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EVALUATION OF THE EXISTING METEOROLOGICAL STATIONS FOR THE AGROMETEOROLOGICAL PROTECTION OF AGRICULTURE IN WIELKOPOLSKA

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Abstract: modern consulting and the automatic Decision Support Systems (DSS) need reliable measurements of the agrometeorological elements in a digital and on-line form. For this purpose, properly equipped and correctly spaced agrometeorological station networks are necessary. When building the networks the existing meteorological infrastructure should be taken into consideration. For this to be possible, a professional inventory of information about the existing points of the agrometeorological elements is necessary. The collected information about stations found in the Wielkopolska Voivodeship and neighboring areas of up to 200 km from Poznań, has been presented in this paper. In the Wielkopolska Voivodeship, 179 stations located in 107 municipalities in all 35 counties have been found. There are no stations in other 119 of the municipalities. In 67 municipality areas, 98 stations were found in the 45 counties from the regions around the Wielkopolska Voivodeship. There are 51 stations located in 39 municipalities of counties bordering the Wielkopolska Voivodeship. No station was found in four of the 27 border counties. The collected information will be helpful for planning the agrometeorological monitoring network. The information we are able to provide is necessary for supporting those decision makers responsible for the management of agriculture in Wielkopolska.

Key words: agrometeorological weather station, Wielkopolska, precision agriculture, DSS

INTRODUCTION

Precise agriculture technologies require a constant and reliable monitoring of meteorological elements in the agricultural areas. Monitoring allows for better organized work, especially field work. The result is increased plant production efficiency (Kędziora 1994; Mjelde *et al.* 1998; Orlandini *et al.* 2006; Stigter *et al.* 2006; Leśny *et al.* 2007). Monitoring irrigation range, particularly as far as plant protection is concerned, is significantly related to better validity. Pesticides then show higher effectiveness, there is a lower burden on the environment, and lower contamination of the crops. The manual and automatic agrometeorological field stations are used for registering local data. Due to the political and economic transformations in Poland as well as access to the latest electronic and computer solutions, the number of automatic stations has gradually increased in agriculture and other branches of the economy.

Unfortunately, the number of manual stations is decreasing, and the results coming from them are not directly comparable with the results coming from the automatic weather stations (AWS). Hence according to the experts, manual measurements should be continued, together with the simultaneous introduction of the automatic system of meteorological element recording. Archived results can be used in the models, to define the occurrences in the cultivation of plants (Sutton *et al.* 1984; Hartman *et al.* 1999; Rijks and Baradas 2000), or to predict the development of pests which may be threatening the crops (Phipps *et al.* 1997; Kessel *et al.* 2006; Palmieri *et al.* 2006). The models are also useful for forecasting weather phenomena in plant surroundings. Stations must be well equipped (WMO 2008; Durło and Kajewska 2009; Czaczyk 2010), and located so as to provide good, reliable measurements (Gillespie and Duan 1987; Sacchelli *et al.* 2008; WMO 2008; Juszczak *et al.* 2010). The existing meteorological stations are managed by various operators. In many cases there is no information about exact location, equipment or the way in which the sensors are installed and so on. The stations are a technical base, necessary for the functioning of the agrometeorological shield of agriculture in the region.

The weather is a non-controlled phenomenon and it has an impact on every domain of human activity. To create a coherent regional independent system, it is necessary to do an inventory of the existing weather stations and assess their current conditions. Information gained, will be used to decide about further action. So far, there is no elaboration that covers the region of Wielkopolska.

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State of the art

The institution responsible for the meteorological protection of Poland is Institute of Meteorology and Water Management (IMWM). The measurement points of meteorological elements realized by IMWM are located at airports, and basically in urban areas. For example, Łukasiewicz (2005) reported, that there is a difference between data collected at a typical airport and data from a AWS located in an area covered by plants. In various countries, independent weather station networks for Decision Support Systems (DSS) use in agriculture *e.g.* California Irrigation Management Information System (CIMIS), (Sivertsen 2000; Stigter *et al.* 2005; Matese *et al.* 2009) were established. Some of them provide weather data on the Internet for free:

www.homepages.paradise.net.nz
www.au.poznan.pl/sady/
www.ipm.ucdavis.edu
www.weatherstations.co.uk
www.penteli.meteo.gr
www.nc-climate.ncsu.edu
http://81.169.184.214/wetter/weather.shtml
www.agrometeo.pl
www.monitoring.a-ster.net.

Others provide weather data for a fee (www.hortplus.com). Some (www.esteburg.de), Association of Potatoes Growers in Luboń (APG), Marktgemeinschaft Bodenseeobst (MABO) are for the use of their owner only. The weather data generated for agrometeorological cover of agriculture, and dedicated for DSS should be (similar to the ownership of DSS systems) free from product advertisers (chemicals, fertilizers, equipment). For example, in Germany about 440 weather stations (WS) deliver data for agricultural needs, but only about hundred of them belong to the governmental meteorological system. About 340 remaining WS belong to different owners and are located very close to fields (Triloff 2011). The results of the collected measurements of agrometeorological elements can be applied in many different domains of agriculture *e.g.* CIMIS, and Wielkopolska Internet Agrometeorological Information Service (WIAIS) at Poznań University of Life Sciences (PULS). For DSS, data should be measured near cultivated crops; far from urban areas (Sutton *et al.* 1988; Leśny *et al.* 2004; Juszczak *et al.* 2005; Kuśmierek 2008; Matese *et al.* 2009). Most IMWM measurement points do not have such a localization. In the other countries, such as Germany (*e.g.* Esteburg, MABO) there are independent agrometeorological networks created for agricultural advisory services, and they are financed in a different way. They can allow to generate fast weather forecasts, useful both in early warning systems and DSS with various degrees of advancement. The application of registered agrometeorological data needs to predict the course of fungal disease development, and determine the results of spore sowing and infection (Sutton *et al.* 1984, 1988; Hartmann *et al.* 1999; Palmeri *et al.* 2006). Forecasting pest outfall can be calculated *e.g.* www.nc-climate.ncsu.edu, www.ior.poznan.pl, from the sum of the daily average temperatures. The evaporation rates and the state of the soil moisture can be used for proper steering of irrigation systems. Water resources available for irrigation continue to decline. Various possibilities for reducing water consumption are being studied (Spreer *et al.* 2007). Forest fire warning systems are based on AWS networks (www.lasy.gov.pl). The agrometeorological results also allow for the customization of the working parameters of the sprayers, thus preventing spraying during negative phenomena (Mokeba *et al.* 1998; Nuyttens *et al.* 2006). Thanks to agrometeorological data, it is also possible to predict the amount of yield (Nigam *et al.* 1998; Meinke *et al.* 2001) and influence on food security (Hoogenboom 2000; Szwejkowski *et al.* 2010), convenient conditions for animal husbandry (Igono *et al.* 1992; Lacetera *et al.* 2003) as well as climate changes (Suthers and Maywald 1985; Ratajkiewicz 2009; Szwejkowski *et al.* 2010).

State of meteorological observations in Wielkopolska

The report of the Expert Team (Hayman 2010) gives the incomplete information that Institute of Plant Protection – National Research Institute (IPP – NRI) has a net of AWS, but in fact it is the property of APG. It omits the information that General Directorate for National Roads and Motorways (GDNRM), Directorate General of the State Forest (DGSF) and Provincial Inspectorate of Environment Protection (PIEP) possess AWS on the scale of the entire country, as well as the orchard in Grójec region, and APG, WIAIS agrometeorological systems in Wielkopolska. During the time period from 2004 to 2007 WIAIS was created. It deliver very important information for agriculture in Wielkopolska, but calculated with the predicted values. With the measured data from AWS, it is possible to generate much more accurate information. In fact, since 2006, a network in the Białośliwie orchard areas was established (www.sadownictwo.com.pl/6388_Inauguracja-Systemu-Agro-meteo-w-Sadach-Krajny-narok-2009) based on the help of the Piła governor. There was a workshop in Piła (in county hall) initiated by Institute of Agricultural Engineering (IAE) (at PULS) in cooperation with Department of Plant Protection Methods (DPPM) (at PULS), on the 9th of December 2009. The workshop sponsored a guest from south Germany who is a professional advisor and author of an autonomous agrometeorological network (seven AWS Campbell Sci.) in Baden – Württemberg (www.mg-bodenseeobst.de). The MABO system works for internal purposes without access from the outside. Any generated information is used directly by DSS for the protection of orchards MABO Group members. Since autumn 2007, on IAE initiative, the Marshal of the Wielkopolska region has been involved. An accepted inter-institutional version of creating the advisory system, based on the agrometeorological system of the Wielkopolska agricultural shield, coordinated by IMWM, not yet built. For proper functioning of the DSS and warning systems (DGSF), the weather component of the system may not be the superior unit, but it may be optimized for the needs of users of agrometeorological data, such as in fire warning structure in DGSF. The functioning of a regional agrometeorological system requires the cooperation of various institutions. The emphasis must be on obtaining the highest quality of data.

MATERIALS AND METHODS

Information about existing measurement stations of the agrometeorological elements has been collected via the Internet (web searching) and electronic mail (e-mail), also directly by phone, and personally at the place where the station is located. Wielkopolska Voivodeship and its neighbouring counties have been investigated in detail. Due to the usefulness of the results from the other stations working on the outskirts of Wielkopolska, the remaining regions within a radius of up to about 200 km from Poznań, have been treated similarly (this concerns the range of collected information), but not less thoroughly – (not every station was searched for). Information was collected about: the location (place/village, municipality, county, voivodeship, geographical coordinates), the instrumentation, the method, and the form of data archiving, the possibility of data transfer via the Internet, the visualization (data access on the Internet), and the basic data about the property. The collected information has been compiled in such a way as to be useful for the improvement of the existing station network.

In this article, the words referring to areas, are listed below according to size, from smallest to largest: place, municipality, county, voivodeship (according to system of local government).

RESULTS AND DISCUSSION

The tabulation of the obtained information is a result of those actions taken (Tables 1, 2, 3). The interactive map of AWS working in the area covered by the inventory, is also in the final stage.

Table 1. Meteorological stations (manual and automatic) in the counties of the Wielkopolska Voivodeship

County	Number of WS in the county	Number of municipalities with WS	Number of municipalities without WS	Number of WS with data available via Internet
Chodzież	3	2	3	3
Czarnków – Trzcianka	3	2	6	3
Gniezno	7	6	4	7
Gostyń	3	3	4	1
Grodzisk Wielkopolski	4	4	1	2
Jarocin	5	3	1	3
Kalisz	7	5	7	5
Kępno	3	2	5	3
Koło	5	4	7	3
Konin	7	7	8	7
Kościan	6	3	2	4
Krotoszyn	4	3	3	3
Leszno	1	1	7	1
Międzychód	3	1	3	2
Nowy Tomyśl	5	4	2	3
Oborniki	2	2	1	2
Ostrów Wielkopolski	4	3	5	4
Ostrzeszów	1	1	6	1
Piła	11	7	2	9
Pleszew	4	3	3	3
Poznań city c.	21	1	0	14
Poznań land c.	31	13	4	23
Rawicz	3	3	2	2
Słupca	7	5	3	4
Szamotuły	7	2	6	5
Środa Wielkopolska	4	2	3	2
Śrem	3	3	1	1
Turek	1	1	8	1
Wągrowiec	4	3	4	3
Wolsztyn	2	1	2	2
Września	5	4	1	5
Złotów	3	3	5	2
Total (Σ)	179	107	119	133

Table 2. Meteorological stations localized in the neighboring counties to the Wielkopolska Voivodeship

Neighboring voivodeship	Number of counties with WS	Number of neighboring counties	Number of neighboring counties without WS	Number of neighboring counties with WS	Number of WS in neighboring counties	Number of WS located near Wielkopolska Voiv.
Dolnośląskie	11	4	0	4	6	13
Kujawsko-Pomorskie	9	6	2	4	5	22
Lubuskie	11	6	0	6	23	37
Łódzkie	5	5	1	4	5	7
Opolskie	1	2	1	1	1	1
Pomorskie	4	1	0	1	1	5
Zachodnio pomorskie	4	3	0	3	11	13
Total (Σ)	45	27	4	23	52	98

Table 3. Location of WS operated by different operators/owner

Operator/owner	Wielkopolska Voivodeship	Neighboring voivodeships
General Directorate for National Roads and Motorways	42	19
Directorate General of the State Forest	25	15
Association of Potatoes Growers in Luboń	8	–
Management of Urban Roads	8	no data
Adam Mickiewicz University	3	1
Poznań University of Life Sciences	11	2
Provincial Inspectorate of Environment Protection	6	4
Globe Program	5	1
Agropogoda	5	2
Airports	6	6
Institute of Meteorology and Water Management	13	14
Polish Agricultural Advising	–	4
TRAX elektronik	69	32
A-ster	10	4
WeatherLink	1	7
Wunderground	10	3
Other institutions	11	20

*ownership of the results from the stations located in the: Research Centre for Cultivar Testing (RCCT), ISSPC-SRI, PAS institutions is not clear, because some of them are co-financed by the IMWM

The Wielkopolska Voivodeship

The Wielkopolska Voivodeship is divided into 35 counties (powiats): four city counties and 31 land counties, and is not territorially identical with the historical region of Wielkopolska. These counties are further divided into 226 municipalities (gminas). In the Wielkopolska Voivodeship there is at least one automatic meteorological station (AWS) in each of the city counties (The Poznań county has 21 AWS, Kalisz county – three, Konin and Leszno county – one each). In the cities located in the city counties there are a total of 26 stations functioning (manual and automatic). The Leszno station is the only one found in the whole Leszno city county as well as in the Leszno land county. At least one meteorological station in the all counties has been inventoried. There is one station in the following land counties: Ostrzeszów (Kochłowy, Ostrzeszów municipality) and Turek (Wielopole, Tuliszków municipality). There are 153 meteorological stations functioning in the 31 land counties. They are located in 103 municipalities. No meteorological stations were found in 119 municipalities. There are results available on the Internet (or may be available – with a password) coming from 133 stations, from the total amount of 179 stations identified in the region. The largest number of stations has been found in the Poznań land county (31). The number of WS in the following counties were: Piła (11) and Gniezno, Kalisz, Konin, Słupca, Szamotuły (7 in each), and Kościan (6). In the land counties of the Wielkopolska Voivodeship, most of the stations are located in the Kórnik and Suchy Las municipality (five in each). The highest number of municipalities without stations is in the Konin and Turek counties (8 in each). In the Kalisz, Koło and Leszno counties, no WS were found in the seven municipalities in each county. Six municipalities do not have a meteorological WS in the Czarnków – Trzcianka, Ostrzeszów and Szamotuły counties, while five municipalities are without stations in the Kępno, Ostrów Wielkopolski and Złotów counties. The lack of stations has been stated in the four municipalities of the Gniezno, Gostyń, Poznań (land) and Wągrowiec counties. There are no WS in the three municipalities of the Chodzież, Krotoszyn, Międzychód, Pleszew, Słupca and Środa Wielkopolska counties, nor in the two municipalities of the Kościan, Nowy Tomyśl, Piła, Rawicz and Wolsztyn counties. One municipality of the counties: Grodzisk Wielkopolski, Jarocin, Oborniki, Śrem and Września had no meteorological stations. The owners of a considerable number of WS in the Voivodeship are: GDNRM (42), DGSF (20), PULS (11),

APG and Management of Urban Roads (MUR) (8 each), PIEP (6), and the other research units have the following 14 measurement points of the meteorological elements (Table 3). The whole Voivodeship structure of Agricultural Advisory Centre (AAC) (in the Sielinko, Opalenica municipality, Nowy Tomyśl county) has only one station. The largest number of automatic stations is operated by TRAX elektronik (www.traxelektronik.pl) from Kraków (69). The A-ster Company operates 10 stations. Six stations are self maintained by PIEP in Poznań. Five schools regularly participate in the Globe Program, entering the manually collected results into the Globe system which are available on the Internet (www.globe.gov).

The TRAX company provides the operation system and service of 51 AWS (GDNRM – 42, MUR – 5, WIAIS – 3, IPP – NRI – 1) together with the data sharing on the Internet. The data of the next 18 stations (DGSF) are available with a password. The data from 10 automatic weather stations are available on the Internet at www.wunderground.com. There are about 20 traditional – manual WS. Most of the AWS are owned by GDNRM. Many of them are located in open spaces along the roads, especially in non-urban areas. This location seems to be useful for DSS needs in agriculture. A lack of quantitative measurements of rainfall is a shortcoming of these WS due to the DSS needs. Stations belonging to GDNRM, provide observations confirming precipitation and road surface wetness. There is a technical possibility of equipping them with a rain-gauge.

Another significant owner of the automatic weather stations is DGSF which owns about 20 of them in the Wielkopolska Voivodeship. The results are available and they contain a quantitative element of rainfall with a resolution of 10 minutes. Seven more WS operate in the forest environment and they serve different purposes (co-operation of various units dealing with the agriculture, forestry and meteorology). Some of the stations are operated by institutions related to forestry, making it possible to use the results for the needs of DSS in agriculture. Properly configured electronic results can easily be made available by using an access password. Many of the following inventoried automatic stations of the other owners generate digital files of the results and archive them. A large number of the owners agree to make their results available for non-commercial purposes since such an agreement would aid towards protecting the environment. At the present time, the results obtained from the manual stations are archived in the universal word text editors or spreadsheets. Entering the results to the acquisition system of computer data should not cause a technical problem. The units cooperating with Plant Breeding and Acclimatization Institute (PBAI) set out 10 stations, mainly manual. Some of them are related to IMWM. The PULS, also has ten WS in a typical agricultural environment. The Polish Academy of Sciences (PAS) (Borówiec, Kórnik municipality, Poznań land county and Turew, Kościan municipality) and Institute of Natural Fibres and Medicinal Plants (INFMP) (Stary Sielec, Jutrosin municipality, Rawicz county and Pętkowo, Środa Wielkopolska municipality) have by two stations. One station was located in IPP – NRI – Winna Góra, Środa Wielkopolska municipality, and also one in Institute of Soil Science and Plant Cultivation – State Research Institute (ISSPC-SRI) – Baborówko, in Szamotuły municipality.

The results from the stations located in cities and urban areas are of little direct use to the DSS in agriculture but they lend themselves to forecasting abilities. There are about 30 urban locations in the whole voivodeship. Three of these stations are at major airports, (Krzesiny, Ławica and Powidz), and three are at the grassy aero club airports (Bednary, Ligowiec and Zborowo).

Regions around the Wielkopolska Voivodeship

Weather phenomena has a cross-border character. Meteorological elements registered in the places surrounding the area considered, are also useful for forecasting purposes. Therefore, the neighboring districts were included in the search for stations which could contribute to the weather forecasting needs of Wielkopolska. The same care was used in the surrounding area search as was used in the search in the Wielkopolska Voivodeship. Additionally, areas lying up to about 200 km around Poznań were taken into account when doing the research, but treated in less detail.

The weather stations inventoried in the area surrounding the Wielkopolska Voivodeship have been tabulated in table 2. There are 27 counties represented in these areas. There were 51 stations found in the 23 counties. They are located in 39 municipalities. No stations were found in the four bordering counties (Radziejów and Sępolno: Kujawsko-Pomorskie Voivodeship, Wieruszów – Łódź Voivodeship and Namysłów – Opole Voivodeship). In total, 98 functioning WS have been found in the 45 counties, in the area of 67 municipalities within the areas surrounding Wielkopolska Voivodeship, covered by the inventory. In addition, 20 WS were located in the urban area. There are six stations located at airports: Babimost, Bydgoszcz, Inowrocław, Mirosławiec, Przylep (aero club of Ziemia Lubuska, Zielona Góra municipality) and Toruń. The largest number of counties with WS (11 in each) is in the Dolnośląskie Voivodeship – in 13 municipalities, and in the Lubuskie Voivodeship – in 21 municipalities. In the Kujawsko-Pomorskie Voivodeship, WS were found in 12 municipalities in 9 counties. In the Łódź Voivodeship there were stations in 7 municipalities, in the 5 counties.

Four counties with WS were found in the Pomorskie Voivodeship (in 4 municipalities) and in the Zachodniopomorskie Voivodeship (in 9 municipalities). Two agrometeorological WS are controlled by AAC. One of these stations is in Barzkowice – Stargard Szczeciński municipality (www.zodr.pl), and the second in Kalsk, Sulechów municipality, in the Zielona Góra land county. Both of these stations are located nearest to the Wielkopolska Voivodeship. A private company Polish Agricultural Advising (PAA), provides consulting services in agriculture. This company owns four stations in the Śląskie Voivodeship in four counties (Legnica, Oleśnica, Wrocław and Złotoryja). Institutions related to agriculture also have WS in this region: ISSPC-SRI – 5, PBAI/ISSPC-SRI – 4, PULS – 2. Nine stations were found in the counties belonging to the historical Wielkopolska Region: Międzyrzecz (4 sta-

tions in 3 municipalities), Wschowa (3 WS in 2 municipalities) and Żnin (one in each of the 2 municipalities).

Most of the WS located in areas around the Wielkopolska Region belong to: GDNRM – 19, DGSF – 15, IMWM 14, PIEP and PAA (four in each). Twenty WS held by other institutions were also found – table 3.

For several years, in IAE at PULS, the idea of creating an inter-institutional center of the agrometeorological shield of Wielkopolska has existed. This is the most appropriate place for this task as it allows for efficient and effective running of a modern agricultural advisory regional system. The project can and should exploit the potential of: the specialists from PULS, research institutes, the Marshal Office of the Wielkopolska Region, the local government as well as other enterprises. Due to the rising threat to agricultural production by adverse weather events, on-line monitoring of the weather is necessary to ensure proper activity of the DSS. The system should efficiently meet all requirements needed for preparing the agrometeorological forecast of the weather. This is possible in the form of a non-stop service. Funds covering the cost of operating a regional agrometeorological system should be provided by funds from the Marshal's office to be used for environmental protection and agriculture, supported by the Regional Fund for Environmental Protection and Water Management in Poznań.

CONCLUSIONS

1. All the counties of the Wielkopolska Voivodeship are equipped with at least one automatic meteorological station. There were 179 measurement points found of the meteorological elements located in 107 municipalities, in the administrative area of the Wielkopolska Voivodeship. There is more than one station in 35 of the municipalities. No station has been found in the other119 municipalities.
2. In the Leszno, Ostrzeszów and Turek counties there occur the least number of stations (one in each).
3. There is a good possibility for building an integrated monitoring system of agrometeorological elements in the region of Wielkopolska and DSS using the collected information about existing systems of meteorological observations. At the majority of the measurement points, the three most important meteorological elements for agriculture and DSS: relative humidity of air, air temperatures as well as the amount of rainfall were registered.
4. Professional analysis of the existing equipment and an indication of the places where new agrometeorological stations should be located in the Wielkopolska Region, will be necessary to create a network with the proper density which can be useful for the agrometeorological shield of agriculture.
5. The preliminary assessment shows that many of the automatic stations are assembled incorrectly. For example, the rain-gauge is installed on the mast instead of far from it. This installment means the rain-gauge cannot reliably measure rainfall. Fixing the rain-gauge and the radiation sensor does not respect the requirements for the reliable calculation of evapotranspiration, which is necessary for the proper steering of the irrigation systems. In many cases, the automatic stations are located and fastened in an inappropriate way (roof, chimney, and/or building wall are too close to a building or to aforestation). Such inappropriateness confirms the need to carry out a professional inventory of the stations. The analysis of technical parameters and the correctness of the assembly of the existing stations is in the process of being elaborately put into detail. The result of the analysis will be helpful in determining which stations should be included and which are deemed useful in terms of localization into a regional system agrometeorological shield for the Wielkopolska area. The GDNRM stations located along roads, require rain-gauges so that the stations can be adapted to the needs of DSS.
6. The preliminary information analysis about the inventoried stations shows the need for better planned technical assumptions of the location method for the stations which monitor the conditions in crop cultivation. A need to check the selection of the appropriate tooling (the place of fastening and the characteristics of the measurement sensors) so that all meet the individual needs of the different DSSs was also noted.
7. It is essential to the professional analysis covering the demand for agrometeorological information, that proper localization be made of missing stations and that existing ones be retrofitted to cover the needs of an agrometeorological system for Wielkopolska. The act should first of all cover the regions where there are poor network stations and the regions of special crop production. This focus would lead to a more efficient, correct use the DSS system.

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