it allows obtaining the current values of the atmosphere of a particular area and quickly reacting to their sharp changes. The weather station prepares the weather forecast for the coming days, which allows agricultural producers to plan field work.

Data from an automated weather station is free, while data from Roshydromet is expensive. In this regard, it is proposed to develop a network of meteorological stations located in different parts of the peninsula on the basis of the Research Institute of Agriculture of the Crimea, with the support of the

Ministry of Agriculture of the Republic of Crimea, and provide of farmers with access to meteorological data from these stations. Along with meteorological data receive, it is proposed to diagnose the moisture supply of agricultural crops by means of coupled measurements of the volumetric water content of soil and capillary pressure of soil moisture. The results of these measurements make it possible to calculate the precise irrigation rate using the physical substantiated mathematical model of the soil hydrophysical properties, taking into account the phenomenon of hysteresis [23-28].

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