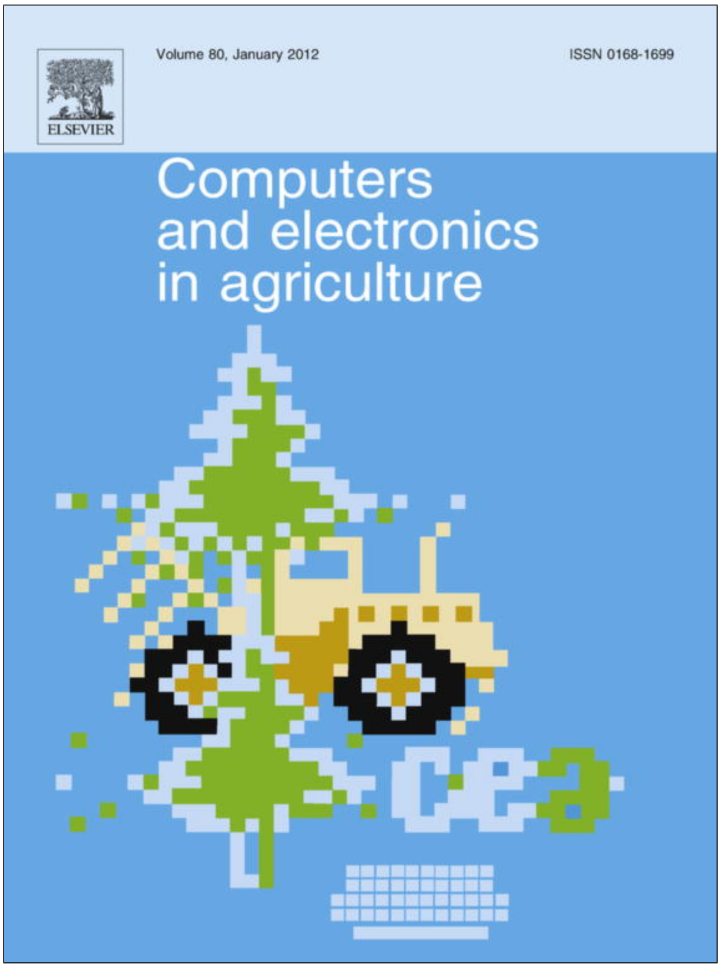

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Meteorological automated weather station data application for plant water requirements estimation

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ABSTRACT

In order to adequately control water requirements for plants, it is necessary to perform continuous standardized meteorological conditions measurements from the largest possible number of points. This is possible by automated measurements which lead to an increase in the number of records and their immediate accessibility. Automatic stations provide a large amount of data; however, in comparison to standard stations, they do not obey the existing standard procedures. This particularly applies to the comparability of instruments and, to some extent, the time of measurements. Similarly, other differences include data processing procedures; hence a risk of results others than the standard ones. The observations of plant water requirements are based on the results of agrometeorological indices, mostly on the precipitation measurements. The aim of this research was a comparison of the selected agrometeorological indices essential in agriculture (precipitation, reference evapotranspiration, climatic water balance and standardized precipitation index), measured or calculated in the growing season (from April to September) at standard and automatic weather stations and a verification whether the automated station data can be applied without any modifications whatsoever. The investigation was drawing on the data collected between 2000 and 2004 in the Kuyavia region, central Poland. The focus of the research was the interaction between the data series compared. Searching for the ways to adjust the automated to standard 10-day growing season data was an important aspect of the investigation. Despite the different measurement results between both stations compared, great correlation coefficients of the results facilitated the development of mathematical formulas to allow for the use of the automated data series instead of standard records.

1. Introduction

The advantage of the total summer half-year precipitation over the winter one is most essential for agricultural production in Poland. However, a large variation in consecutive years and a large share of evaporation in the water balance are typical for our climate (Degirmendžić et al., 2004) and lead to periodic water deficits, causing significant fluctuations in crop yields (Żarski et al., 2000; Kuchar and Iwański, 2011; Treder et al., 2011). Therefore there is a need to supplement the shortage of rainfall using irrigation systems controlled by meteorological indicators, compliant with changing plant water requirements (Hogenboom, 2000; Smith, 2000; Olesen and Bindi, 2002; Burri and Petitta, 2004; Sacks et al., 2008; Wisser et al., 2008). To quantify the water deficits, researchers often use indicators solely based on standard precipitation measurements (Sevruk, 1996), for example the standardized precipitation index (SPI) (Mc Kee et al., 1993; Vermes, 1998; Paulo and Pereira, 2006; Łabędzki, 2007), or the relationship between the precipitation and the values of various types of reference evapotranspiration (ETo). In this case, the difference between precipitation (*P*) and reference evapotranspiration (ETo), known as atmospheric water balance index (Rojek, 1987; Kar and Verma, 2005) are most frequently used.

Regardless of the method, the crop water deficit is evaluated based on the years of homogeneous observations and meteorological measurements (Doorenbos and Kassam, 1979; Allen, 1986; Doorenbos and Pruitt, 1977; Drupka et al., 1997; Enciso and Wiedenfeld, 2005). The application of modern automated measurement stations affects the homogeneity of the long series of meteorological measurements, which is due to the differences in the standard measurement equipment and methodology. This means that the replacement of traditional measurements methods with the automated methods could affect the climate data recorded, and a ‘new’ series can be created.

All that raises the question of uniformity and comparability of the automated series with the multi-year standard sequences of measurements taken with traditional instruments (Tuomenvirta,

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2001; Alexandersson, 2007), which has been covered by numerous domestic and international research (Milewska and Hogg, 2002; Rudel, 2003; Pinto et al., 2006; Pavlyukov, 2007; Kuśmierek, 2008; Sevruk et al., 2009; Fiebrich and Crawford, 2009). An uncritical approach to precipitation data generated by automated measurements can result in erroneous conclusions when predicting the availability of water requirements for agricultural production (Frankhauser, 1998; Upton and Rahimi, 2003; Chang and Harrison, 2005; Molini et al., 2005; Shedekar et al., 2009).

The aim of this research was a comparison of the selected agrometeorological indices essential in agriculture (precipitation, reference evapotranspiration, climatic water balance and standardized precipitation index), measured or calculated in the growing season (from April to September) at standard and automatic weather stations and a verification whether the automated station data can be applied without any modifications whatsoever.

2. Materials and methods

The study involves meteorological measurements taken over 2000–2004 at the Research Station of the University of Technology and Life Sciences, Poland. There were compared measurements taken at the standard station and at an 8-channel automatic weather station (model 16.99 Eijkelkamp Agrisearch Equipment, Giesbeek, the Netherlands). The data collected included the amount of precipitation (P) and air temperature and vapor pressure deficit. The air temperature and vapor pressure deficit were used to calculate reference evapotranspiration, however, they were not subject to comparison. The results of the comparison of air temperature and vapor pressure deficit are presented in an earlier report by Kuśmierek (2008). The Indicators calculated, based on the measurements taken using both methods, included climatic water balance (P-ETo) and the standardized precipitation index (SPI).

The climatic water balance is a difference between total rainfall (P) and reference evapotranspiration (ETo). The reference evapotranspiration (ETo) was calculated using the Grabarczyk model (1989), derived from the measurements of the actual water consumption by grass vegetation under optimal water supply conditions. This model is based on the strong relationship between the field water consumption and the temperature and vapor pressure deficit, which are mostly related to the water requirements of plants, which, however, does not take into account the amount of solar radiation due to radiation measurement errors leading to an incorrect estimate of evapotranspiration (Llasat and Snyder, 1998). The ETo model is given as $\text{ETo} = 0.32\ (\varDelta + 1/3t)$, where: ETo = reference evapotranspiration (mm), 0.32 = unit conversion factor, $\varDelta$ = mean vapor pressure deficit (hPa), t = mean air temperature (°C).

Values of the standardized precipitation index (SPI) for a given P were calculated from equation: $\text{SPI} = [f(P) - \mu]/\delta$, where: $f(P)$ = transformed sum of precipitation, μ = mean value of the normalized precipitation sequence, δ = standard deviation of the normalized precipitation sequence; $f(P) = x^{1/3}$, where: x = the element of precipitation sequence. The atmospheric drought index (SPI) was classified according to Polish meteorological conditions; the threshold value of the first drought class (moderate dry period) is fixed at $\text{SPI} = -0.50$ to -1.49. Smaller index values indicate a very dry period ($\text{SPI} = -1.99$ to -1.50) and an extremely dry period ($\text{SPI} \leqslant -2.00$) (Łabędzki and Bąk, 2004).

Under Polish climatic conditions, this model complies well with the actual evapotranspiration measured with lysimeters, as well as with the models developed by Turc and by Penman, recommended by the FAO (Grabarczyk and Żarski, 1992). Treder et al. (2010) compared the estimates made using the Grabarczyk model (1989) and the Penman–Monteith model recommended by the FAO (Allen, 1986,1993; Allen et al., 1996), and reported significant correlation coefficients and emphasized that the Grabarczyk method is easy to use on family farms to control irrigation.

The standard measurements were carried out at the point of observation and measurement of the University of Technology and Life Sciences, the Experiment Station of the Faculty of Agriculture and Biotechnology (latitude 53°13′N, longitude 17°52′E, elevation = 98 m above sea level) three times a day: at 06.00, 12.00 and 18.00 UTC, which is consistent with the principles of the Polish Institute of Meteorology and Water Management. The conventional psychrometer was placed in an instrument shelter 2 m above the ground surface, and the total daily precipitation was measured by the Hellmann rain gauge at the accuracy up to 0.1 mm. The catch area was 200 cm^2 (diameter was 16 cm) and the inlet located at 1 m above the ground. The automatic station was located in the vicinity of the traditional station and equipped with a thermistor sensor, 16.99.15 model, installed at the height of 2 m. The tipping-bucket rain gauge, model ARG 100 16.98.47, was installed at the same height as the Hellmann gauge. The catch area of the tipping-bucket rain gauge was 507 cm^2 (diameter was 25.4 cm) over two-times bigger, as compared with the Hellmann gauge. The device resolution was 0.2 mm, which means that the total precipitation smaller than 0.2 mm was neither detected nor reported. Sampling took place at 5-min intervals. The data were stored in the memory logger as hourly averages/sums and were used as the basis for calculating the daily values for the period of 23.00-22.59 UTC.

The statistical evaluation of the results was based on 10-day periods in the growing season (April to September). The amount of data in the sets being compared for the whole growing season was 90 (5 years × 6 months × 3 decades) and 15 in each month (5 years × 3 ten-day periods a month). The mutual relations between the data sets were examined using the regression analysis and described applying regression equations, taking into account the size of the standard error. The significance of the differences between each pair of data sets was verified by Student's t-test related pairs. The degree of compliance was determined by the correlation coefficient with confidence level $\alpha < 0.05$. All the calculations were made using the Statistica 6.0 software package.

3. Results and discussions

The comparison of the mean 10-day values of selected indicators, measured or calculated based on the standard and automatic measurements, allowed the researchers to determine whether the results of the measurements relevant to estimating the plant water requirements from traditional station could be replaced with the data generated by the automatic station.

As a result of the five-year own experiments, it was found that the results of the measurements of the precipitation amount applying the automatic method were greater than those of the standard measurement, and the degree of correlation of the data series compared was quite great. The average total growing-season precipitation for a 10-day period was 1.3 mm greater for the automated measurements, as compared with the standard ones (Table 1). This was probably due to different orifices of the gauges compared and the differences in the measurement sensitivity between the two instruments. The automatic rain gauge is equipped with the mechanism in a form of a tipping-bucket the change in the position of which triggers an electric impulse sent to the station memory where it gets stored as precipitation of 0.2 mm. It was the case even on the days clearly rainless, however with the weather conditions favorable to the formation of deposits, e.g. dew. Furthermore, each elevated rain gauge distorts the wind field

Table 1
Comparison of 10-day mean values of precipitation (*P*) (mm), reference evapotranspiration (ETo) (mm), climatic water balance (P-ETo) (mm) and standardized precipitation index (SPI) received from standard (*S*) and automated (*A*) measurements.

Time	Index	Mean		*S*–*A*	Maximum		Minimum		SD		*R*	RE	SEE
		S	*A*		*S*	*A*	*S*	*A*	*S*	*A*			
IV	P	8.4	10.4	-2.0^*	27.9	30.8	0	0.2	7.2	8.1	0.974	$S = 0.868A - 0.674$	1.7
	ET_o	21.7	19.5	2.2^*	48.5	51	7.3	5.9	9.7	10.6	0.978	$S = 0.901A + 4.152$	2.1
	P-ET_o	−13.4	−9.1	-4.3^*	7.3	14.1	−48.5	−50.8	13.1	14.8	0.982	$S = 0.868A - 5.468$	2.6
	SPI	0.1	0.31	-0.21^*	1.46	1.57	−1.62	−1.03	0.76	0.73	0.962	$S = 1.002A - 0.211$	0.2
V	P	16.4	17.3	-0.9^*	57.9	60.6	0	0	15.7	15.4	0.989	$S = 1.017A - 1.209$	2.4
	ET_o	37.1	32.4	4.7^*	55	45.4	22.6	19.5	9.2	8.8	0.882	$S = 0.927A + 7.051$	4.5
	P-ET_o	−20.7	−15	-5.7^*	21.2	30.8	−51.9	−45.2	18.2	19.3	0.973	$S = 0.921A - 6.823$	4.4
	SPI	0.18	0.27	-0.09^*	1.9	1.97	−1.73	−1.73	0.94	0.89	0.992	$S = 1.045A - 0.104$	0.1
VI	P	13.4	14.9	-1.5^*	31.6	33	0	0.2	13.4	14.9	0.969	$S = 0.905A - 0.063$	2.4
	ET_o	40.4	34.7	5.7^*	65.1	55.9	25.4	19.4	9.9	9.9	0.914	$S = 908A + 8.873$	4.1
	P-ET_o	−27	−19.8	-7.2^*	−1.1	6.3	−60.6	−50.7	16.6	17.8	0.952	$S = 0.886A - 9.424$	5.3
	SPI	−0.2	−0.09	-0.11^*	0.78	0.82	−2.36	−1.78	0.77	0.67	0.98	$S = 1.136A - 0.103$	0.2
VII	P	32.1	33.1	-1.0^*	87.5	113	2.6	4.2	22.3	27.5	0.905	$S = 0.737A + 7.875$	9.9
	ET_o	41.3	34.9	6.4^*	56.8	48.6	26.2	23.8	10.1	7.8	0.948	$S = 1.224A - 1.396$	3.4
	P-ET_o	−9.2	−1.9	-7.3^*	52	84	−54.2	−44.4	25.7	30.4	0.928	$S = 0.785A - 7.560$	9.9
	SPI	0.52	0.53	-0.01^*	1.79	2.22	−0.9	−0.79	0.81	0.82	0.937	$S = 0.922A + 0.026$	0.3
VIII	P	21.4	21.8	-0.4^*	53.8	46.6	0	0	18	16.6	0.952	$S = 1.034A - 1.048$	5.7
	ET_o	44.1	40.5	3.6^*	66.3	59	28.5	27.6	9.9	7.2	0.883	$S = 1.210A - 4.933$	4.8
	P-ET_o	−22.7	−18.7	-4.0^*	13.2	11.2	−66.3	−59	24.9	21	0.948	$S = 1.123A - 1.556$	8.2
	SPI	0.21	0.27	-0.06^*	1.5	1.35	−1.9	−1.74	1.04	0.95	0.979	$S = 1.076A - 0.083$	0.2
IX	P	20.5	22.3	-1.8^*	52.2	55.8	0	0.6	16.6	17.9	0.997	$S = 0.923A - 0.055$	1.3
	ET_o	25.6	23.9	1.7^*	45.7	38.8	16.5	14.4	8.3	6.3	0.914	$S = 1.210A - 3.328$	3.5
	P-ET_o	−5.1	−1.6	-3.5^*	30.5	32.5	−28.4	−26.4	21.6	21.2	0.993	$S = 1.010A - 3.452$	2.7
	SPI	0.34	0.46	-0.12^*	1.64	1.72	−1.98	−1.41	1.1	1.04	0.994	$S = 1.060A - 0.143$	0.1
IV-IX	P	18.7	20	-1.3^*	87.5	113	0	0	17.1	18.1	0.952	$S = 0.898A + 0.814$	5.2
	ET_o	35	31	4.0^*	66.3	59	7.3	5.9	12.5	11	0.945	$S = 1.078A + 1.628$	4.1
	P-ET_o	−16.3	−11	-5.3^*	52	84	−66.3	−59	21.4	22	0.953	$S = 0.927A - 6.076$	6.5
	SPI	0.19	0.29	-0.10^*	1.9	2.22	−2.36	−1.78	0.92	0.86	0.975	$S = 1.043A - 0.114$	0.2

SD – standard deviation (for P, ETo and P-ETo expressed in mm).
R – correlation coefficient.
RE – regression equation.
SEE – standard estimation error (for *P*, ETo and P-ETo expressed in mm).
[*] Significance of differences at the confidence level of $p = 0.05$ indicated by the Student's *t*-test for linked pairs.

above the gauge orifice and, as a result, the precipitation measurements might be subject to a repetitive error. The slight deviations of gauge parameters which affect the aerodynamic properties like the shape of the gauge body and the orifice rim, and the orifice rim thickness can result in changes in the characteristics of the wind field above the gauge orifice and, consequently, different precipitation values (Sevruk, 1996).

The differences calculated for all the months of the growing season were the same in nature. The greatest total of the 10-day rainfall throughout the research was recorded in July 2001, when the traditional method was applied, and amounted to 87.5 mm. The rainfall measured at the automatic station was 25.5 mm greater. The difference could have been due to another measurement methodology applied at the standard and automatic station. The measurements taken at the automatic station cover the period from 23.00 to 22.59 UTC, while the traditional precipitation measurements taken by the observer were taken every day at 06.00 UTC, which means that on the first day of the decade period in July 2001 the measurement performed with the automatic rain gauge took 7 h more that with the Hellmann rain gauge. The intensive precipitation was recorded with the automatic rain gauge already starting at 23.00 UTC, whereas rainfall recording on that day at the standard station started at 06.00 UTC. Additionally, the automatic rain-gauge mechanism divides the precipitation into portions. With intensive precipitation, the mechanism tipping-bucket could have still kept some of the remaining rainfall, which could have got totaled in time, thus increasing the daily total precipitation. Similar observations were reported by Chvila et al. (2005).

Despite significant differences across total decade precipitation means, the regression analyses and the correlations show a consistency of the rainfall measurements taken with the two methods throughout the growing season ($R = 0.952$) (Table 1) (Fig. 1a). A better data compliance was reported in September ($R = 0.997$) (Fig. 1b), however it was slightly worse in May, April, June and August. The smallest correlation coefficient value was noted for July ($R = 0.905$) (Fig. 1c), which was due to the greatest differences in the total decade precipitation recorded with both methods for that month, the source of which is accounted for above.

Similar results to the present ones are reported by Perini and Carmen Beltrano (2003), by comparing the total precipitation across decades. The discrepancies between the results in the present research could have resulted from three reasons; the first one being the differences in the orifice size: 200 cm^2 for the standard one and 507 cm^2 for the automatic one, the second one being the automatic device sensitivity which might recorded even a dew, as 0.2 mm rainfall and, finally, the third reason for the differences being the daily total precipitation calculation method.

The reference evapotranspiration was calculated by applying the Grabarczyk model based on the air temperature and vapor pressure deficit measurements taken at both stations. The comparison of the measurement results of those conditions have not been covered by this paper since such comparison constituted the research material published in yet another paper by Kuśmierek (2008).

Significant differences occurred for the comparison of 10-day mean values of reference evapotranspiration. The 10-day mean reference evapotranspiration values 4.0 mm greater in the growing

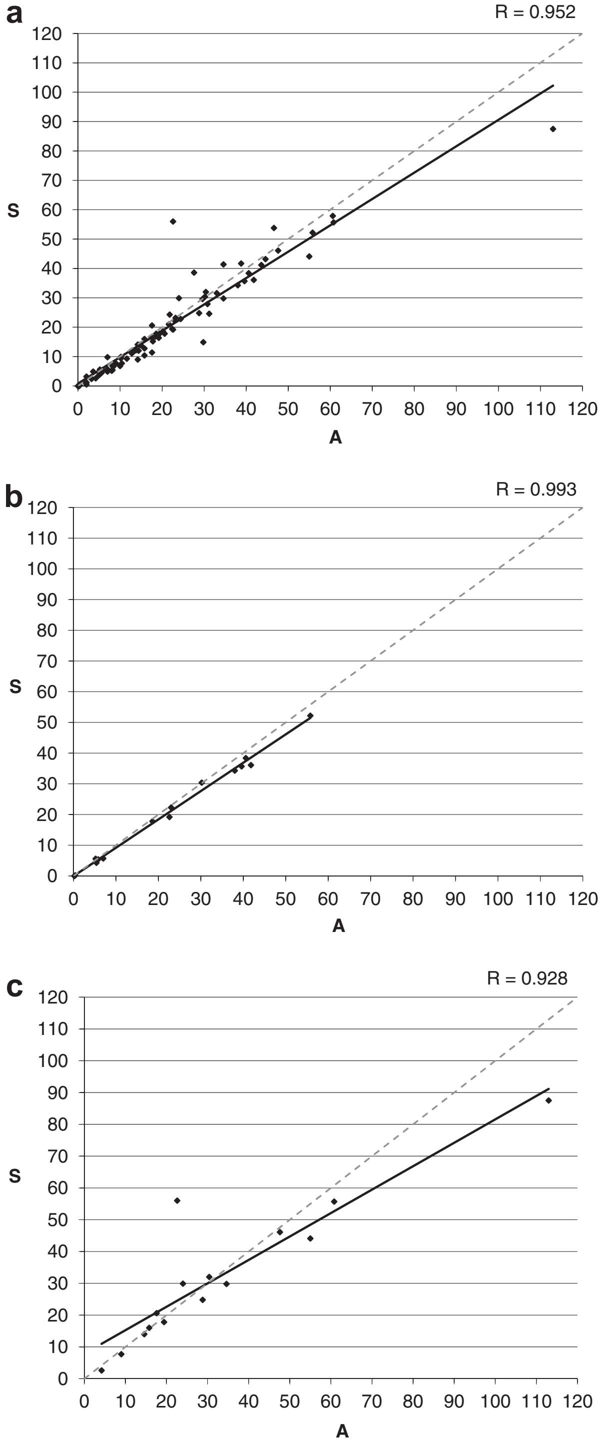

Fig. 1. Linear regression of 10-day total of precipitation measured with the standard (*S*) and automated (*A*) rain gauge in the growing season (a), September (b), and July (c).

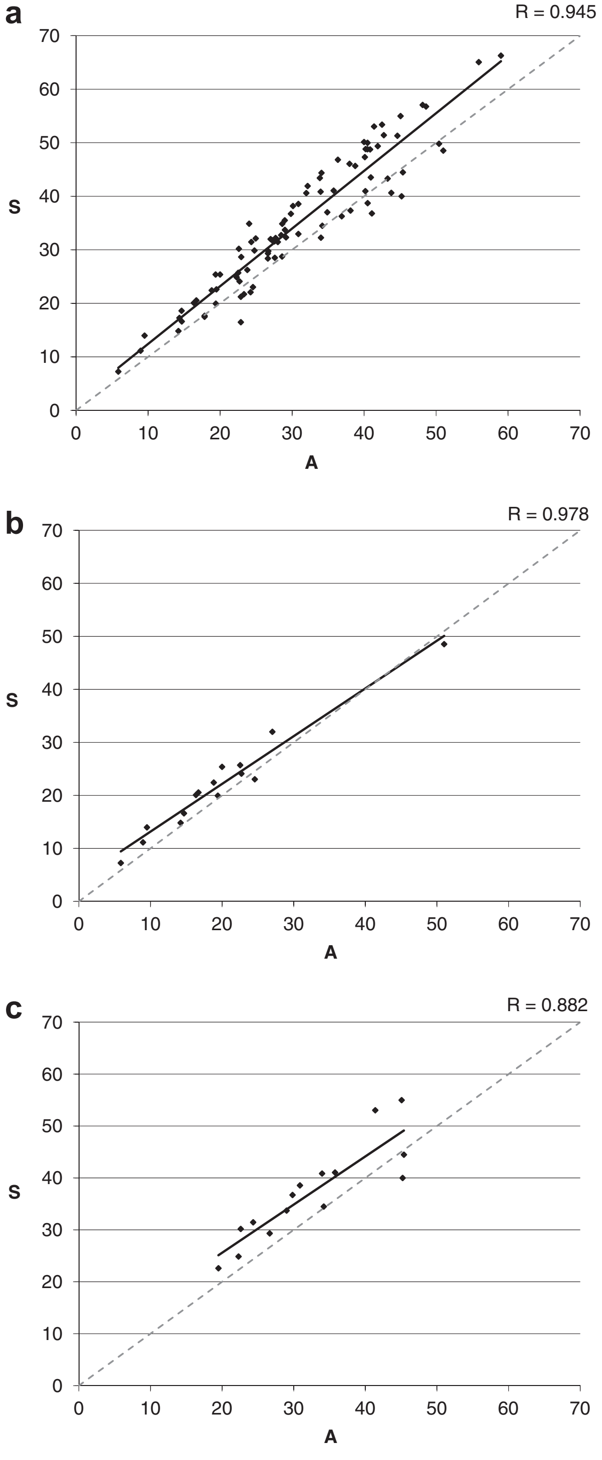

Fig. 2. Linear regression of 10-day total of evapotranspiration calculated based on standard (*S*) and automated (A) measurements in the growing season (a), April (b), and May (c).

season were provided from the traditional measurement method, as compared with the results from the automated measurement station (Table 1). Each month the differences were the same in nature and ranged from 6.4 in July to 1.7 in September. The statistical analysis of the 10-day mean reference evapotranspiration values show their great correlation. The correlation coefficient for the 90 pairs of data was 0.945, while the best compliance was achieved in April ($R = 0.978$), and the weakest one – in May ($R = 0.882$) (Fig. 2a–c). Commonly evapotranspiration is determined following the Penman–Monteith formula modified by FAO-56 (Allen et al. 1996). Pereira et al. (2002) confirmed a better evaluation of evapotranspiration calculated according to that model based on the standard data, as compared with the automatic measurements data.

As a result of s rainfall, accompanied by greater values of reference evapotranspiration, the 10-day average of climatic water balance in the growing season, based on the standard station data, assumed the value of −16.3 mm, in comparison with the −11.0 mm recorded with the automated method (Table 1).

Similarly, each month, the greater value of 10-day climatic water balance was based on automatic measurements. The coefficient of correlation calculated for all the 10-day climatic water balance values in the vegetation periods over the 5 years of study was 0.953, which indicates a significant compliance for the data compared (Fig. 3a). The best compliance was noted in September ($R = 0.993$), while the weakest one in July ($R = 0.928$) (Fig. 3b and c). The climatic water balance values recorded in the present research demonstrated a great correlation confirmed by great correlation coefficient values. The differences across the measurement results applying both measurement methods were due to the application of various total precipitation and evaporation, reported based on the measurement taken using the standard and automatic methods. The total precipitation values recorded using the standard method were much smaller and the reference evaporation slightly greater than the results of the measurements taken

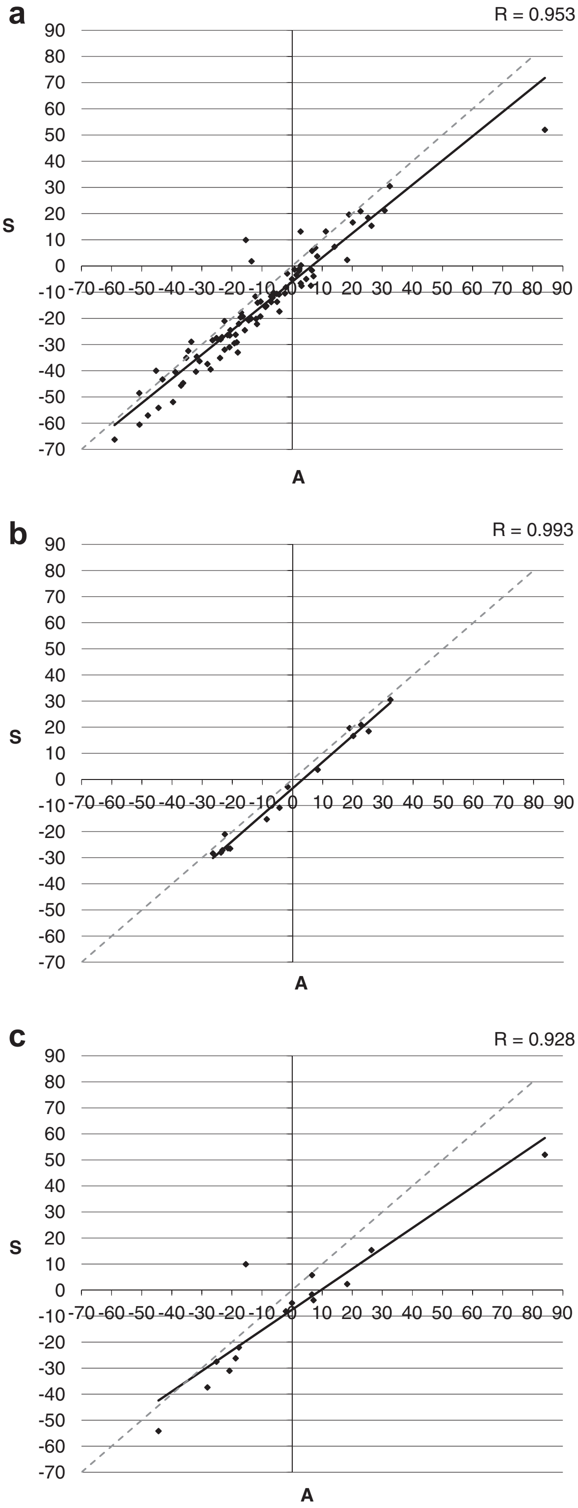

Fig. 3. Linear regression of 10-day mean total of climatic water balance calculated based on standard (S) and automated (A) measurements in the growing season (a), September (b), and July (c).

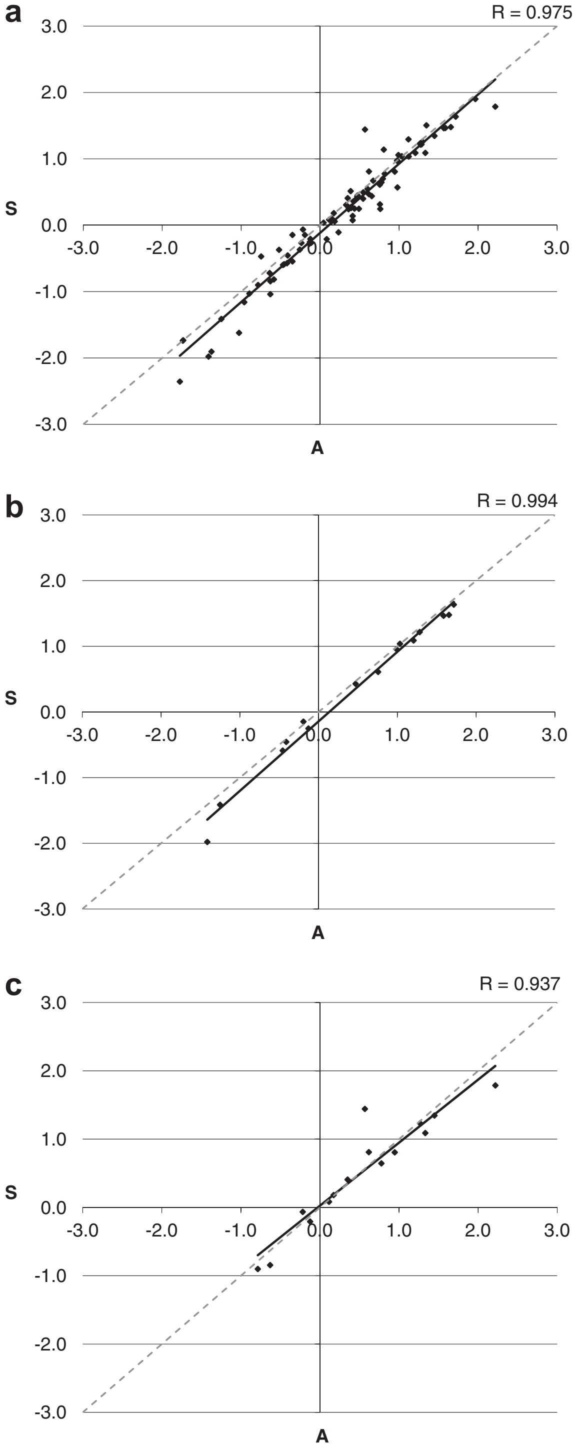

Fig. 4. Linear regression of 10-day mean values of SPI calculated based on standard (S) and automated (A) measurements in the growing season (a), September (b), and July (c).

Table 2
Drought frequency in the growing season over 2000–2004 based on 10-day mean SPI values calculated from standard (*S*) and automated measurements (*A*).

Period	Extremely dry SPI $\leqslant -2.00$		Very dry SPI -1.99 to -1.50		Moderate dry SPI -1.49 to -0.50		Total SPI $\leqslant -0.50$	
	S	A	S	A	S	A	S	A
IV	–	–	1	–	2	3	3	3
V	–	–	1	1	2	2	3	3
VI	1	–	–	1	3	2	4	3
VII	–	–	–	–	2	2	2	2
VIII	–	–	2	1	1	2	3	3
IX	–	–	1	–	2	2	3	2
IV–IX	1	0	5	3	12	13	18	16

with the automatic method. For that reason climatic water balance values calculated based on the automatic measurements in most of the periods investigated were more favorable, however, the differences turned out insignificant.

The 10-day mean values of standardized precipitation indices, in the 2000–2004 consecutive growing seasons were calculated by referring the rainfall totals to mean values for the 30-year standard measurements between 1971 and 2000. The comparison of this index, determined based on the measurements taken with the standard rain gauge and the automatic tipping-bucket rain gauge, indicated a significant compliance (Fig. 4). Among all the 90 ten-day periods analyzed, the SPI mean values indicated that 17.7–20% of the periods were extremely dry, very dry or moderately dry (depending on the method of measuring rainfall). Applying the automatic rain gauge to calculate SPI resulted in a less strict drought intensity evaluation (Table 2). As a result of the statistical comparison of the 10-day SPI values calculated based on the standard and automatic precipitation measurements, some differences were found in all the periods and they were unidirectional in character (greater SPI values were indicated with the automatic method) (Table 1).

The correlation and regression analyses confirmed the significance of the compliance of data reported using both rainfall measurement methods. The correlation coefficient defining the dependence of all the 90 pairs of data was 0.975 and the relationship was linear (Fig. 4a). Among all the monthly periods analyzed, the 10-day SPI values were most consistent in September ($R = 0.994$) and least in July ($R = 0.937$) (Fig. 4b and c).

The division of the results for SPI into the drought classes made it possible to notice that the use of the automatic measurement data for the drought monitoring resulted in a less strict drought intensity evaluation, which was directly due to the fact that the automatic method indicated generally greater total precipitation, as compared with the results of the measurements using the manual rain gauge.

The number of days with rainfall during the growing season (April to September), when based on the standard rain gauge versus the automatic method, differed significantly. A larger number of days with precipitation $\geqslant$0.1 mm were recorded by the automatic rain gauge (88 days), whereas the observations based on the manual gauge recorded 31 days less (Table 3). All that could have been due to the differences in the measurement sensitivity of both instruments. As for the automatic rain gauge, even on clearly rainless days but the weather conditions of which enhance the formation of hydrometeors, e.g. dew, the tipping-bucket mechanism changed the positions sending the electric impulse transmitted to the station memory and recorded as precipitation of 0.2 mm. The differences in the number of days with precipitation, recorded with the two measuring methods, related mainly to small precipitation (ranging from 0.1 to 0.9 mm) and, secondly, to precipitation in the range of 1.0–4.9 mm. In the case of rainfall, when the diurnal total exceeded 4.9 mm (range 5.0–9.9 mm, and $\geqslant$10.0 mm), both methods reported a very similar or identical numbers of days.

Table 3
Number of days with precipitation of $\geqslant$0.1 mm, $\geqslant$1.0 mm, $\geqslant$5.0 mm, $\geqslant$10.0 mm based on standard (*S*) and automated (*A*) rain gauge measurements.

Number of days with precipitation in growing period (IV–IX)					
Year	Method	$\geqslant$0.1 mm	$\geqslant$1.0 mm	$\geqslant$5.0 mm	$\geqslant$10.0 mm
2000	*S*	49	42	15	8
	A	86	50	16	9
	S–A	−37	−8	−1	−1
2001	*S*	65	56	29	14
	A	97	62	31	15
	S–A	−32	−6	−2	−1
2002	*S*	56	50	23	10
	A	84	55	23	9
	S–A	−28	−5	0	1
2003	*S*	54	41	12	3
	A	81	44	11	3
	S–A	−27	−3	1	0
2004	*S*	61	53	23	11
	A	92	59	20	12
	S–A	−31	−6	3	−1
Mean 2000–2004	*S*	57	48	20	9
	A	88	54	20	10
	S–A	−31	−6	0	−1

In his research, Sevruk (1996), by a comparison of the amount of daily rainfall and the number of days with precipitation ($P \geqslant 0.1$ mm), observed greater precipitation as well as a greater number of days with precipitation using the traditional method, as compared with the number when using the automatic measurements. However, the results reported by Tekusová et al. (2003) showed that an automatic tipping rain gauge recorded a greater rainfall in 60% of the cases and smaller rainfall in 20% of the cases, as compared with the manual rain gauge. All that leads to the conclusion that the results of the comparison of the amount of precipitation measured at the conventional and automated stations are not representative and must be treated individually. For example, of the eight stations tested by Spengler (1999), in 43% of the cases the volume of rainfall recorded with the automatic rain gauge was smaller, and in 23% of the cases the volume was greater than when recorded using the manual rain gauge. The total amount of precipitation recorded at the automatic stations accounted for 96% of the total noted at the traditional stations.

4. Conclusions

The water consumption in agriculture depends on the interaction between the climatic parameters that determine water supply from precipitation and crop evapotranspiration. The analysis of the appropriate meteorological information is, therefore, a key factor for the plant water requirements evaluation strategy development. The effect of the automation on the continuity of the climatological observations of precipitation, reference evapotranspiration, climatic water balance and droughts estimation was investigated at the station in the agricultural region of Kuyavia, central Poland. This five-year research should make climate researchers alert when joining standard and automated records for the purpose of creating homogeneous time series. Searching for the ways to adjust the automated to standard 10-day growing season data was an important aspect of the investigation. However, obviously, there is no method that could transform the series from the automated station into the standard one accurately.

Automatic data monitoring can be affected by some types of error, related to instrumentation, exposure and sampling. The statistical comparison of precipitation, reference evapotranspiration, climatic water balance and drought index (SPI) generated by adjacent automated and standard weather stations shows small but significant discrepancies. It might be a response of different instruments and the timing of readings. At the same time the research results point to a great correlation between the mean values/10-day totals, which is seen from the correlation coefficients. The differences recorded in the values of the indices were unidirectional. The automated measurement method showed greater total precipitation and SPI values and a much greater number of days with rainfall, as compared with the standard method. The standard method, on the other hand, as compared to the automated one, recorded greater evapotranspiration totals. The use of the automated station precipitation records to calculate the parameters defining the water conditions resulted in more favorable climatic water balance values and a less strict SPI-based drought intensity evaluation. The greater the differences between 10-day values of a given parameter, the smaller the degree of correlation of the data based on the measurements taken with both methods. The equations provided in Table 1 describe the relationship between the automated measurements and the standard observations. The equations allow for the replacement of the data acquired from the automated station with the standard data. However, the calculations made based on those equations will be always encumbered with an error; the smaller the degree of data compliance (correlation coefficient), the greater the error. The research results comprising the 10-day values of the applicable parameters presented in this paper can offer a springboard for further investigations and provide an insight into the characteristics of the indices drawing on the measurements from standard and automated stations. However, the precipitation amounts adjustment calls for further improvement and elaboration.

This research emphasizes that the availability of few-years standard and automated measurements is crucial to the development of transfer functions. The need for overlapping data cannot be disregarded since the site changes contribute to the differences observed and each station demonstrates unique site characteristics. Taking a transfer function calculated for one station and using it for other stations would be impossible. Long-term measurements are necessary in the studies of trends, changes and the variability of agroclimatological indices. A precipitation trend, for example, would be vulnerable to the artificially increased totals. The change of trend would be misleading since the measurement system has changed. Therefore there is a need for more research in this area.

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