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CONTENTS

INTRODUCTION

Agriculture is one of the most important branches of national economy. It is also a branch whose success depends, to a great extent, on environmental criteria and particularly on climatic conditions as well as on temporary weather course. The following monograph has been devoted to agrometeorology research i.e. the research which analyses the connections between climate and weather course and agriculture. The study contains the discussion of selected research issues and the latest findings.

The first two chapters of the monograph present the analysis of the influence of precipitation and fertilization on the yield and sugar content in sugar beet root in the southern and eastern Poland. The data used in the study come from the Station of Cultivar Evaluation located in these areas of the country.

The third chapter presents a general characteristics of spatial variation of ground frost occurrences during two spring months (April, May) in the eastern Poland.

Next chapter of the study investigates the spatial patterns of Sum of Active Temperatures (SAT) and Growing Degree Days (GDD) in Poland and selected countries of Central Europe in order to conduct a general climatology assessment of the suitability of these areas for vine cultivation. These crops come back to these areas after a long break and it is necessary to discuss the possibilities of their redevelopment.

The purpose of the analyses presented in the next chapter is the assessment of the influence of weather conditions on the yield of corn and indication of the trend of the changes in its yielding. The study uses agrometeorlogical models of yield forecasts which were expressed by weather yield indices (WI).

Very interesting issue was presented in chapter six where low-altitude remote sensing used to assess the impact of drought effects on the state of crops in different regions of Poland has been described. The chapter describes the elaborated methodology of taking and analysis of aerial photographs.

Next part of the monograph is devoted to the influence on climatic changes on agriculture and possible adaptation activities in this field. The biggest threats for agriculture in Poland in the future climatic conditions were determined as follows: increase of frequency and intensity of occurrence of extreme climatic conditions, more problems connected with water supply for plants, intense development of native phyto-pathogenes, and also the expansion of thermophilic species. The following adaptation measures were proposed: the increase of water resources accessible for agriculture and the increase of efficiency of its use, and also decrease of plants water demand. Additionally, as far as plant protection is concerned such adaptation of cultivation technology was proposed that it can limit the incidence of agrophages and introduce effective methods of preventing the appearance of new types of agrophages. In the case of extreme meteorological events it is concluded that the most effective preventive measure is the development of special insurance for farmers.

Chapter eight addresses the issue of weather derivatives used in agriculture insurance. The topic was noticed as completely new and not very well known so a great emphasis should be put on education regarding policy and strategy of using weather derivatives. Particularly the dangers connected with using them by people who have little business experience.

Subsequent chapters were devoted to the area of the north-eastern Poland, regarding the research into the length of vegetation period and time of occurrence of spring and autumn ground frosts. Also the influence of meteorlogical conditions on the growth, development and yield of *Lupinus angustifolius* was considered.

Chapter eleven contains information on quality verification of the decision supporting system in agriculture. It was concluded that agrometeorology information service is a precious tool in farmers' hands but it requires huge knowledge and experience in order to interpret the information contained in the service properly.

Last chapter discus the occurrence and harmfulness of agrophages of crops in agriculture. One of non-observational methods of forecasting of pest occurrences was described by means of the so called degree-days and the changes which may be brought about by climatic variations.

The presented monograph will allow the reader to learn about the range and the latest achievements of the agrometeorology research conducted in Poland at present.

Dr Jacek Leśny

1. EFFECT OF PRECIPITATION AND FERTILIZATION ON YIELDING AND SUGAR CONTENT OF SUGAR BEET IN SOUTH POLAND

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INTRODUCTION

In the production of sugar beet of much importance are the meteorological conditions, the amount of rainfall in particular (Water needs …..1989, Grzebisz *et al.* 2004). In the development cycle of this plant one can distinguish the spring period of small water needs (IV-V), early summer, when water needs are increasing (VI), the critical summer period of largest water needs, concurrent with the phase of the most intensive development of foliage and growth of roots (VII-IX), and the autumn period of decreasing water needs (after 15 IX) (Nowak 2006). A great influence on sugar beet yielding has fertilization, especially with nitrogen and potassium (Nowak 2006, Wyszyński *et al.* 2002). The progress in breeding results in more and more efficient cultivars of sugar beet, and hence in studies on a broader group of cultivars it seems necessary to make restriction to cultivars of similar yielding, with allowance for time trend. The previous investigation of the effect of the above mentioned factors on the performance of the beet are concerned mainly with root yield and quality parameters, especially sugar content. It is also important to consider the yield of foliage of the plant, which is the basic assimilation apparatus and a valuable animal fodder.

MATERIALS AND METHODS

The data came from the Stations of Cultivar Evaluation: Zybiszów, Tarnów Śląski, Głubczyce, Słupia Jędrzejowska, Przecław and Zadąbrowie; which are located in the southern belt of Poland and thus insured similar thermal conditions for the plants. The following sugar beet cultivars were included: Alyssa, Kujawska, Lupus, Tristan, Elan, Kassandra, Leo, Dojana, Saskia, Diadem, Cordelia, Nilla, Kutnowska; cultivated on soils of very good and good wheat complex from 1989 till 2005. Variation of root and foliage yield as well as percent sugar content in roots were tested with the regression method, as affected by the following factors: rainfall during the period of smaller water needs (April-June), rainfall during the critical period (July-September), fertilization with nitrogen, phosphorus and potassium. Time trend was taken into account. The model was of the form:

$$y = b_0 + \sum_{i=1}^{5} (b_i x_i + b_{ii} x_i^2) + b_6 x_6 \qquad (1)$$

where: y – yield of roots/foliage (dt ha^{-1}) or sugar content (%),
x_1 – rainfall in April-June (mm),
x_2 – rainfall in July-September (mm),
x_3 – nitrogen fertilization (kg ha^{-1}),
x_4 – phosphorus fertilization (kg ha^{-1}),
x_5 – potassium fertilization (kg ha^{-1}),
x_6 – year of investigation.

Calculations for beetroots yield and sugar content were conducted on a pool of 274 cases, and those of foliage yield on 234 cases.

Based on the regression equation (1), for individual factors (x_i, i = 1...5) the following functions were drawn:

$$f_i(x_i) = b_i x_i + b_{ii} x_i^2 + c_i \qquad (2)$$

where: c_i – a constant selected in such a way that the minimum value of the function $f_i(x_i)$ is zero in the range studied (factor mean ± standard deviation).

The plots illustrate the effect of an individual factor on yield or sugar content. Moreover, the range of yield and sugar content variation in the intervals has been determined and optimum value of factors specified.

RESULTS AND DISCUSSION

From the analysis performed it follows that yield of sugar beet roots was modified in a similar way by rainfall in April-June and July-September (Tab. 1). In the first period, in the studied range 140-240 mm, the optimum value of factor was 223 mm. For successive months of that period, Klatt and independently Dzieżyc determined the following optimum values of rainfalls: IV – 50 and 17 mm, V – 50 and 62 mm, VI – 77 and 60 mm, respectively (Water needs …1989). These values when summed up for the three months are lower than those obtained from the model. In the second period (July-September) the yield of roots increased with increasing number of rains in the whole period (150-310 mm) and reached an optimum value for 310 mm. This value is lower than the sum of monthly rainfalls for the III quarter as determined by Dzieżyc and Klatt (229 mm and 240 mm, respectively).

Table 1. Modification of sugar beet yield and sugar contents due to examined factors

Factor	Range of factor tested	Root yield		Leaves yield		Sugar contents	
		Optimum value of factor	Changes due to factor (dt ha^{-1})	Optimum value of factor	Changes due to factor (dt ha^{-1})	Optimum value of factor	Changes due to factor (%)
Rainfall in April-June (mm)	140-240	**223**[*)]	**30**	240	45	**140**	**2,8**
Rainfall in July-September (mm)	150-310	**310**	**29**	**310**	**130**	**150**	**5,5**
Nitrogen fertilization (kg ha^{-1})	110-160	160	42	**114**	**53**	160	0,3
Phosphorus fertilization (kg ha^{-1})	60-100	**60**	**62**	100	39	60	0,2
Potassium fertilization (kg ha^{-1})	120-180	**180**	**42**	120	59	**180**	**1,1**

[*)] in bold – values obtained from statistically significant ($p<0.05$) regression coefficients.

The yield of sugar beet roots was considerably modified by the use of fertilization (Fig. 1). Nitrogen fertilization (at the rate 110-160 kg ha^{-1}) induced an increase in yield of 42 dt ha^{-1} (not confirmed statistically). Borówczak (1991) and Rzekanowski (1992) obtained increased yield of roots with doses that increased up to 140-160 kg ha^{-1}.

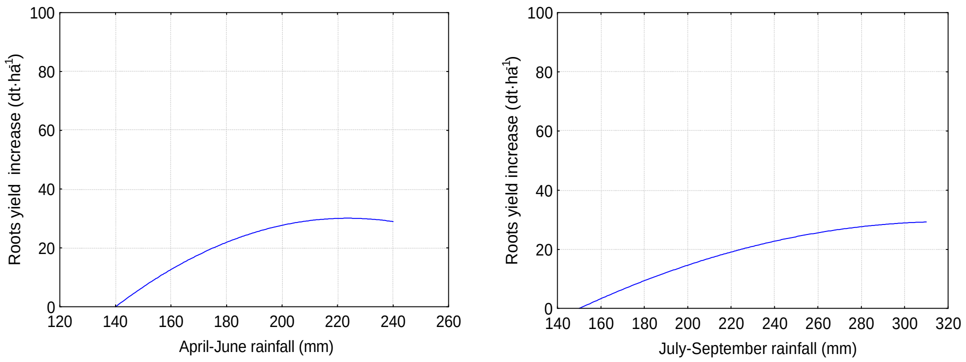
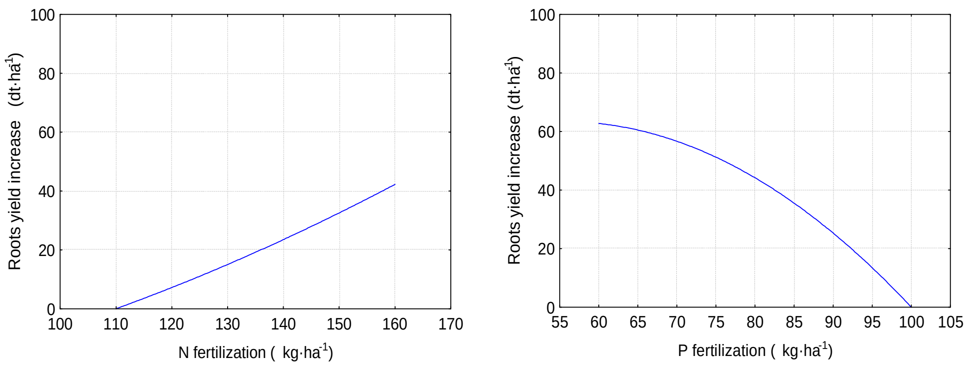


Fig. 1a. Dependence of sugar beet roots yielding on factors tested



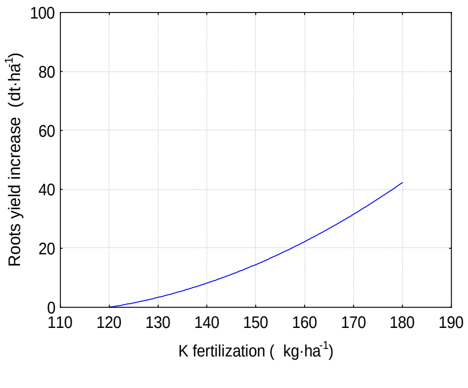


Fig. 1b. Dependence of sugar beet roots yielding on factors tested

The optimum phosphorus fertilization was found to be 60 kg ha^{-1}. Larger doses caused a decrease in beetroot yield even by 60 dt ha^{-1}. Czuba (1993) reported results that indicated at an increase of even 140 kg ha^{-1} in root yield. The difference between our results and the literature ones may be due to the high phosphorus contents in Stations of Cultivar Evaluation experiments (average 34 mg 100 g^{-1} of soil).

Potassium fertilization in the range 120-180 kg ha^{-1} caused an increase of 42 dt ha^{-1} and its optimum value was reached with maximum doses of 180 kg ha^{-1}. Likewise, in the studies by Nowakowski *et al*. (2007) potassium fertilization up to 166 kg ha^{-1} induced an increase in beet root yield.

The yield of sugar beet foliage was most strongly modified by rainfall in July-September (Fig. 2). The difference in foliage mass between the least beneficial value of 150 mm and the optimal of 310 mm was 130 dt ha^{-1}. Rainfall in the period April-June contributed less to the yield of foliage. With precipitation of 140 mm the obtained mass of foliage was by 45 dt ha^{-1} smaller than with precipitation 240 mm.

Optimal fertilisation, with regard to the yield of foliage, was 112 kg ha^{-1} nitrogen, phosphorus – 100 kg ha^{-1} and potassium – 120 kg ha^{-1}. In the ranges studied, the increasing doses of nitrogen and potassium caused lower mass of foliage by over 50 dt ha^{-1}, whereas by nearly 40 dt ha^{-1} due to increased phosphorus. These dependencies were statistically confirmed only in the case of nitrogen fertilization. In the studies by Nowakowski (2007) the yield of foliage reacted to potassium fertilisation to the amount of 166 kg ha^{-1}.

The content of sugar in roots of sugar beet was strongly modified by rainfall in the vegetation season (Fig. 3). When analysing this parameter, both in the period April-June and July-September, optimal proved to be the lowest precipitation, i.e. 140 and 150 mm, respectively. Under the least favourable conditions in the first part of the vegetation season (240 mm rainfall) the content of sugar in roots was by 2.8 pp lower. Sugar content was lowered even more by rainfall in the second part (July-September). With maximum rainfall (310 mm) this parameter was lower by 5.5 pp relative to the value with the optimum rainfall of 150 mm. The significant negative, linear relationship between sugar content and rainfall in the whole vegetation season was obtained by Niedbała *et al*. (2007) in a regression model.

Sugar content in roots of sugar beet did not depend on nitrogen and phosphorus fertilisation, whereas this parameter was increased by 1.1 pp due to potassium fertilisation. Prośba-Białczyk *et al*. (2001) and Borówczak *et al.* (2006) have found a significant decrease in sugar content with increasing nitrogen fertilisation when investigating the substantially broader ranges of N variation 0-240 kg ha^{-1} and 0-150 kg ha^{-1}, respectively. Niedbała *et al.* (2007) in a regression model showed a negative, linear relation between sugar content and phosphorus fertilisation. In turn, Nowakowski *et al*. (2007) found an increased sugar content in root pulp due to potassium fertilisation of 166 kg ha^{-1}.

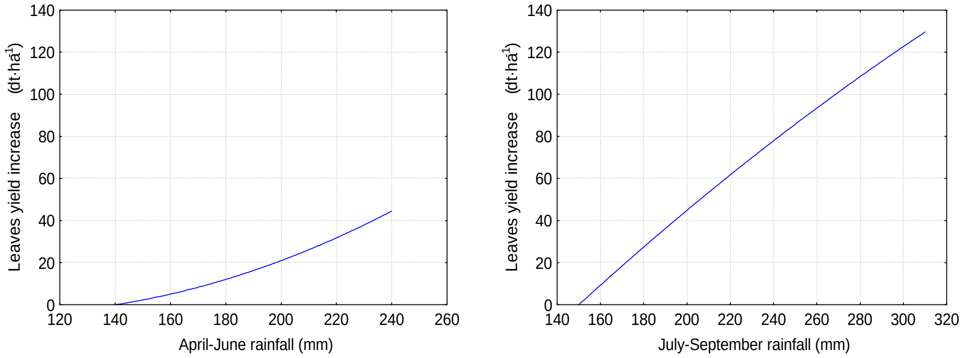
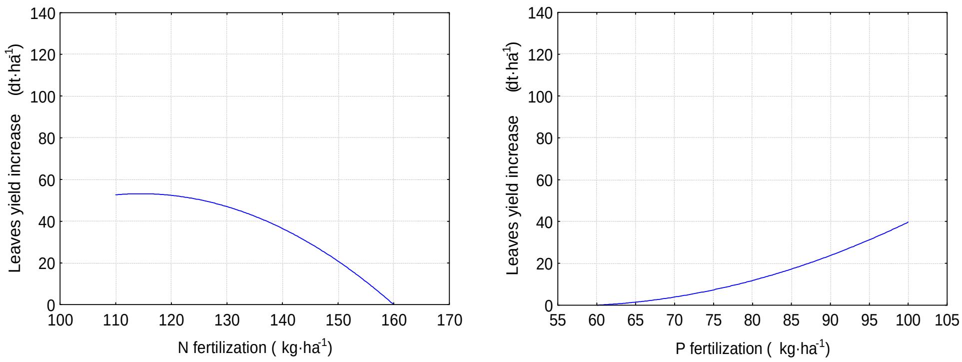


Fig. 2a. Dependence of sugar beet leaves yielding on factors tested



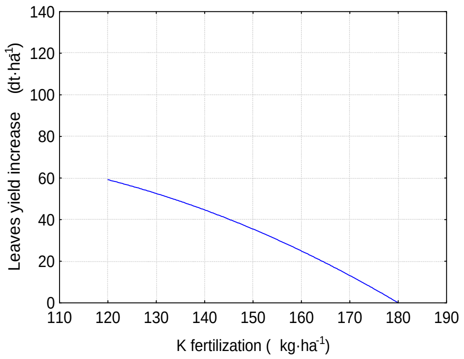


Fig. 2b. Dependence of sugar beet leaves yielding on factors tested

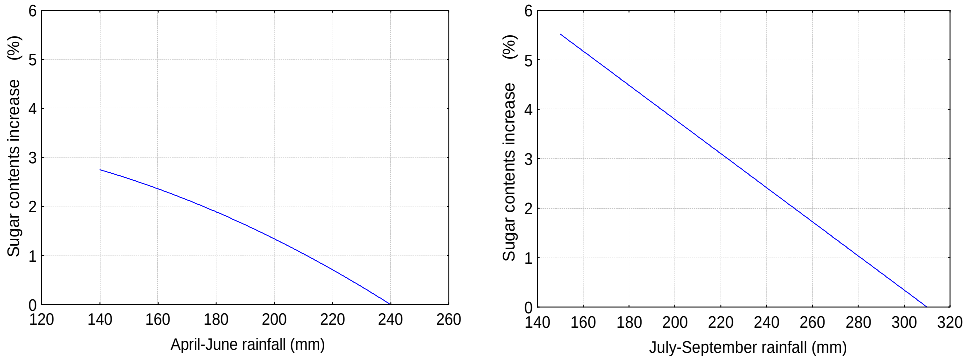
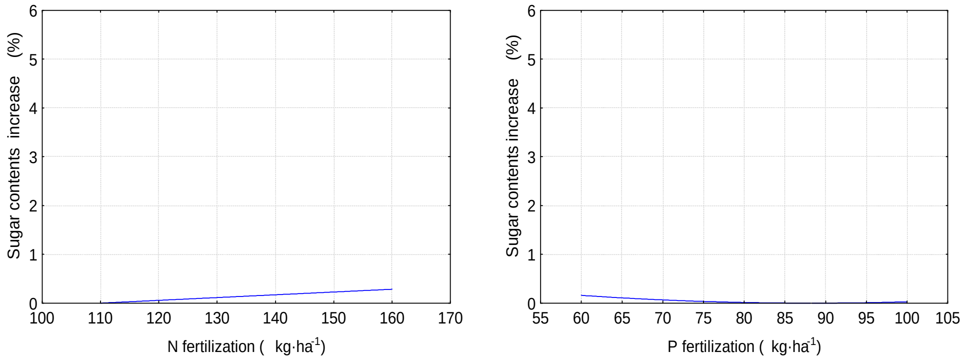


Fig. 3a. Dependence of contents of sugar in sugar beet roots on factors tested



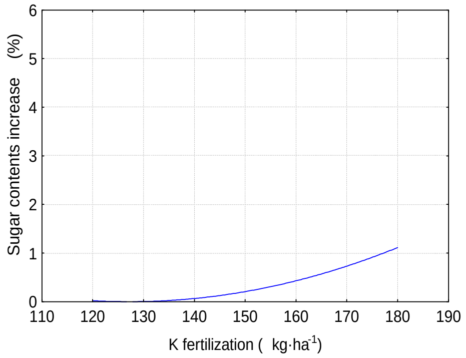


Fig. 3b. Dependence of contents of sugar in sugar beet roots on factors tested

CONCLUSIONS

1. In cultivation of sugar beet in south Poland precipitation in April-June and July-September modified the yields of roots in a similar manner, i.e. approx.

30 dt ha^{-1}. In the case of leaf yield decisive were rainfalls of the summer period (increase by 130 dt ha^{-1}). Precipitation in July-September decreased sugar content by 5.5 pp, and that of April-June – by 2.8 pp.

2. The yield of sugar beetroots increased owing to nitrogen and potassium fertilization (optimum: 160, 180 kg ha^{-1}, respectively), and that of leaves by due to phosphorous (optimum: 100 kg ha^{-1}). Potassium fertilization caused an increase in sugar content, whereas fertilization with nitrogen and phosphorous did not affect it significantly.

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2. EFFECT OF PRECIPITATION ON YIELD AND SUGAR CONTENT OF SUGAR BEET IN EASTERN POLAND

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INTRODUCTION

About precipitation requirements of sugar beet, which are fundamental for that plant cropping (Water requirements …1989, Grzebisz *et al*., 2004), it is spoken with reference to determined optimal rainfalls in individual months, agrofenological phases or decades of vegetation season (Water requirements …1989, Panek 1993). It is, however, known that rainfall requirements of a plant in a given period are determined, to a considerable degree, by the amount of rainfall that occurred earlier. Hence, when studying the effect of rainfall on the size and quality of a crop, it is advisable to consider the interaction between rainfalls in individual periods.

In the development cycle of sugar beet can be distinguished the spring period of small water requirements (IV-V), the early summer period of increasing needs (VI), the critical period of greatest water needs during intensive development of leaves and roots (VII-IX) and the autumn period of decreasing water requirements (after 15 IX) (Nowak 2006).

In simple terms, with regard to water requirements, the vegetation season of sugar beet can be divided into: the spring stage – April-June and summer stage – July-September. Making allowance for the interaction of rainfalls in the two periods, one can precisely answer the question: which combinations of the two factors are more and which less favorable, and what differences (in root and leaf mass, sugar percentage) they cause, and to what extent a rainfall of the first period determines the water requirements in the second period.

MATERIALS AND METHODS

Data were taken from stations of cultivar valuation located in eastern Poland: Krzyżewo, Czesławice and Bezek. The following varieties of sugar beet were considered: Alyssa, Kujawska, Lupus, Tristan, Elan, Kassandra, Leo, Dojana, Saskia, Diadem, Cordelia, Nilla, Kutnowska, cultivated on soils of very good, good and faulty wheat complex from 1991 to 2005. The variation in root and leave yield of sugar beet that was due to precipitation in the spring period of smaller water needs (April-June) and precipitation in the summer, critical period (July-September). The time trend was considered. The following regression model was applied:

$$y = b_0 + b_1 x_1 + b_{11} x_1^2 + b_2 x_2 + b_{22} x_2^2 + b_3 x_3 \quad (1)$$

where: y – root yield, leaf yield ($dt \cdot ha^{-1}$) or sugar content (%),
x_1 – precipitation in April-June (mm),
x_2 – precipitation in July-September (mm),
x_3 – year of study,
b_i, b_{ii} – regression coefficient.

Calculations for the yield of beet roots and sugar content were done on a set of 142 cases, and those for leaf yield on 133 cases. The coefficients of multiple correlation for the yield models of root, leaf and sugar content were 0.67; 0.65 and 0.65, respectively.

Based on the regression equation, the dependences of the yield of roots, leaves and sugar content on spring and summer precipitation were plotted. For x_3 was assumed the mean of the variable. The range of rainfall variation in IV-VI and VII-IX was the mean ± standard deviation. The yield value was calculated for some sets of factors and the optimal and the least advantageous set were determined. It was found what is the optimal precipitation of the summer period for various precipitation values in the spring period.

RESULTS AND DISCUSSION

The variation of precipitation in April-June in the range 119-215 mm and in July-September in the range 124-266 mm modified the mass of sugar beet roots considerably (Fig. 1). The yield of 763 dt ha^{-1} reached with the most optimal set, i.e. spring precipitation 119 mm and summer – 266 mm, was by 113 dt ha^{-1} (17%) higher than with the least favorable precipitation, i.e. 215 and 124 mm, respectively. An increase in precipitation in the period IV-VI caused a decrease and in the period VII-IX an increase in the yield, the effect of the summer precipitation being stronger. The optimum value of the summer precipitation did not depend on the spring precipitation and was 266 mm (Tab. 1).

Dzieżyc *et al*. (1987) have summed up the decade optimum precipitation for sugar beet for east Poland, which summed over the period IV-VI are 136 and 156 mm depending on region; whereas in the period VII-IX - 223 and 221 mm. Klatt (Water needs … 1989) reported monthly precipitation as optimal, which for spring period were 160 mm and for summer period 240 mm. For both the author cases these values are higher for IV-VI and lower for VII-IX than the obtained in this research. On the other hand, Wiśniewski (1991) differentiated water needs of sugar beet in relation to soil compaction. Thus, for light soils the optimum precipitation in IV-VI was 185 mm and for heavy soils – 119 mm; whereas for the period VII-IX the values were 362 mm and 246 mm, respectively. Values of optimal precipitation for heavy soils were close to those obtained in our study. Rudnicki et al. (1997), when analyzing the effect of precipitation in individual months, noticed that rainfalls in May and June are not advantageous when July is dry, this partly confirming the set of factors we got for the lowest yield of roots.

The yield of leaves was markedly stronger modified by variation in precipitation than that of roots (Fig. 2). Under optimum conditions, with lowest rainfall in the months IV-VI (119 mm) and highest in VII-IX (266 mm), the yield amounted to 598 dt ha^{-1}, and was by 245 dt ha^{-1} (58%) greater than under the least favourable conditions: rainfall in IV-VI – 119 mm and rainfall in VII-IX - 124 mm. Analysing the obtained model, it was also found that optimum rainfall of the summer period was affected by rainfall of the spring period. Thus, for the lowest value of spring rainfall the optimum was 266 mm, for mean value – 223 mm, and for the highest value – 181 mm. A greater spring rainfall had a positive effect on leaf yield when rainfall of the summer period was low, and negative when they were high. With maximum rainfall in both the periods the yield fell to 356 dt ha^{-1}.

Precipitation caused sugar content in sugar beet roots in the range 17.6-19.2%. Maximal contents were reached with low values of spring and summer precipitation (119 i 128 mm) (Fig. 3). Other sets of the two factors proved unfavourable, the least favourable being the set of the two precipitations occurring at a maximum. For an average and high spring rainfall the optimum rainfall of the summer period was 150 i 172 mm, respectively. However, the losses in sugar content caused by a too high spring rainfall proved to be too high to compensate in a later period. A significant, linear relationship between sugar content and precipitation in the whole vegetation season was obtained by Niedbała *et al*. (2007).

Table 1. Sugar beet yield and sugar content in roots as dependent on April-June and July-September rainfall

Factor tested		VII-IX rainfall (mm) min. 124	VII-IX rainfall (mm) avera-ge 195	VII-IX rainfall (mm) maks. max. 266	Optimal VII-IX rainfall for fixed IV-VI rainfall	Optimal case of IV-VI and VII-IX rainfall (mm/mm)	The least favourable of IV-VI and VII-IX rainfall (mm/mm)
Roots yield (dt ha^{-1})							
IV-VI rainfall (mm)	min. 119	710	741	763	266	119/266	215/124
	average 167	683	721	751	266		
	max. 215	650	697	735	266		
Leaves yield (dt ha^{-1})							
IV-VI rainfall (mm)	min. 119	253	512	598	266	119/266	119/124
	average 167	365	520	503	223		
	max. 215	425	477	356	181		
Sugar content (%)							
IV-VI rainfall (mm)	min. 119	19.2	19.0	18.1	128	119/128	215/266
	average 167	18.7	18.6	17.9	150		
	max. 215	18.0	18.1	17.6	172		

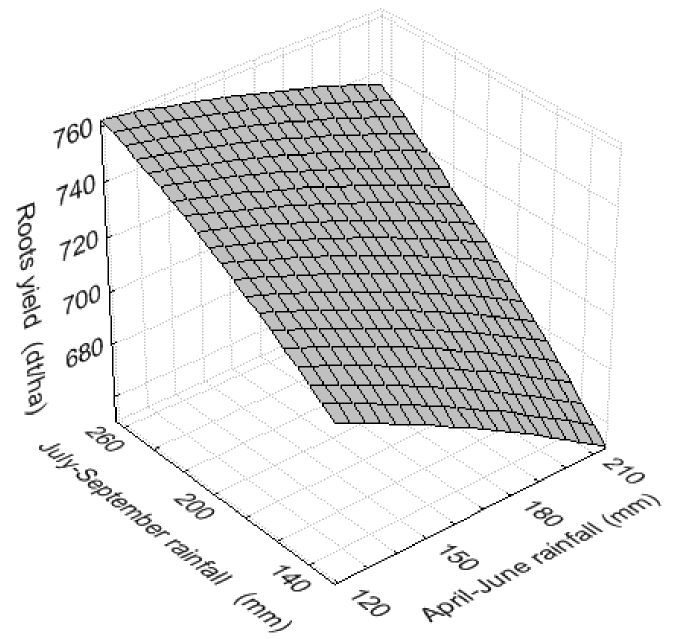

Fig. 1. Yield of sugar beet roots as dependent on rainfall in April-June and July-September

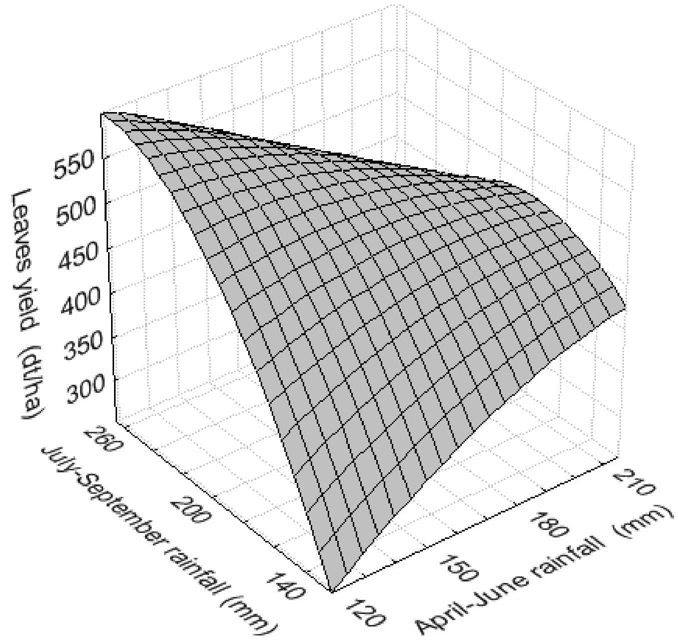

Fig. 2. Yield of sugar beet leaves as dependent on rainfall in April-June and July-September

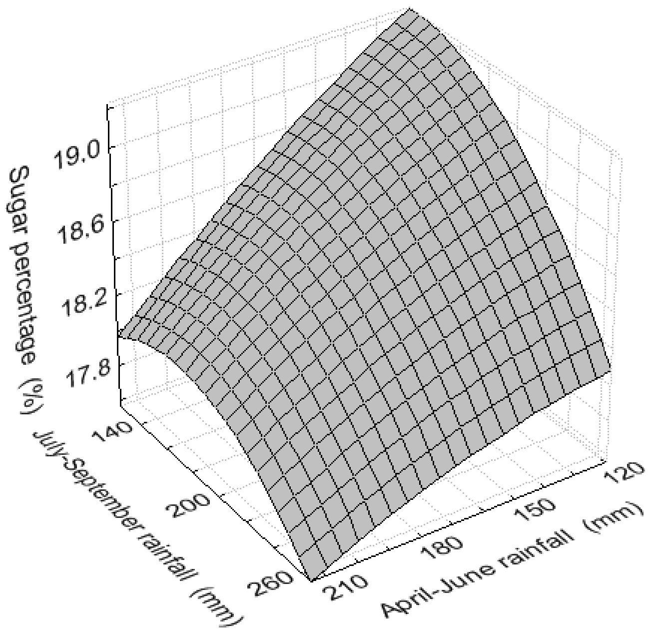

Fig. 3. Sugar content in roots of sugar beet as dependent on rainfall in April-June and July-September

CONCLUSIONS

1. An optimum set for best crop of sugar beetroots and leaves was the following: April-June rainfall – 119 mm (minimum) and July-September rainfall – 266 mm (maximum). The least favourable for root yield was the set in which the highest precipitation in April-June (215) was accompanied by the lowest precipitation in July-September (124 mm), and for leaves – when precipitation in both the periods was the smallest (119 mm and 124 mm).

2. The highest sugar content was obtained when rainfall of April-June and July-September was at a minimum (119 mm and 124 mm), and the lowest when it was at a maximum (215 mm and 266 mm).

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3. FROST OCCURRENCE IN APRIL AND MAY IN THE EASTERN POLAND AREA IN THE PERIOD 1988-2007

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PREFACE

Spring frosts are a big threat for a fruit tree correct growth and development, which effects in crops amount and quality. Decrease in air temperature below 0^oC causes ice forming in plant tissues. Ice crystals can burst cells from inside and lead to sinking, for example fruit trees young buds (Rodrigo 2000).

In moderate latitudes occurrence of spring decreases in air temperature below 0^oC depends not only on height a.s.l. and area relief, but also on the character of atmospheric circulation . Analysis of data from meteorological stations provides to general results about frost occurrence in time and space variability. More information about frost genesis we can obtain by evidencing synoptic situations which favor frost day occurrence in first two months of vegetation period.

In agroclimatic and climatic literature, frost occurrence on the area is most often characterized as mean number of days with frost in single months. Moreover, frost sequences with specified length and frost intensity (air temperature decrease below 0^oC size).

Characteristic frost (on 5 and 200 cm a.g.l.) in the whole country area was made by Pieślak (1955) and Koźmiński (1976). In regional scale this issue was worked out by Kołodziej and Węgrzyn (2000a, 2000b) (Lublin region) and also Dragańska *et al*. (2004) (north-eastern Poland).

DATA AND METHODS

An object of this work is a general characteristic of frost occurrence space variability in two spring months, April and May, in the eastern Poland, in the period of 1988-2007. For majority of orchard plants, spring frosts are widely more dangerous than autumn (Koźmiński 1976). Moreover, on average, the break of March and April the beginning of the vegetation period is observed in this part of country (Węgrzyn 2007). It is important that in the end of the 80 s the beginning of a new circulation epoch is dated, which has the highest zone index in the XX century (Degirmendžić *et al.* 2000).

The analysis is based on the air temperature measurements at height 200 cm a.g.l., which were made on 17 meteorological stations (therein two stations from western Belarus and Ukraine – Table 1).

Table 1. Localization of meteorological stations

No	Meteorological station	Latitude	Longitude	Altitude a.s.l. (m)
1	Bezek	51º11′	23º15′	225
2	Białystok	53º07′	23º11′	139
3	Brześć (B)	52º07′	23º41′	143
4	Czesławice	51º19′	22º16′	205
5	Felin	51º14′	22º38′	215
6	Kielce	50º51′	20º37′	268
7	Lublin-Radawiec	51º13′	22º24′	240
8	Przemyśl	49º48′	22º46′	237
9	Rzeszów	50º06′	22º03′	200
10	Sandomierz	50º41′	21º45′	202
11	Siedlce	52º11′	22º16′	146
12	Tarnów	50º02′	20º59′	209
13	Uhrusk	51º18′	23º37′	180
14	Warszawa-Okęcie	52º09′	20º59′	106
15	Włodawa	51º33′	23º33′	175
16	Włodzimierz Wołyński (U)	50º50′	24º19′	194
17	Zamość	50º42′	23º15′	212

Data are from archive of Agrometeorology Department of Life Sciences University in Lublin and from climatological database National Climatic Data Center (NCDC NOAA). Data from NOAA were checked by comparing random air temperature values with data from listings IMGW (Krzyżewska 2007). In result there were no significant differences.

All day was summed, within which minimum air temperature was below or equal to 0°C and daily mean air temperature reached positive value. Next, separately for every month and every meteorological station, there was listed mean number of days with frost, also in specified air temperature ranges (0 to –2ºC; –2.1 to –4ºC; –4.1 to -6ºC; <-6ºC) and occurrence of frost sequences with different days number (1, 2, 3, 4 i >4 days).

Days with frost were summarized with circulation types according to Hess-Berezowsky typology, what let to point this synoptic situation, which provides the most often decrease in air temperature below 0°C in April and May. Conditional probability (%) was calculated for each type of circulation. It means the number of day with frost, which were recorded during the occurrence of a type, in relation to the number of days with this type of circulation.

RESULTS AND DISCUSSION

In the analyzed period of 1988-2007, the highest mean number of days with frost in April was noticed in Białystok (10.9 days) and Kielce (8.8 days). The lowest number of these days was noticed in Przemyśl and Sandomierz (4.6 and 4.7 days – Fig. 1a; Tab. 2). In May, such days most often occurred in Białystok and Warszawa (average 2 days) and sometimes in Bezek, Sandomierz and Tarnów (0.3 day – Fig. 1b; Tab. 2). Increase of average number of days with frost from Sandomierz Hollow area toward Podlaska Lowland is unquestionably related to the increasing of northern east climate temperature continentalism. Some aberrations of direction of these changes are caused by relief and altitude effect (e.g. Roztocze area). Referring to the results of Kołodziej and Węgrzyn (2000a), from the years 1971 to 1990, can be generally concluded that the analyzed area in the last period reported fewer days with frost, both in April and May.

Important characteristics are frost sequences, because single and intensive frost causes smaller damages than milder, but occurring several times day in and day out (Bednarek and Liniewicz 2007). In April, in eastern Poland, most often 1-day frost shows (at most – 2 cases – in Białystok – Tab. 2). The longest sequences (>4 days) were noticed in this month on average once in 2 years in Rzeszów,

Table 2. Basic characteristics of days with frost in meteorological stations in period 1988-2007

Meteorological station	Average number of days with frost		Average number of frost sequences 1		2		3		4		>4 days		The longest frost sequences (days)	
	IV	V	IV	V	IV	V	IV	V	IV	V	IV	V	IV	V
Bezek	5.1	0.3	0.9	0.1	0.5	0.1	0.4	–	0.1	–	0.4	–	7	2
Białystok	10.9	2.0	2.0	0.9	0.9	0.3	0.5	0.1	0.3	–	0.8	0.1	8	5
Brześć	5.9	0.5	1.9	0.3	0.4	0.1	0.4	–	0.2	–	0.2	–	7	2
Czesławice	5.9	0.6	1.7	0.3	0.5	0.1	0.5	0.1	0.2	–	0.3	–	6	3
Felin	4.9	1.0	1.3	0.4	0.3	0.2	0.5	0.1	0.3	0.1	0.1	–	6	4
Kielce	8.8	1.3	1.7	0.7	1.1	0.1	0.4	0.2	0.3	–	0.4	–	7	3
Lublin-Radawiec	5.7	0.7	1.5	0.3	0.8	0.1	0.3	–	0.2	0.1	0.2	–	6	4
Przemyśl	4.6	0.5	1.1	0.3	0.9	0.1	0.3	–	0.1	–	0.2	–	6	2
Rzeszów	8.0	1.2	1.3	0.8	1.0	0.2	0.3	0.1	0.3	–	0.5	–	7	3
Sandomierz	4.7	0.3	1.4	0.2	0.6	0.1	0.1	–	0.2	–	0.2	–	6	2
Siedlce	7.9	1.2	1.6	0.3	0.7	0.2	0.3	0.1	0.3	0.1	0.5	–	8	4
Tarnów	5.2	0.3	1.1	0.2	0.8	–	0.3	0.1	0.2	–	0.2	–	8	3
Uhrusk	6.3	0.5	1.4	0.3	0.9	0.1	0.3	–	0.3	–	0.3	–	5	2
Warszawa-Okęcie	7.7	2.0	1.5	0.9	0.5	0.3	0.4	0.1	0.4	–	0.4	0.1	9	5
Włodawa	7.1	1.0	1.9	0.4	0.7	0.2	0.3	0.1	0.3	–	0.4	–	6	3
Włodzimierz Wołyński	6.6	0.5	2.0	0.3	0.7	0.1	0.4	–	0.2	–	0.2	–	7	2
Zamość	8.1	1.0	1.7	0.5	0.8	0.2	0.4	–	0.3	0.1	0.5	–	10	4

Siedlce and Zamość and little more often in Białystok. In May, frost sequences above 3 days occurred only in few meteorological stations (average once for decade). Moreover, in April, 1-day frosts were 22.7%, 2-day – 20.8%, 3-day – 15.0%, 4-day – 12.9% and over 4-day was 28.6% of general number of days with frost. However, the share of these sequences in every station is very different. In May, there is shown a distinct disproportion between the shortest and the longest sequences: 1-day are 44.7%, 2-day – 28.7%, 3-day – 12.3%, 4-day – 6.8% and over 4-day only 7.5% of general number of days with frost.

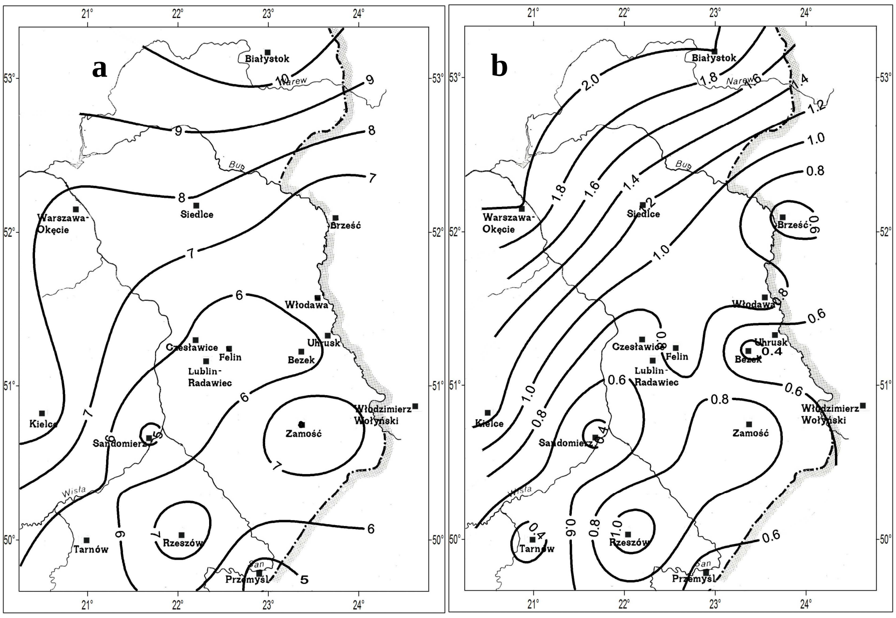

Fig. 1. Average number of days with frost in April (a) and May (b) in period 1988-2007

In April in all stations, the most frequently occurred mild frost (–2.0ºC ≤ t_{min} ≤ 0.0ºC – Tab. 3). A view space variability of average number of days with stronger frost (second and third range; Fig. 2a and 2b) is near to the general average number of days with frost (Fig. 1), which raises toward Podlaska Lowland. Very strong frost (t_{min} < –6.0ºC) was very rare and not in all stations (once a several years in Białystok and Kielce). In May mild frost prevailed too, and days with t_{min} ≤ –4.1ºC showed episodically.

Table 3. Average days with frost in defined intensity ranges of minimal temperature in period 1988-2007

Meteorological station	<0; –2ºC>		<–2.1; –4ºC>		<–4.1; –6ºC>		< –6 ºC	
	IV	V	IV	V	IV	V	IV	V
Bezek	3.4	0.2	1.4	0.1	0.4	–	–	–
Białystok	6.0	1.4	3.2	0.6	1.3	0.1	0.4	–
Brześć	3.7	0.5	1.7	.	0.5	–	–	–
Czesławice	4.0	0.5	1.5	0.1	0.4	0.1	0.1	–
Felin	3.4	0.8	1.4	0.3	0.1	–	0.1	–
Kielce	5.5	1.2	2.0	0.1	1.0	0.1	0.3	–
Lublin-Radawiec	3.8	0.5	1.6	0.2	0.3	0.1	–	–
Przemyśl	3.2	0.4	1.3	0.1	0.2	–	–	0.1
Rzeszów	5.0	0.9	1.9	0.2	1.2	0.1	–	–
Sandomierz	3.1	0.3	1.3	–	0.3	–	–	–
Siedlce	4.7	0.8	2.5	0.4	0.7	–	0.1	–
Tarnów	2.8	0.3	1.5	0.1	0.9	–	0.1	–
Uhrusk	3.8	0.5	2.2	–	0.4	–	–	–
Warszawa-Okęcie	5.1	1.4	2.2	0.6	0.4	0.1	–	–
Włodawa	4.9	1.0	1.8	–	0.5	–	0.1	–
Włodzimierz Wołyński	4.3	0.4	2.0	0.1	0.4	–	.	–
Zamość	4.6	0.8	2.2	0.2	1.2	–	0.1	–

The addition to researches about occurrence of spring frosts in eastern Poland is the characterization of circulation conditions propitious for periodical decreases in air temperature below 0^{o}C. The characteristic feature in April and May over Lublin region is the increased frequency of arctic air masses advections (Kaszewski 2008).

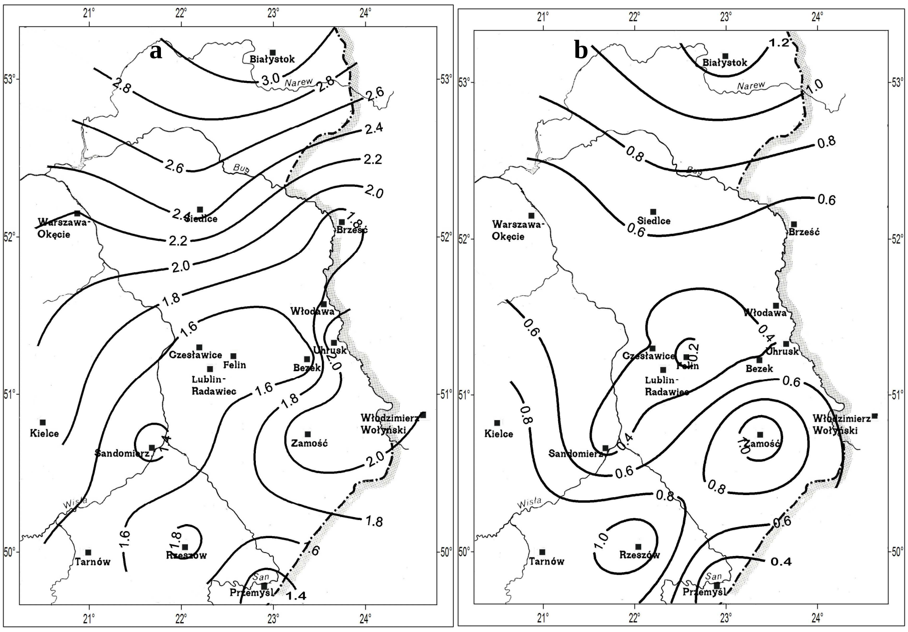

Fig. 2. Average number of days with frost in April and May relatively to intensity: ranges <–2.1; –4.0ºC> (a) and <–4.1; –6.0ºC> (b)

In this work synoptic situations over Central Europe during days with frost were analyzed. Analysis was based on a calendar of circulation types „Grosswetterlagen" (GWL) (Gerstengarbe *et al.* 1999) made by Hess and Berezowsky, where main criteria are: direction of air masses move and kind of dominant pressure system (Tab. 4).

In April in Central Europe about 60% of days with frost occurred during circulation types belonging to two from ten subgroups: meridian circulation with air advection from north (34%; *Na, Nz, HNa, HNz, HB, TrM*) and combined circulation with advanced high pressure system over Central Europe (25,2%; *HM, BM*). In the first subgroup *HNa* type stood out (12.6%; Fig. 3a, Tab. 4) which is conditioning advection of cold arctic air masses (advective frosts) from northern sector. In the second subgroup *BM* type stood out (18.8%; Fig. 3b) which in spring favors decrease of air temperature below 0^{o}C during cloudless nights (radiative frosts). During analyzed 20-year period *HNa* type was shown in April more rarely than *BM* type, that conditional probability frost occurrence with *HNa* type was high and reached almost 50%.

Table 4. Listening of circulation types (after: Ustrnul and Czekierda, 2002) and occurrence frequency (a) (%) and conditional probability (b) (%) in April and May during days with frost

Nr	Symbol	Type description	April		May	
			a (%)	b (%)	a (%)	b (%)
1	*Wa*	anticyclonic westerly	1.2	18.2	0.0	0.0
2	*Wz*	cyclonic westerly	6.9	15.8	2.9	1.1
3	*Ws*	south-shifted westerly	–	–	–	–
4	*Ww*	maritime westerly (block E.Europe)	0.2	2.4	–	–
5	*SWa*	anticyclonic south-westerly	4.0	21.5	0.0	0.0
6	*SWz*	cyclonic south-westerly	0.7	4.3	5.2	2.9
7	*NWa*	anticyclonic north-westerly	0.7	34.7	5.4	7.5
8	*NWz*	cyclonic north-westerly	4.4	30.7	1.3	2.5
9	*HM*	high over Central Europe	6.3	42.4	18.1	12.6
10	*BM*	zonal ridge across Central Europe	18.8	31.4	14.1	3.7
11	*TM*	low over Central Europe	1.2	7.4	0.0	0.0
12	*Na*	anticyclonic northerly	–	–	1.5	4.0
13	*Nz*	cyclonic northerly	4.6	42.9	1.5	3.0
14	*HNa*	Icelandic High. ridge C. Europe	12.6	46.4	13.1	15.5
15	*HNz*	Icelandic High. trough C. Europe	0.1	2.8	0.0	0.0
16	*HB*	high over the British Isles	8.2	50.0	2.4	3.4
17	*TrM*	trough over Central Europe	8.5	21.3	9.8	6.9
18	*NEa*	anticyclonic north-easterly	–	–	0.0	0.0
19	*NEz*	cyclonic north-easterly	1.7	59.9	0.0	0.0
20	*HFa*	Scandinavian High. ridge C. Europe	1.8	81.9	0.3	0.3
21	*HFz*	Scandinavian High. trough C. Europe	6.5	28.3	0.0	0.0
22	*HNFa*	Scandinavia – Iceland. ridge C. Europe	3.7	51.2	20.4	8.1
23	*HNFz*	Scandinavia – Iceland. trough C. Europe	1.4	27.3	–	–
24	*SEa*	anticyclonic south-easterly	1.7	16.3	0.0	0.0
25	*SEz*	cyclonic south-easterly	0.0	0.0	4.0	10.6
26	*Sa*	anticyclonic southerly	0.0	0.0	–	–
27	*Sz*	cyclonic southerly	0.0	0.0	–	–
28	*TB*	low over the British Isles	0.2	2.2	0.0	0.0
29	*TrW*	trough over Western Europe	4.8	9.2	0.0	0.0

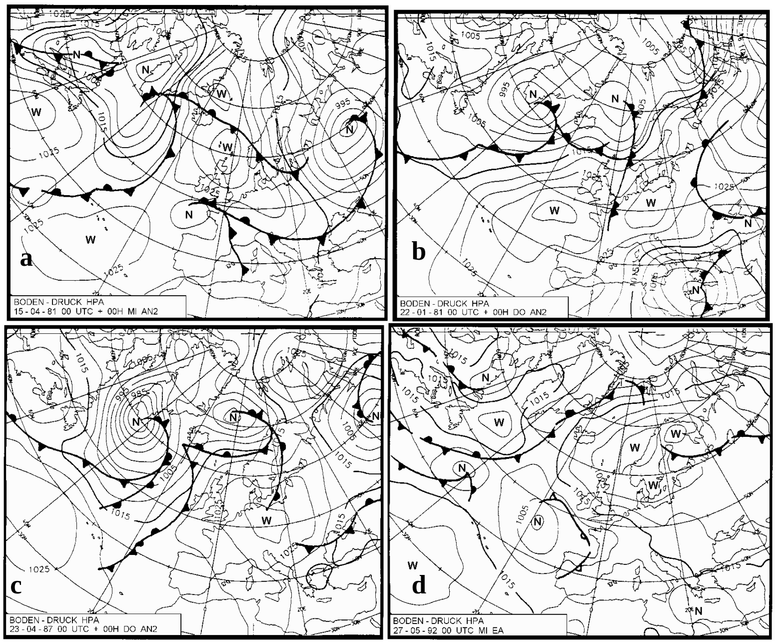

Fig. 3. Circulation types *HNa* (a), *BM* (b), *HM* (c) i *HNFa* (d) according to Hess-Brezowsky circulation typology

In May, 81% of days with frost was related with three circulation types subgroups: meridian circulation with advection of air masses from north (32.3%), combined circulation with advanced high pressure system over Central Europe (28.3%) and meridian circulation with advection of air masses from northern-east and east (20.4%; *HNFa*, *HNFz*). In the first subgroup, similar to April, in such days *HNa* type dominated (13.1%; Tab. 4), in the second subgroup *HNFa* type increased in importance (Fig. 3d), which was shown six times more often than in April.

CONCLUSIONS

1. Average number of days with spring frosts in eastern Poland in the period of 1988-2007 increased toward north (beside area between Rzeszów and Zamość). In April there were six times more such days in Podlaska Lowland than in Sandomierz Hollow and surroundings of Przemyśl (in May almost 2 days).
2. In all meteorological stations 1-days frosts dominated. In April, over 4-days sequences had the biggest share in total number of days with frost. In May, even 2-days sequences was a rarity.

3. The most frequently mild frosts occurred (–2.0ºC ≤ t_{min} ≤ 0.0ºC), on average from 2.8 days in Tarnów to 6.0 days in Białystok. The biggest air temperature below 0ºC decreases was noticed more rarely, but in the majority of stations and sometimes in all stations simultaneously.

4. Since the end of the 80 s of the XX century, frosts the most often occurred in April with advanced high pressure system over Central Europe and during arctic air masses advection from northern sector. In May, frosts occurred often enough during appearance over Scandinavian Peninsula a strong high, which determines arctic air masses advection from northern east.

5. Frosts space variability in eastern Poland is more complicated yet, if we allow for local depressions of land and slope exposition.

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4. THERMAL SUITABILITY OF POLAND FOR WINE-GROWING IN EXTREME YEARS IN COMPARISON TO OTHER CENTRAL EUROPEAN COUNTRIES

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INTRODUCTION

Success in wine growing and wine making is highly determined by natural factors, environmental conditions of vineyard what is usually expressed with a term *terroir* (Gladstones 1992). This French term is the combination of climate, soil and landscape factors, such as temperature and rainfall distribution within the growing season, soil acidity, water retention, exposure to sunlight and slope and drainage. The influence of climatic conditions is observed in local and regional scale and is very important for analyzing the area suitability for grapes (Tonietto and Carbonneau 2004). While searching for the best locations for vineyards the first step is to determine the areas with the most favourable climate conditions in regional scale and after that to identify other factors like soils, geology and local climate.

Poland has long lasting tradition of vine production, which started in 10-11th century, especially for religious and ritual purposes (Żerelik 2003). Other Central European countries, like Czech Republic, Slovakia and Hungary also have very long viticulture tradition, which has been observed since the early Middle Ages till nowadays. In contrary to other countries of the region, since the beginning of 16th century reduction of the vineyards area can be observed in Poland, and it was slow but continuous till the 20th century, due to various factors, mainly of economic and social origins. However, for the last 20-30 years there is a strong tendency of foundation of new and revival of old vineyards in Poland. Longer and warmer growing season noted over the last decade (Chmielewski and Rotzer 2001; Menzel *et al.* 2003), higher monthly and annual temperatures and in consequence better overall thermal conditions expressed for example by such agroclimatological indices like Sum of Active Temperatures (SAT) and Growing Degree Days (GDD), are the reasons for the recent changes in wine industry in Poland. Before founding the vineyard the climatological analysis should be done, especially to recognize the climatic conditions in extreme years (particularly the coldest and driest ones) as these years can be crucial for vineyard existence and the quality of crops.

The main aim of this paper is to recognize the regional, climatological suitability for growing wine grapes in Poland. Spatial patterns of two agroclimatological indices: SAT and GDD in extreme years of 1999-2008 decade are calculated with methods available through Geographical Information Systems (GIS), presented and discussed with respect to the wine-grapes demands. The same analysis is performed for selected Central European countries: Czech Republic, Slovakia and Hungary, to show the climatological potential of Poland for wine-grapes production.

DATA AND METHODS

Meteorological data and climatological indices

The daily meteorological data from 145 meteorological stations in Central Europe (Poland, Czech Republic, Slovakia, Hungary) and its surrounding (Germany, Slovenia, Ukraine, Belarus, Austria, Croatia) are used to derive spatial patterns of selected agroclimatological indices (Fig. 1). The measurements from Germany, Slovenia, Ukraine, Belarus, Austria and Croatia are also used in interpolation to derive realistic spatial patterns of climatological indices at the boundaries of the main countries of interest: Poland, Czech Republic, Slovakia and Hungary. All data originated in the decade 1999-2008. Data was obtained from GSOD database (Global Summary of the Day, ftp.ncdc.noaa.gov/pub/data/gsod). Missing values were complemented using regression techniques basing on the measurements from the closest stations.

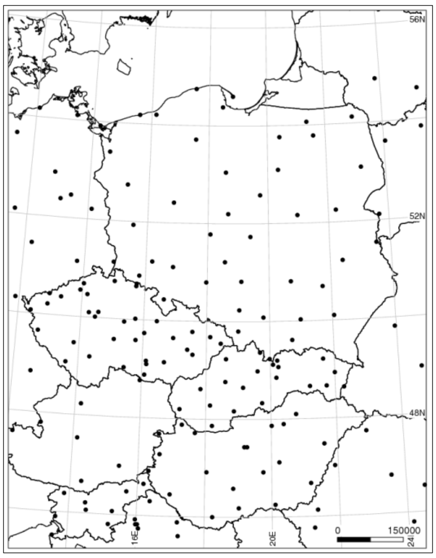


Fig. 1. Study area and location of meteorological stations

Based on meteorological analysis, year 2004 was found to be the one with the coldest of the period 1999-2008, with the least favourable SAT and GDD conditions for wine-growing in Poland. Year 2006 was found to be the warmest in terms of SAT and GDD. The same situation was observed in the rest of the analyzed countries: Czech Republic, Slovakia and Hungary. Spatial patterns of SAT and GDD for these extreme years are further presented and discussed.

Based on the daily climatological data two commonly used parameters for wine-growing are derived: GDD and SAT. The indices are calculated separately for year 2004 and 2006 for all meteorological stations in the study area and interpolated with the method described below to show possible range of the year to year variations in the spatial context.

GDD (Growing Degree Days) can be used to describe the vine's ability to mature as high quality crop in the northern hemisphere (Amerine and Winkler 1944, Winkler *et al*. 1974), and is calculated with the formula:

$$GDD = \sum_{1.04}^{31.10} \left(\frac{T_{\max} + T_{\min}}{2} - 10°C\right) \quad \text{for} \quad \frac{T_{\max} + T_{\min}}{2} \geq 10°C \qquad (1)$$

where T_{max} is the maximum daily air temperature, T_{min} is the minimum daily air temperature.

GDD is calculated similarly to SAT, but the classification is used especially to describe suitability of the area for wine-growing, without any varieties (Tab. 1). All these classes are marked on GDD maps, and the area of each is calculated for the average, warmest and coolest year.

Table 1. Growing Degree-Days' (°C) suitability classes for cool climate regions (Winkler 1974)

Class	GDD	Suitability
1	> 1389	Most suitable
2	1165-1389	Good suitability
3	945-1164	Fair suitability
4	< 945	Questionable suitability

SAT (Sum of Active Temperatures) is the sum of mean daily air temperatures equal to or higher than 10ºC from the period from 1st April to 31st October (Jones and Davis 2000). It is calculated as:

$$SAT = \sum_{1.04}^{31.10} \frac{T_{\max} + T_{\min}}{2} \qquad \text{for} \qquad \frac{T_{\max} + T_{\min}}{2} \geq 10°C \qquad (2)$$

where T_{max} is the maximum daily air temperature, T_{min} is the minimum daily air temperature.

SAT is considered to be one of the most important thermal parameters used in viticulture, together with GDD. While GDD is used to describe the general suitability of the region for wine grapes cultivation, SAT is oriented on varieties and their ripening abilities. Each wine grape variety has got its own minimum average SAT value required during the vegetation period (Tab. 2). The maps of SAT, calculated for the study area, were reclassified to show the classes proposed by Myśliwiec (2003, Tab. 2).

Table 2. SAT (°C) and ripening ability of groups of varieties

Class	Varieties	SAT (°C)	Selected varieties
1	No varieties	<2000	No varieties or some hybrid varieties
2	Very early ripening	2000-2200	Reform, Iza Zaliwska
3	Early ripening	2200-2500	Cardinal, Cascade, Aurora
4	Moderately early ripening	2500-2700	Traminer, Seyval blanc,
5	Late ripening	2700-2900	Pinot blanc, Muskat Hamburg, Cabernet Sauvignon, Merlot
6	Very late ripening	>2900	Muskat of Alexandria, Pinot noir, Riesling, Chardonnay

Spatial interpolation of SAT and GDD

Spatial patterns of climatological indices described above are derived with multiple linear regression method (MLR). MLR is one of a few multi-dimensional interpolation schemes which are used in climatology (Agnew and Palutikof 2000, Ustrnul and Czekierda 2003, Szymanowski and Kryza 2009). The MLR interpolation scheme is used in this paper as it outperforms simple interpolation algorithms in terms of cross-validation errors. The MLR algorithm was earlier tested for interpolation of, among others, GDD and SAT for SW Poland, and the results were quantitatively compared with kriging and inverse distance weighting algorithms by Szymanowski *et al*. (2007).

The MLR interpolation scheme is supported by application of various spatial predictors (independent variables). Here, the spatially continuous independent variables were derived from the digital elevation model (500 m x 500 m grid) to describe the morphological relations over the study area. Statistically significant predictors were identified with the stepwise method and included into the regression model.

The potential spatial predictors used here for multiple regression analysis can be merged into seven groups:

- average elevation index (AEI), the height above the sea level is averaged using focal mean filter within the circle-shaped area of specific radius for each raster element to remove small terrain features, which do not have significant effect on air flow,
- concavity-convexity index (CCI), calculated as a difference between the raster height and the AEI, to describe the effect of the cold valley bottoms. The positive/negative value of this predictor suggests that the given raster is higher/lower than its surroundings and is therefore located on convex/concave landform,
- foehn index (FI), is calculated in three steps (Szymanowski *et al*. 2007). First, the highest raster in given sectors and distance is found, with 90 degrees sectors in S, SW and W directions considered. Second, the highest elevations found in all sectors are averaged. Finally, the difference between the averaged maximum and the actual raster is calculated. When the difference is large, the foehn effect is expected to appear and the areas with higher values of FI are supposed to be warmer than its surroundings.
- other DEM-related predictors like slope, profile and tangential curvature are calculated using standard GIS procedures,
- solar radiation for the area is calculated with the r.sun model (Hofierka and Ŝuri 2002). The monthly averaged potential (i.e. clear sky) global solar radiation is calculated for the growing season (April-October),
- coordinates - easting (X) and northing (Y),
- the distance from the sea, calculated with the standard GIS buffer zones analysis.

The sets of statistically significant predictors were found with the stepwise method, separately for each interpolated climatological parameter and included into the MLR model. Apart from the statistical significance of the independent variables included, their relation with the interpolated climatological phenomena, given by the sign of the regression coefficient β, was also analysed to assure the physical background of the regression model. The MLR models were spatially extrapolated to derive maps of climatological indices for the study area. This was possible because all independent variables were known for the whole study area and available in the form of spatially continuous GIS raster layers. The SAT and GDD maps were reclassified using viticulture classifications presented earlier (Tab. 1 and Tab. 2) to delineate the most favourable, considering the thermal conditions, areas for the wine-growing in Poland and selected Central European countries. The total area of each class was calculated for each country and compared.

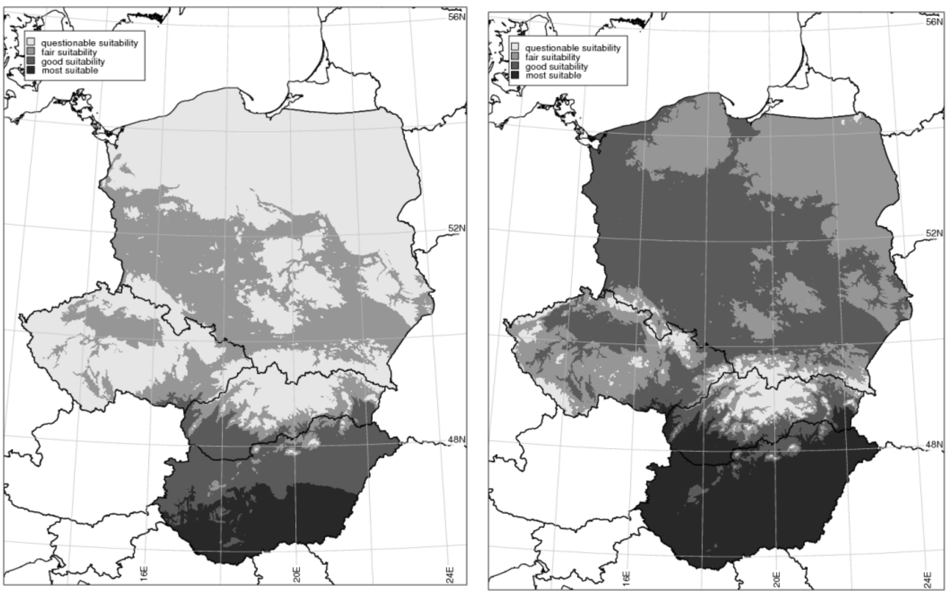
RESULTS AND DISCUSSION

For each considered climatological parameter separate set of independent variables was used in the interpolation procedure. For SAT three independent variables were found to be statistically significant and were included into the MLR model: AEI, X and Y. In case of GDD, the same independent variables were used together with the distance from the sea. More local spatial predictors like Foehn or concavity/convexity indexes, were not statistically significant. This is probably due to large spatial extend of region for which the maps are prepared. On the other hand, this may be linked with the location of the stations available for interpolation. Final maps for the study area are presented on Figure 2 and 3.

For the cold year 2004, the dominant area of Poland is of questionable suitability for wine growing in terms of GDD classification (Fig. 2, Tab. 3). However, there are also extensive areas (36% of the country) of fair suitability. These are located mainly in SW and S part of Poland. For warm year 2006, also c.a 40% of the country area belongs to class of fair suitability for wine growing. These are located mainly in NE and E part of Poland. The remaining regions (excluding mountains in the south) are of good suitability for wine grapes cultivation if warm year is considered. Noticeably, even if the warmest year of the 1999-2008 period is considered, there are no areas of “most suitable” class, which is present in all other countries selected for comparison. Poland seems to have the similar share of GDD classes to Czech Republic for both cold and warm years. Slovakia has extensive areas (c.a. 30% of the country) of good suitability, for both cold and warm years. Hungary has the most stable thermal conditions, with the highest share of the most suitable class, for both years 2004 and 2006.

Table 3. GDD variability for chosen countries in extreme years (in % of total area of the country)

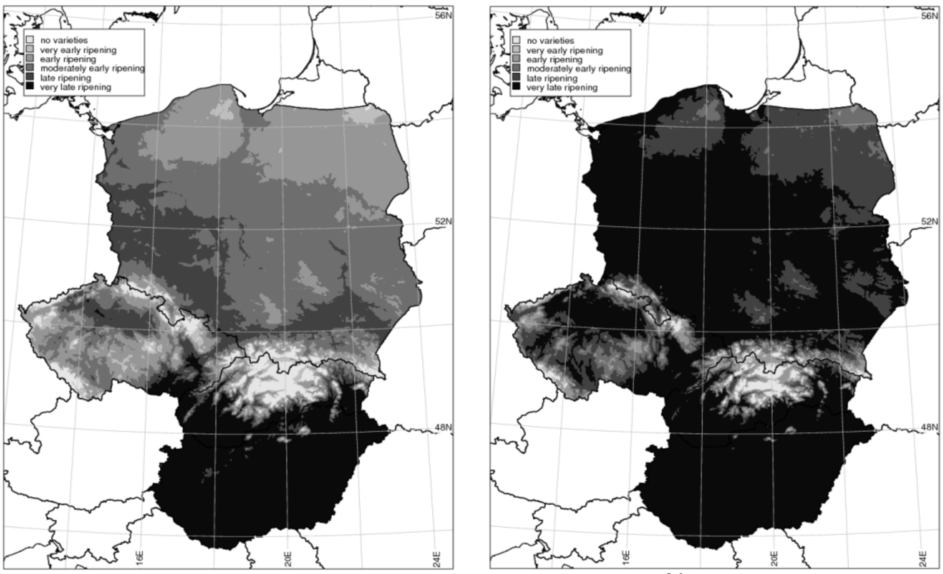
GDD	Poland		Czech Republic		Slovakia		Hungary	
	2004	2006	2004	2006	2004	2006	2004	2006
Questionable suitability	63.99	2.46	65.42	13.10	43.49	25.66	0.50	0.10
Fair suitability	36.01	40.11	32.94	49.91	27.07	22.72	4.80	0.82
Good suitability	0.00	57.43	1.64	35.83	29.44	27.05	50.58	7.87
Most suitable	0.00	0.00	0.00	1.16	0.00	24.50	44.12	91.21



a) **b)**

Fig. 2. GDD classification for general suitability for wine growing in extreme years of period 1999-20008: a) 2004 b) 2006

Spatial patterns of SAT in Poland are in general context similar to GDD (Fig. 3). For the cold year 2004, SAT values noted in Poland are sufficient for very early to late ripening varieties of wine grapes. Areas suitable for late ripening overlap with the GDD class of fair suitability for wine grapes cultivation. The regions suitable for late ripening varieties are extensive, and exceed 19% of the total area of Poland for cold year 2004 (Tab. 4). There are no regions suitable for very late varieties, if cold year is considered. Only 1.5% of the country area is not suitable for wine grapes varieties (mostly mountainous regions on the south and small region in the NW). For the warm year 2006, most area of Poland is suitable for late and very late ripening varieties. The large changes in spatial extend of SAT conditions for extreme years can be therefore a limiting factor for very late ripening varieties of wine grapes and, in some areas, also for late wine grapes.



a) **b)**

Fig. 3. SAT classification for wine grapes varieties in extreme years of period 1999-20008: a) 2004 b) 2006

Large changes in extend of areas suitable for wine growing, in terms of SAT, are also the case of the Czech Republic, but are less pronounced for Slovakia. The most stable SAT conditions are found for the southernmost country of the study region – Hungary, for which areas suitable for very late ripening varieties cover almost 97% of the country in 2004 and over 99% in 2006. The reason for such climatic conditions is that Hungarian climate is composed of Mediterranean, Atlantic and Continental elements. High mean temperature and dry and sunny autumn is favourable even for high quality wine-growing.

Table 4. SAT variability for chosen countries in extreme years (in % of total area of the country)

SAT	Poland		Czech Republic		Slovakia		Hungary	
	2004	2006	2004	2006	2004	2006	2004	2006
No varieties	1.44	0.45	7.64	1.99	17.87	8.60	0.02	0.00
Very early ripening	2.53	0.46	9.55	2.52	8.91	5.82	0.08	0.01
Early ripening	29.01	1.70	33.84	9.57	14.65	12.89	0.38	0.12
Moderately late ripening	47.92	3.83	26.00	17.60	11.30	9.72	0.64	0.24
Late ripening	19.10	26.16	17.41	28.45	10.76	11.41	2.09	0.57
Very late ripening	0.00	67.39	5.57	39.86	36.57	51.56	96.80	99.06

CONCLUSIONS

1. In this paper spatial patterns of SAT and GDD were calculated and analysed in context of wine-grapes cultivation. The SAT and GDD conditions, calculated for warm and cold years for Poland, were compared with other Central European countries, which are well known from production of good quality wines: Hungary, Czech Republic and Slovakia. The results show that, even if the coldest year of the period 1999-2008 is considered, there are still extensive areas in Poland with fair suitability for wine grapes cultivation, also for late ripening varieties. These areas are located mostly in SW and S of the country. Spatial extend of the most suitable SAT class may however change from none to over 200000 km^2 if the thermally extreme years are considered. Much more stable conditions are noted in Slovakia and, particularly, in Hungary. Czech Republic seems to have quite similar to Poland thermal conditions for wine grapes cultivation.
2. The significant changes in suitability of the given area, in terms of SAT and GDD, may be a limiting factor for cultivation of more demanding varieties of wine grapes in Poland. In terms of GDD, large areas of central and NW Poland may

change from questionable to good suitability for wine growing, if cold and warm years are analysed. For the same areas, SAT classes can change from very early to very late ripening. For these regions wine grapes cultivation can be hazardous.

3. To extend the knowledge on climatological suitability of Poland for wine grapes cultivation, other climatological factors should also be considered in future, including annual average air temperature (and its variation), temperatures of the warmest month etc. Temperatures of the warmest month should be mentioned here, as it is found that the highest SAT values within the growing season do not guarantee better and higher yield if the temperature in the warmest month is not high enough (Madej 1952). More complex climatological description of the area of Poland, in context of wine grapes demands, will probably decrease the overall land area suitable for vineyards, delineated on the basis of SAT and GDD only.

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5. EVALUATION OF METEOROLOGICAL CONDITIONS FOR THE CULTIVATION OF MAIZE GRAIN IN POLAND

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INTRODUCTION

The area of maize cultivation for grain in Poland has significantly increased over recent history (Lipski 2003). Nowadays, maize production for grain is located not only in southern parts of Poland, but also in the northern regions (Adamczyk *et al.* 2008). One of the reasons for such expansion is the increase of climate suitability for maize production in the northern parts of Poland (Kozyra and Górski 2004, Górski 2007). Such availability was earlier presented in climate change impacts publications, where authors using phenological models showed that a rise in temperature would significantly improve conditions for maize production in Poland (Deputat 1999, Demidowicz *et al.* 1999, Nieróbca *et al*. 2008). Alternatively, on the Polish market there are more widely available varieties that mature earlier and these allow farmers to better match the varieties to the climatic conditions (Dubas and Michalski 2002, Adamczyk *et al*. 2008). An analysis of cultivation conditions for maize in Poland over the recent years has attributed drought conditions as the main factor that has reduced maize yields in Poland (Michalski *et al*. 1996). In order to assess the effects of temperature and water conditions on maize production conditions in Poland, statistical weather-yield models and long-term weather data can be used (Górski *et al*., 2008, Górski 2009). The aim of this study is to evaluate conditions for maize cultivation that matched an analysis of recorded yield in Poland and weather indexes describing the weather impact on yield formation.

MATERIALS AND METHODS

The maize yield data between 1992 and 2008 used in the study were published by the Central Statistical Office (CSO) in Poland. Between 1992 and 1998, data was available for 49 voivodeships (territorial division of the countries), while between 1999 and 2008, after administrative reform, for 16 voivodeships.

Therefore, data between 1992 and 1998 was amassed for the current administrative divisions by weighing the yield for each region by surface percentage. The variation of yield in the regions was calculated using the formula below

$$V = \frac{S}{\overline{X}} * 100\% \qquad (1)$$

where: V – coefficient of variation for yield (%),
S – standard deviation,
$\overline{X}$ – average yield (t ha^{-1}).

An assessment of weather impact for maize cultivation in Poland was carried out using indexes developed into multiply regression statistical yield models at the Institute of Soil Science and Plant Cultivation in Puławy (Górski *et al.* 1994, Górski *et al.* 1997). The model for maize used in this study consists of three partial weather indexes, which enables an assessment of weather conditions separately in three two-month periods: May-June (WI_{MJ}), June-July (WI_{JJ}), and July-August (WI_{JA}). Each of the partial weather indexes were calculated as a multiple regression function taking into account the monthly average air temperature, climatic water balance (CWB) and the sunshine duration hours. CWB expressed the difference between precipitation and potential evapotranspiration (ETP), and was calculated using a formula developed by Doroszewski and Górski (1995). The sum of the partial weather indexes that are characterised for the whole maize vegetation season is referred to in the paper weather yield index (WI) (2). For example, if the *WI* equalled 110, it means there was a 10% better condition for yield formation than in an average year; whilst if the *WI* equalled 90, this indicates a 10% worse condition for yield formation (Górski et al., 2008). Each partial index WI_{MJ}, WI_{JJ}, WI_{JA} has the same meaning. The analysis of partial indexes enables the identification of factors contributing to a decline or increase of a yield during a season. The analyses were performed based on the data between 1921 and 2009, from a weather station located in the Puławy (Central Poland).

$$WI = WI_{MJ} + WI_{JJ} + WI_{JA} - 200 \qquad (2)$$

where: WI – weather yield index for maize
WI_{MJ} – partial weather index evaluating conditions in May and June,
WI_{JJ} – partial weather index evaluating conditions in June and July,
WI_{JA} – partial weather index evaluating conditions in July and August.

RESULTS AND DISCUSSION

Over recent years, the area of maize cultivation for grain in Poland has increased from about 50 thousand hectares in 1992 to 400 thousand hectares in 2004. After 2004, there was a slight reduction recorded, and the maize area stabilised at a level of about 300 thousand hectares (Fig. 1).

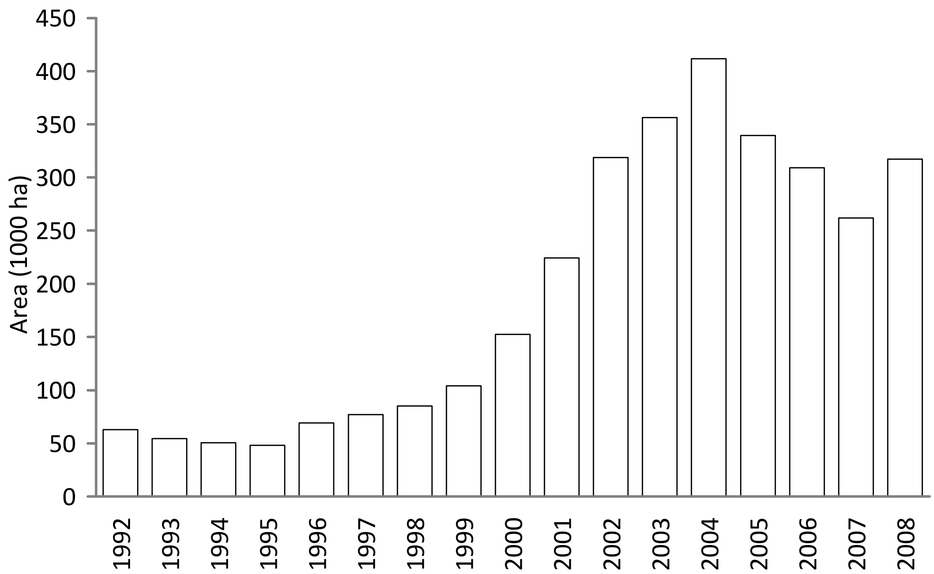

Fig. 1. Total area of maize cultivation harvested for grain between 1992 and 2008 (Source: CSO 1992-2008)

The average grain yield of maize in Poland between 1992 and 2008 was 5.35 t ha^{-1}. This indicates that the maize yield in comparison to other cereals in Poland was characterised with a high production potential (Dubas and Michalski 2002, Sulewska 1997). During favourable weather conditions, the average grain yield was more than 6.0 t ha^{-1} (Fig. 2). However, significantly lower yields were observed in 1992: 3.28 t ha^{-1}, in 1994, 3.75 t ha^{-1}, and 2006: 4.16 t ha^{-1} in adverse weather conditions such as a cold spring or drought (Michalski *et al*. 1996). Such variability in the yield level indicates a high sensitivity of this crop to weather conditions in Poland.

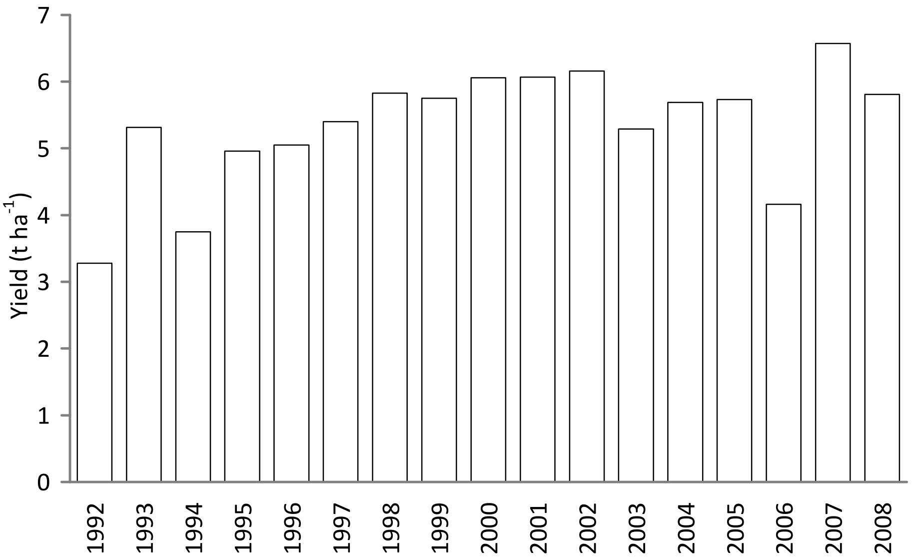

Fig. 2. The yield of maize grain in Poland (Source: CSO 1992-2008)

The differences in the yield of maize in the voivodeships indicate the regional diversity of maize production in Poland (Fig. 3). The highest yields were obtained in the south-western voivodeships: Śląskie (5.9 t ha^{-1}), Dolnośląskie (5.7 t ha^{-1}), Opolskie (5.5 t ha^{-1}) and in the Wielkopolskie (5.5 t ha^{-1}). These voivodeships are characterised with intensive agricultural practices, but also good climatic conditions for maize cultivation (Kozyra and Górski 2004). However, in the voivodeships of northern and north-eastern parts of the country, yields were much lower: Pomorskie (4.3 t ha^{-1}), Warmińsko-Mazurskie (4.4 t ha^{-1}), Zachodnio-Pomorkie and Podlaskie (4.5 t ha^{-1}) and there are the low probability of maize maturity (Kozyra and Górski 2004).

The variation coefficient of national yield (CV) over the period 1992-2009 was 14.4%. Significant differences in this factor were dependant on the regions. The smallest coefficient variation in yield was obtained for the voivodeships located in eastern and south-eastern parts Poland: Podkarpackie (5.4%), Lubelskie (5.5%), and Małopolskie (6.8%). Slightly larger values for the coefficient of variation were characterised by voivodeships: Świętokrzyskie (11.0%), Warmińsko-Mazurskie and Śląskie (12.7%). The largest coefficient variation was obtained for the north voivodeships, i.e. in the Pomorskie (25.6%). This indicates that in the northern parts of the country the limiting factor for maize yield is still a lack of heat (Nieróbca *et al.*

2008). In contrast, the high variability of maize yield that occurs in the Lubuskie (22.7%) and Wielkopolskie (19.7%) regions, together with a high yield, may indicate that the probable cause is a low precipitation in the vegetation period and drought occurrence (Kozyra 2006, Górski 2007).

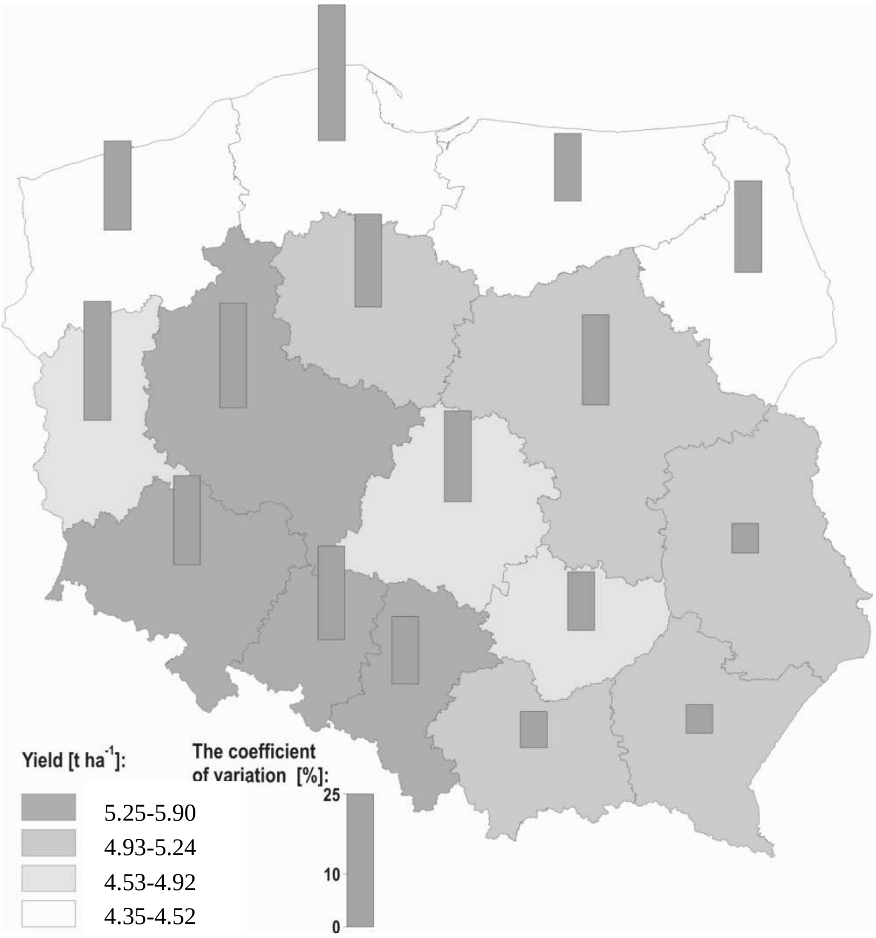

Fig. 3. The grain yield of maize and coefficient of variation in voivodeships between 1992 and 2008

The high relationship between yield and weather conditions (R^2 = 78.8% – (3)) where found (CSO, Lubelskie voivodeship, 1992-2009). Where 71.3% of variability explains the weather index influence (*WI*), and 7.5% the genetic progress (trend yield).

$$Y = 1.56 + 0.035 \cdot WI + 0.036 \cdot T \quad (3)$$
$$R^2 = 78.8\%$$

where: Y = yield (t ha^{-1}),
WI – weather index for Puławy,
T – analysed years.

The partial weather index evaluating conditions in May and June (WI_{MJ}) between 1921 and 2009 in Puławy, reached its lowest value in 1930 (83), and highest in 1999 (114) – Figure 4. Next, the WI_{MJ} high values occurred in 1959 (111), 1981 (111), 2009 (111), 1946 (109), and 1968 (109). The WI_{MJ} lowest values were evaluated in 1928 (86), 1923 (87) 1941 (87) and 1921 (89). In recent years, the lowest values were observed in 2006 (93), 2000 (93), and 2003 (94). In the last twenty-nine years (1981-2009), the percentage of years in which the WI_{MJ} exceeded 105 was 24% and increased significantly compared to the years 1921-1950 when it was only at 7%.

In comparison, there was a double percentage reduction from years WI_{MJ} values <95 (Tab. 1). This means that there are less recorded years with unfavourable weather conditions in the beginning of the maize vegetation period.

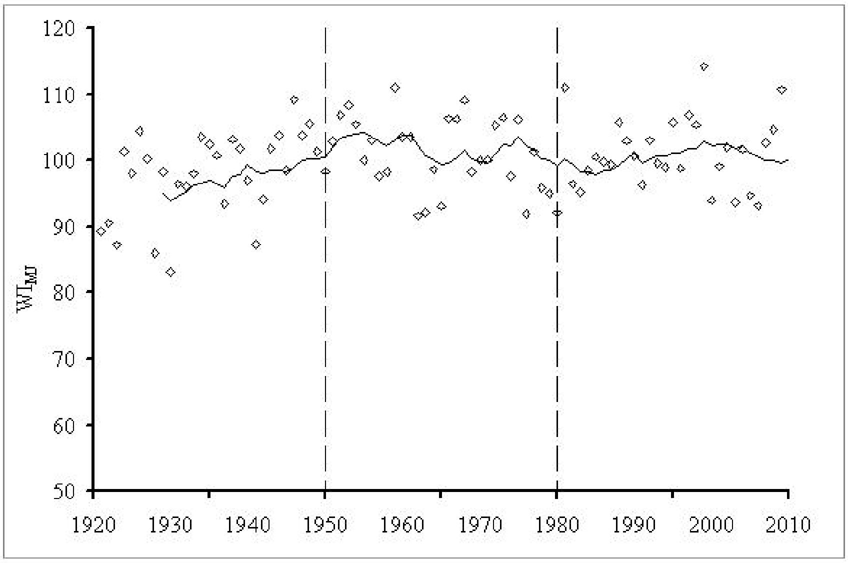

Fig. 4. The partial weather index evaluating conditions for May and June (WI_{MJ}) in Puławy between 1921 and 2009

Table 1. The percentage of years in which the weather indexes for maize yield were higher than 105 and less than 95 for 1921-1950, 1951-180 and 1981-2009

Years	WI_{MJ}	WI_{JJ}	WI_{JA}	WI	WI_{MJ}	WI_{JJ}	WI_{JA}	WI
	>105				<95			
1921-1950	7	20	0	10	27	30	20	40
1951-1980	33	13	0	10	17	40	20	33
1981-2009	24	14	3	31	14	31	7	21

The partial weather index that evaluates conditions for June and July (WI_{JJ}) shows a large variation in years (Fig. 5). It should be highlighted that in the latter years of the research, the lowest values have been found in 2006 (58) and in 1994 (71). The most likely cause of such large reductions in the index for particular years was drought conditions. This was referred to in previous studies from Michalski et al (1996). This index shows no clear trend in the analysed long-term periods (Tab. 1).

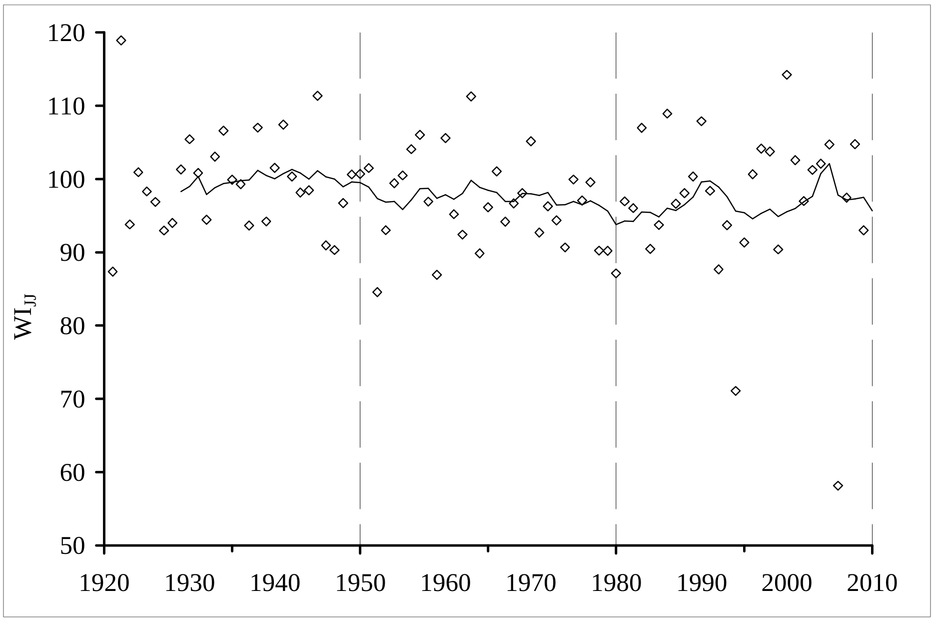

Fig. 5. The partial weather index evaluating conditions in June and July (WI_{JJ}) in Puławy between 1921 and 2009

In recent years, the partial weather index evaluating conditions in July and August (WI_{JA}) shows an improvement of weather conditions for maize grain cultivation in Puław (Fig. 6). Since 1980, the WI_{JA} values are higher or closer to 100 with the exception of two years: 2006 (91) and 1987 (93). The lowest values of WI_{JA} were found in 1977 (88) and 1978 (89), which were caused by a deficiency in heat for those years.

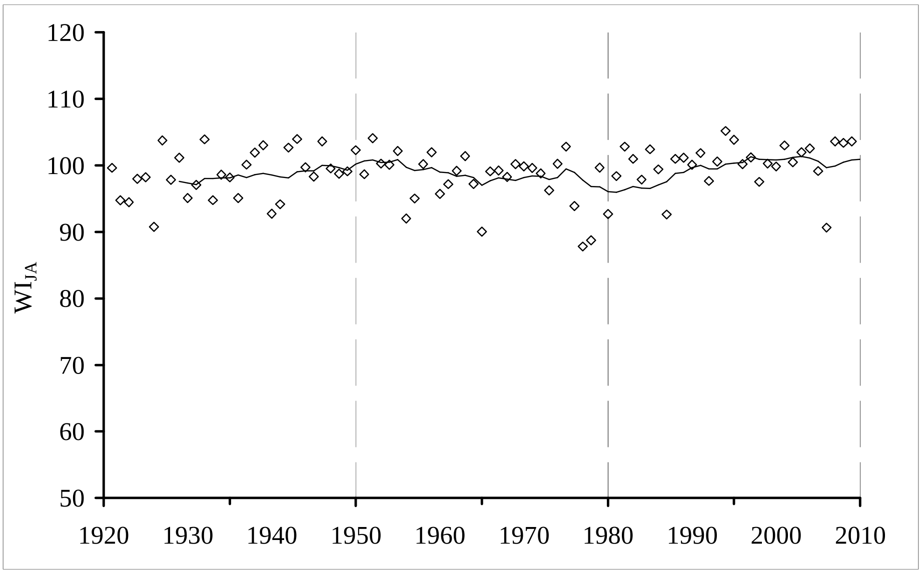

Fig. 6. The partial weather index evaluating conditions for July and August (WI_{JA}) in Puławy between 1921 and 2009

In the period 1921-2009 the highest value equal 105 of the WI_{JA} was observed in 1994. In the 1921-1980 years WI_{JA} <95 were noticed in 20% cases, but during the last period (1981-2009) in 7%.

The final weather yield index for maize (*WI*), describing the weather conditions from May to August, showed an upward trend until the mid-fifties of the last century (Fig. 7). After this period until the end of the 1970s, large fluctuations were observed in the value of *WI*. Since the early 1980s, a rising value of *WI* was witnessed with the same significant reductions in the *WI* index under extreme conditions, which occurred in 1994 and 2006. The lowest value in the analysed long-term *WI*, was reported in 2006 (42). Low values of *WI* were also achieved in the years: 1980 (72), 1978 (75), 1994 (75), 1921, and 1923 (76).

The highest values of *WI*, i.e. the best conditions for maize grain yield occurred in 2008 (113), 1938 (112), 1997 (112).

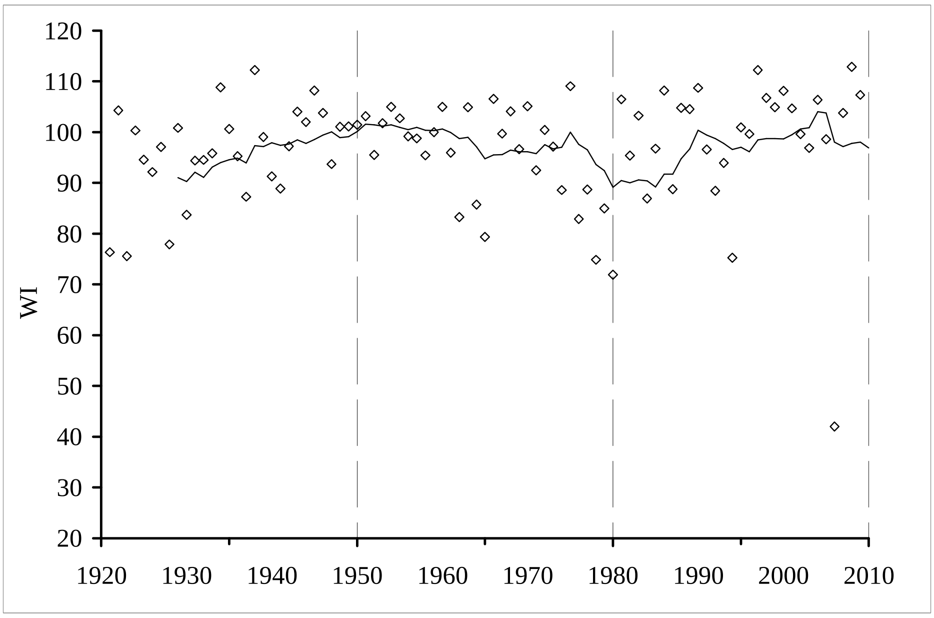

Fig. 7. The weather yield index for maize (WI) in Puławy between 1921 and 2009

The percentage of years with favourable conditions for the yield of maize (*WI*> 105) as compared to the percentage of years with adverse conditions (*WI* <95), is better expressed as a general improvement in the conditions than the average values of *WI*. In the long-term, 1981-2009, increased the percentage of cases with *WI*> 105, which accounted for 20% of the analysed years, whilst in previous sub periods it was only 10% of the analysed years. While the percentage years of *WI* <95 had decreased, which accounted for 21% while in earlier periods the percentage of years was at 40% and 33% (Tab. 1). The changes indicate a general improvement in conditions for agro-meteorological yields of maize in Poland.

In Table 2, there are five years listed with the lowest *WI* values in the analysed 1921-2009 period, together with main meteorological indices used in weather-yield model. The data shows that in 2006, a major cause of low *WI* 42 values were found to be drought conditions in June (CWB: –104) and July (CWB: –159), and excess precipitation in August (CWB: 129). Similar to 2006, a low *WI* 75 was evaluated for 1994, and this was caused by low *CWB* values for June (–

67 mm) and July (–141 mm). A low value of the *WI* 72 in 1980 had an impact on the low temperature during the vegetation of maize in addition to high precipitation. The average temperature in May of this year amounted to 10^{o}C, and low insolation in July, only 104 hours at high values of climatic water balance. In 1978, a decisive influence on the reduction of the *WI* 75 was a lack of heat expressed by low temperatures during the vegetation period of maize. In 1923, the low value of the *WI* (76) was a shortage of heat in June.

Table 2. Average temperature, sunshine duration, and climatic water balance in Puławy for the years with the lowest values of *WI*

Year	*WI*	Average temperature (^{o}C)				Sunshine duration (h)				Climatic water balance (mm)			
		May	June	July	Aug.	May	June	July	Aug.	May	June	July	Aug.
2006	42	13.9	17.7	22.5	17.7	246	299	**402**	190	–53	**–104**	**–159**	**129**
1980	72	**10.0**	**15.7**	**16.8**	**16.3**	194	160	**104**	150	–15	**33**	**2**	**22**
1978	75	**12.1**	**15.6**	**16.5**	16.2	200	249	243	190	–44	–53	–80	**90**
1994	75	13.3	16.5	21.9	18.6	208	267	362	204	–28	–67	**–141**	–23
1923	76	14.1	**13.2**	18.4	16.1	241	170	273	241	–41	–20	–79	–89
1921-2009	100	13.9	16.9	18.7	17.8	225	230	233	221	–45	–40	–34	–35

CONCLUSION

In Poland, there is considerable variation of maize yield between regions. The smallest variation in yield occurs in the south-eastern part of the country where there is more suitable climatic conditions for maize cultivation than in northern part of the country. For northern regions, the shortage of heat is still an important factor limiting maize production. The analysis of weather maize yield index (*WI*) for Puławy in 1921-2009, shows a tendency to improve climatic condition for maize cultivation in Poland. There is an increase in the frequency of years with favourable conditions for maize cultivation *WI*> 105, while decreasing the number of years with adverse conditions (*WI* <95). In 1994 and 2006 in the spring and summer, a drought occurred and caused very low yield, which in turn expressed a low *WI*. An analysis of partial weather maize yield indexes shows higher variability of $WI_{JJ,}$ whilst the WI_{MJ} and WI_{JA} have more stable high values.

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6. LOW ALTITUDE REMOTE SENSING OF AGRICULTURAL DROUGHT

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INTRODUCTION

Methods of remote sensing are becoming increasingly popular in the agricultural and environmental research. The development of digital recording and computer image processing method, now enable the application of non-metric cameras to obtain the data sets. GIS based methods make possible a high accuracy calibration and mosaic process of non-metric aerial photos. As a result of this process are derived photomaps, ready for further analysis of the content of the image. In studies of agri-environment, elaborated aerial photographs are a valuable source of information about the state of vegetation. For this purpose, maps of vegetation indices (VI) are drawn (Gitelson *et al.* 2002). The most popular is NDVI (Normalised Difference Vegetation Index), which based on the differences in spectral reflection of radiation in the red and infrared (Tucker 1979).

Matrices of digital cameras allow for registration of radiation in the spectral range 350-1100 nm (Pudełko *et al.* 2006). In order to obtain the full range of registration available for the matrix, special adapted camera can be used; therefore, the cameras commonly found in a commercial offer have factory limitations. This is due to the quality of photography in the visible band. Matrices of digital cameras may not be literally considered as multispectral sensors, because their calibration is well suited for colour images similar to the image recorded by the human eye. This does not mean inability to use such devices in scientific research. Among the most popular kinds of research using non-metric digital aerial photographs, in agriculture are: the plant protection (Nieróbca *et al.* 2007, Pudełko *et al.* 2008b), vegetation assessment and crop monitoring (Jensen *et al.* 2007, Igras and Pudełko 2008, Nieróbca *et al.* 2008, Pudełko and Igras 2008), modelling of yields (Domsch *et al.* 2007) and agri-environmental analysis (Piekarczyk 2006, Pudełko *et al.* 2008c). The research value of digital cameras is growing as they adapted to register a narrow band (after montage the selective filter) or they converted to infrared registration (e.g. Fujifilm IS-1).

Remote sensing is potentially one of the possible methods for determining the areas affected by drought (Dąbrowska-Zielińska and Ciołkosz 2007, Piekarczyk 1995). Due to the increasing availability of low cost multispectral sensors, an alternative method for the costly purchase of metric aerial photos and satellite imagines is low-altitude remote sensing (Pudełko *et al.* 2008c).

The study was conducted for the need of the Agricultural Drought Monitoring System for Poland (ADMS), which is provided by the Institute of Soil Science and Plant Cultivation - National Research Institute (IUNG-PIB) on behalf of the Ministry of Agriculture and Rural Development (Doroszewski *et al.* 2008). The system is designed to identify the areas where the potential losses occurred, due to drought conditions for the crops according to the Act on subsidies to the insurance of agricultural crops and farm animals (Dz. U. Nr 150, poz. 1249.

The purpose of the tests carried out using low altitude remote sensing is field verification (ground and aerial methods) of potential agricultural drought maps in vulnerable regions of Polish.

MATERIALS AND METHODS

The drought analysis results are published as thirteen reports per year. Information on the droughts are sent to the Ministry of Agriculture and Rural Development and are made available on the website www.susza.iung.pulawy.pl. As described in the Act, a drought is defined as damage caused by the occurrence in any period, from 1 April to 30 September each year, where the climatic water balance (CWB) is below a specific value for individual species or groups of crops, in addition to the soil category (Fig. 1A). The analysis carried out shows that in 2009, for the winter cereal, drought occurred only in the first reporting period (1 IV-31 V). Drought by the ADMS could have an adverse effect only on crops located on category No.1 soil (very light soil, granulometric group: sand). The drought range is shown on the map in Figure 1B. On this basis the route of flight was designated.

Digital aerial photography was performed using two gyro-stabilised cameras Fujifilm IS-1, registering an image in the range of 350-980 nm. After applying selective filters, the photo-set has been optimised for shooting in four spectral channels: blue (B), green (G), red (R), and near infrared (NIR) – Figure 2.This allowed drawing up vegetation indices maps that characterise the condition of plants. Low altitude flights (up to 2 km) allowed obtaining high-resolution photos, which then can be transferred to an assessment into the impact of a soil mosaic, terrain, cropping patterns and field management for the diversity of spectral reflection within the fields. The flight was made on the 15.06.2009, and 440 (RGB-NIR pair) photos were obtained.

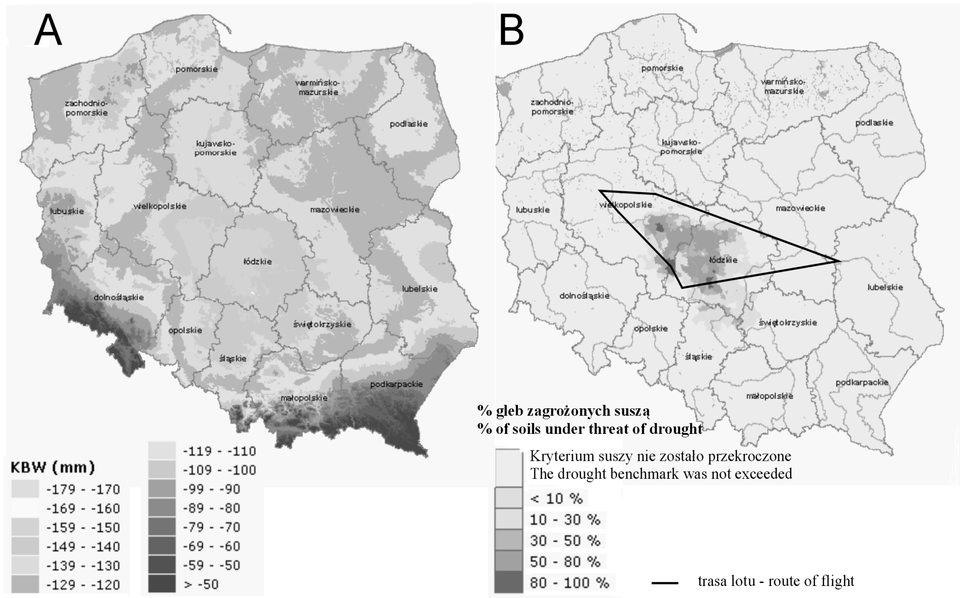

Fig. 1. Agricultural Drought Monitoring System – the situation for the period 1 IV – 31 V. A) CWB map, B). Map of the potential presence of agricultural drought with marked route of flight (www.susza.iung.pulawy.pl)

Field verification of remote sensing data was carried out in selected fields that had a cultivation of winter wheat. The field monitoring was conducted between 16th and 18th of June. Identification of the plants condition was made by a LAI (Leaf Area Index) measurement with a LI-COR LAI 2000 sensor. Additionally, an assessment of field management and habitat conditions were done. The soil categories of the analysed fields were preliminary assessed in the field and then compared with the soil-agricultural map, 1:25 000 scale (Strzemski *et al.* 1965).

The spatial analysis was carried out by using GIS-based methods. The photos were combined into a R-G-B-NIR (four bands) photos by using the FotoLot 1.4, ArcEngine software developed in IUNG-PIB. Photos were geo-referenced and two kinds of VI maps: NDVI and VARI (Visible Atmospherically Resistant Indices) were performed with ArcGIS 9.3 (Fig. 3). The indices were calculated based on algorithms (Golzarian *et al.* 2007):

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}), \quad (1)$$

$$\text{VARI} = (\text{G} - \text{R}) / (\text{G} + \text{R} - \text{B}), \quad (2)$$

where: NIR – value of infrared spectral channel,
R – value of red spectral channel,
G – value of green spectral channel,
B – value of blue spectral channel.

Fig. 2. Mounting the photo-platform on board the Cessna. NIR – infrared spectral channel, RGB – red, green, blue spectral channels (photo IUNG-PIB)

For all tested locations, the value of the two vegetation indices, the CWB and soil category were combined.

The results of the analysis are summarised in Table 1. The fields were sorted according to latitude (from east to the west direction), which corresponded to the sequence of photographs.

Assumed working hypothesis:

1. LAI measurements should be correlated with indices of vegetation, defined on the basis of aerial photographs.
2. areas affected by drought (CWB < –150 mm and soil category No. 1) should have significant lower indices NDVI, VARI and LAI.

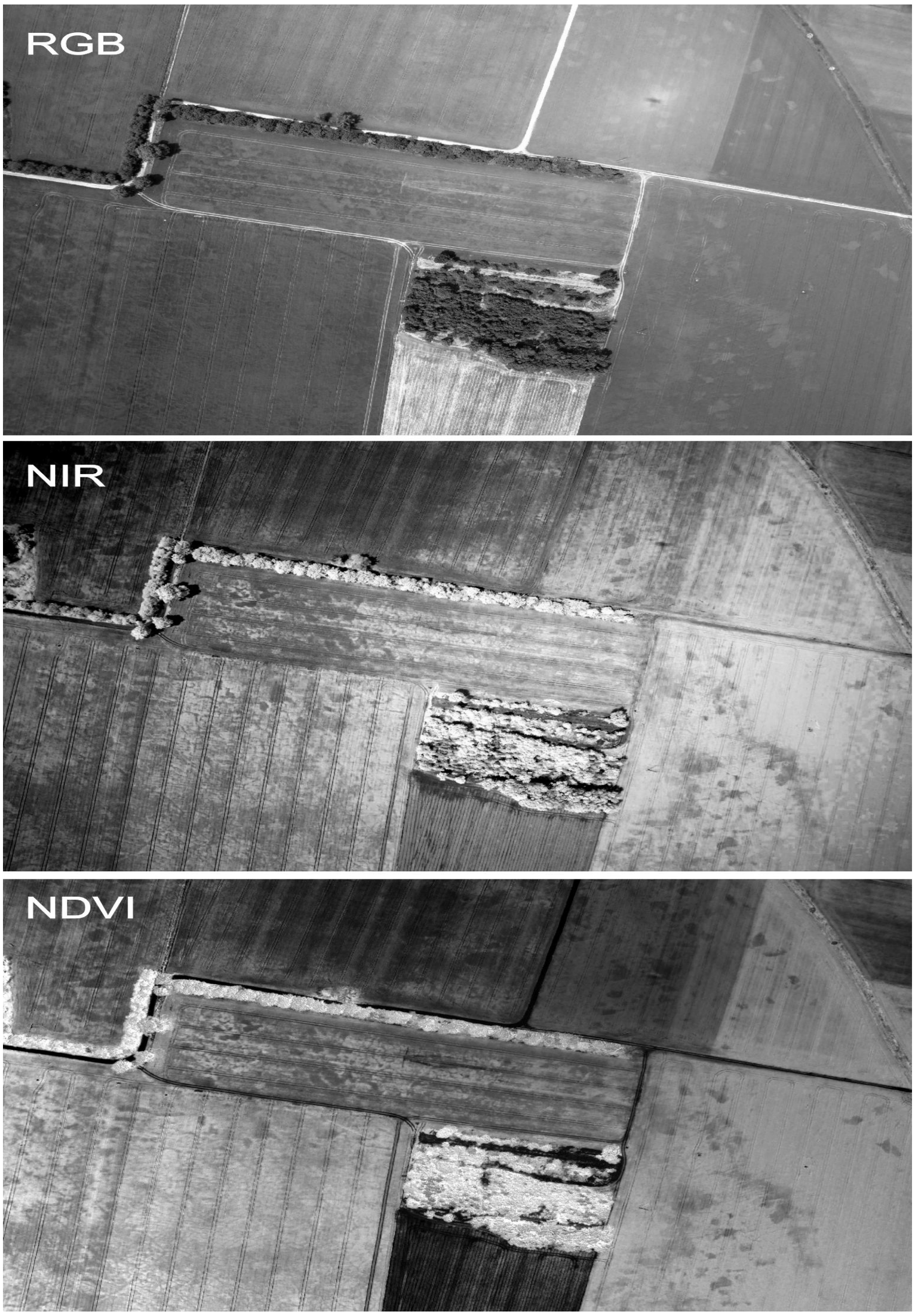

Fig . 3. Aerial photos (RGB and NIR) and NDVI map (photo IUNG-PIB)

RESULTS AND DISCUSSION

The CCD matrix used in popular digital photography is characterised by a lower sensitivity of infrared registration (Pudełko *et al.* 2008c). Therefore, the ratio of registered values in the NIR and R channels will differ from the actual ratio. It had an influence on the lower valuation NDVI index, which is shown on the presented Table 1. Consequently, a negative value of NDVI may occur.

The results of NDVI and VARI correlation with LAI are shown in Figure 4. In both cases, the regression between the ground-based and remote measurements is not as important as was assumed. However, obtained a significantly better correlation NDVI – LAI (R^2 = 0.43) than VARI – LAI (R^2 = 0.08).

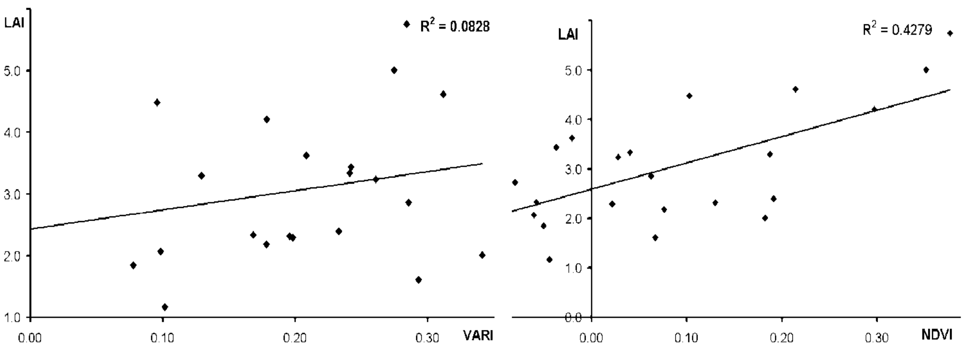

Fig. 4. VARI and NDVI correlation with LAI

The most likely cause of such a non-significant dependency is spatial variability of canopy into the fields. These examples are clearly visible on aerial photographs (Fig. 3). This diversity can have many causes, such as soil mosaic or relief. A significant impact on the assessment of the radiation reflected from the canopy was also the date of taking the photos. Winter wheat, in this period, was in the grain filling stage and depending on the soil categories, significant differences in canopy greenness are observed. Local variability (even a few meters interval) in most cases is the result of a soil's mosaic. The other example of short distance greenness variability is lower greenness observed close to technical paths (Fig. 3). For these reasons, the precise link between the place of performance measurement of the LAI and VI maps is difficult. This result suggests a need of an improved assessment of the LAI measurements localisation. This can be done by predetermination LAI-points, based on earlier aerial photos. But in this case non long-time intervals between remote and ground measurement must be assumed.

For assessing the condition of crops in regions with varying degrees of drought, an analysis was performed into the relationship between NDVI and CWB values, which were determined on the basis of modelling in the ADMS (Fig. 5). The result of this comparison is an obtained regression at the level of R^2 = 0.20. On the chart six specific zones, corresponding to particular regions, were separated. Zone 1 – these points described the CWB-NDVI correlation that was observed on the fields of Experimental Station IUNG-PIB in Baborówko.

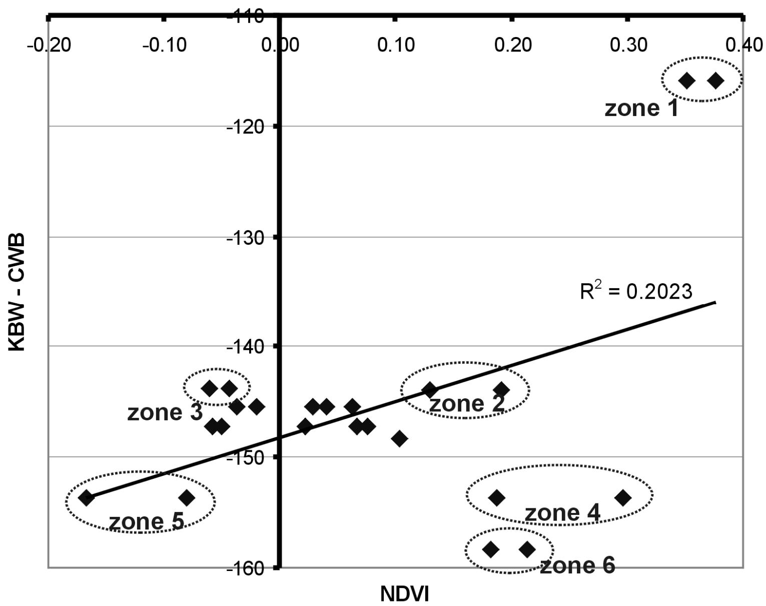

Fig. 5. CWB and NDVI correlation. Characteristically zones were marked

There the highest values of NDVI were registered and expected, because this region had the best meteorological conditions (modelled CWB = –116 mm) and the Station's assure an optimal level of field management. Zones 2 and 3 correspond to the locations of the same values of CWB, but the difference is the soil categories. Zone 2 correspond to soil category No. 4 (location of the most resistant to drought), zone 3 represent much more light soils (category No. 3, medium drought resistant). As assumed, wheat cultivated on much heavier soil showed higher NDVI values compared to the plants grown on lighter soil. Zones 4, 5 and 6 were in the area threatened by drought (Fig. 1). In this case, one would expect the lowest NDVI values, especially since these fields are the most vulnerable soils (Tab. 1). However, for zones 4 and 6, NDVI values are quite high. An analysis of the location of these fields showed the impact of an advancement cultivation state on plant conditions (zone 6) and habitat influence. Fields of zone 4 were situated in the vicinity of drainage systems, but the fields of zone 5 were situated at a distance of 500 m, on the top of small hill (light sand in the background).

Table 1. Characteristics of chosen fields (winter wheat)

No. of field	Latitude	Longitude	VARI	NDVI	LAI	CWB	Soil categories
1	52.58	16.64	0.28	0.38	5.8	–116	2
2	52.58	16.64	0.27	0.35	5.0	–116	2
3	52.13	17.44	0.20	0.13	2.3	–144	4
4	52.13	17.44	0.23	0.19	2.4	–144	4
5	52.07	17.53	0.10	0.10	4.5	–148	2
6	51.87	17.89	0.18	0.30	4.2	–154	1
7	51.87	17.89	0.13	0.19	3.3	–154	1
8	51.87	17.89	–0.06	–0.08	2.7	–154	1
9	51.87	17.89	–0.07	–0.17	2.4	–154	1
10	51.82	17.99	0.31	0.21	4.6	–158	1
11	51.82	17.99	0.34	0.18	2.0	–158	1
12	51.26	18.63	0.20	0.02	2.3	–147	2
13	51.26	18.63	0.17	–0.06	2.3	–147	2
14	51.26	18.63	0.29	0.07	1.6	–147	2
15	51.26	18.63	0.08	–0.05	1.9	–147	2
16	51.27	18.63	0.18	0.08	2.2	–147	2
17	51.35	19.87	0.24	0.04	3.3	–145	2
18	51.35	19.87	0.21	–0.02	3.6	–145	2
19	51.35	19.87	0.26	0.03	3.2	–145	2
20	51.35	19.87	0.24	–0.04	3.4	–145	2
21	51.35	19.87	0.29	0.06	2.9	–145	2
22	51.38	20.03	0.10	–0.06	2.1	–144	2
23	51.38	20.03	0.10	–0.04	1.2	–144	2

The lack of significant NDVI-CBW correlation in the tested regions was also the result of little space differentiation CBW in Poland in the first reporting period and the absence of drought in the later periods. Rainfall recorded in the third period of May and early June resulted in an increase of greenness intensity after a shortage of rainfall during early spring. Therefore, NDVI values depended much more on the other (non meteorological) conditions.

CONCLUSIONS

Research on the use of low altitude remote sensing in monitoring agricultural drought presented in this work, are an initial attempt of using this kind of spatial information to validate the results obtained in the Agricultural Drought Monitoring System provided by the Institute of Soil Sciences and Plant Cultivation – National Research Institute in Puławy. The conclusions that have been formulated below will be included in the study, which will be conducted in future years of monitoring.

1. Remote sensing is an effecting method of assessing the spatial variation of a crop's vegetation. In comparison with field observations, aerial photos allow an assessment into the condition of a whole field.
2. Validation of the results obtained in the Agricultural Drought Monitoring System in Poland, conducted on site, should be based on different types of spatial data. In addition to meteorological and soil data, used in modelling, the information about the advancement of cultivation methods and habitat conditions should take into account. This will allow avoiding the random selection of fields or sampling places, not representative of the tested region (e.g. poor field management) or fields (the mosaic effect of soil).
3. Using an extended range (near-infrared) of a non-metric digital photography, significantly improves the outcome of an evaluation into the vegetation state. In this study prove a stronger correlation between NDVI and LAI index than the correlation between VARI and LAI.
4. No strong correlation between the relationships established through the working hypothesis is largely attributable to a small intensity in the occurrence of drought, which was observed in the first reporting period (ADMS) and the lack of drought for every variety of field crops at later dates.
5. Aerial photos made for the purpose of monitoring the status of cereals vegetation, should be done (if weather conditions allow it) within a earnings season.

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7. THE ADAPTATION OF AGRICULTURE TO CLIMATE CHANGES – THE POINT OF VIEW OF A POLISH FARMER

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INTRODUCTION

The expected effects of climate changes on agriculture will be different in various parts of the world (Parry *et al*. 1999, Olesen *et al*. 2007). According to the latest IPCC report, in the northern part of Europe we can be expecting an increase of yield, while the southern regions of Europe may experience a strong decline in yield (Alcamo *et al*. 2007). Europe is of course highly diverse in terms of soil types, land uses, infrastructure, economic and political situation, etc. (Rabbinge and van Diepen 2000). This diversity will also greatly influence the response of agriculture to climate changes (Parry 2000). It appears that in Poland the main factor limiting the amount of yield in future climatic conditions will be the availability of water. In the last 25 years droughts occur more frequently, they are more extensive and cover much larger areas of the country (Łabędzki 2006). Moreover, modeling (e.g. HadRM3-P according to the A2 scenario) of the future climatic conditions also indicates the extension of the longest dry period from 5 to 10 days (daily rainfall $\leq$ 0.5 mm) (Kundzewicz *et al*. 2006). Potentially positive effects can include the extension of the growing period due to the general increase of temperature, allowing the more efficient growth of thermophilic crops in Poland. By 2010, the eighty percent probability of maize ripening will have been reached on almost whole territory of Poland, with the exclusion of small areas in the north (Kozyra and Gorski 2004).

Regardless of whether the climate changes will be affecting the agriculture favorably or negatively, attempts are being made to develop preventive and adaptive strategies. The proposed adaptive measures are based, among others, on such factors as the change of land use, the introduction of new varieties of crops, as well as on shifting the dates of field work (Stuczynski *et al*. 2000, Olesen and

Bindi 2002, Alcamo *et al*. 2007). However, scientific publications are often insufficient to implement the proposed adaptive measures to agricultural practice at farming level. Therefore, when devising adaptive strategies, it is necessary to use a bottom-up approach. This method takes into consideration the knowledge and opinions of the final recipient (the farmer) to develop a better strategy. In the case of agricultural adaptation to climate changes, it is also important to know the farmers' willingness and capacity to implement adaptive measures. This publication will present the point of view of Polish farmers on the impact of climate changes on agriculture, as well as their opinions on the possibilities of adapting to these changes. Furthermore, it will show the differences between the opinions and the suggestions of scientists, as well as the possibility of their implementation by farmers.

THE DESCRIPTION OF THE STUDY AND GENERAL CHARACTERISTICS OF THE SURVEYED FARMERS

Farmers' knowledge about climate changes was studied on the basis of a questionnaire which was prepared under the ADAGIO project (Adaptation of Agriculture in European Regions At Environmental Risk Under Climate Change, contract no. 044210) (Eitzinger *et al*. 2009a, 2009b). The original questionnaire was designed for Spanish farmers from the region of Castilla y Leon. The results of Spanish ADAGIO survey were published by Utset and del Rio (2008).

Some of the questions during the translation into Polish, were slightly modified in order to adapt it to the Polish conditions. The Question Form (Annex 1) was constructed in such a way as to obtain direct information from farmers on the following subjects:

1. Farmers' level of knowledge about climate changes.
2. Currently observed climatic risks for the local agricultural production.
3. Potential threats to agriculture resulting from future climate changes.
4. Inclination and ability to implement the proposed adaptive methods.

The questionnaire (Annex 1) was sent in July 2007, to sixteen Provincial Agricultural Advisory Centers with a request of possibly widest distribution of the questionnaire among farmers and returning it upon completion 1157 questionnaires were received back from 9 voivodeships (Fig. 1). In this paper, the survey results are presented as a whole, which means that they are considered in national terms, without a detailed analysis by region or province.

The study involved mostly men, who comprised 78% of all respondents, women respondents constituted only 22% of the population. The majority of the surveyed were people within the age range of 46-59 years and 36-45 years, who constituted 40% and 36% of respondents respectively. Farmers below the age of 35 accounted for 20% of the sample, while people over 60 were represented only by 4%. Given the education degree, the largest group of respondents consisted of persons with secondary technical and basic vocational education (Fig. 2).

Fig. 1. The number of completed surveys in respective provinces

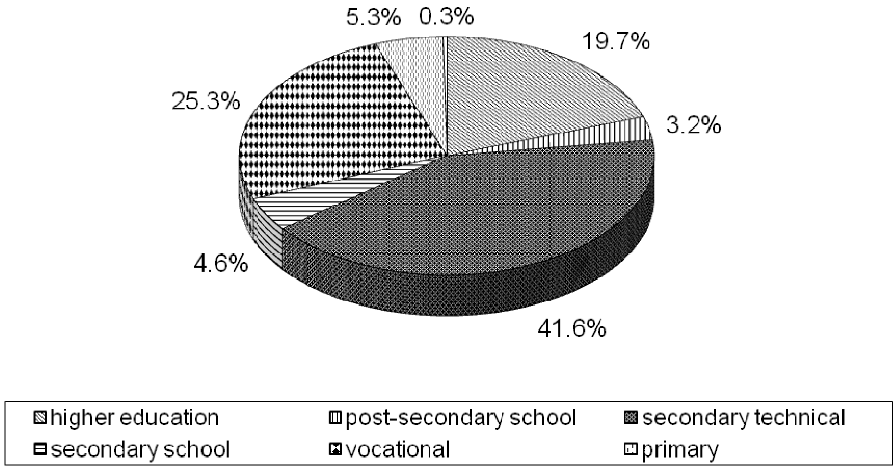

Fig. 2. The structure of respondents' education

Comparing this structure of respondents' education with the data obtained from the Central Statistical Office we can conclude that the test group was better educated than an average Polish farmer. According to the CSO (2008) the most, i.e. as many as 38% of farms in Poland are run by people with basic vocational education. By contrast, the largest group of respondents consisted of those with secondary technical education (41.6%). Almost 20% of farmers had higher education, while according to the CSO, only 7% of those in charge of farms have a university degree (CSO 2008). Average farm size among the surveyed farmers was about 26 hectares. Nearly 50% of farms were within the size range from 5 to 20 ha, multi-territorial farms (above 50 hectares) accounted for 10% (Fig. 3). According to the CSO, an average agricultural area per 1 farm involved in agricultural activities in 2007 amounted to 6.63 ha (CSO, 2008).

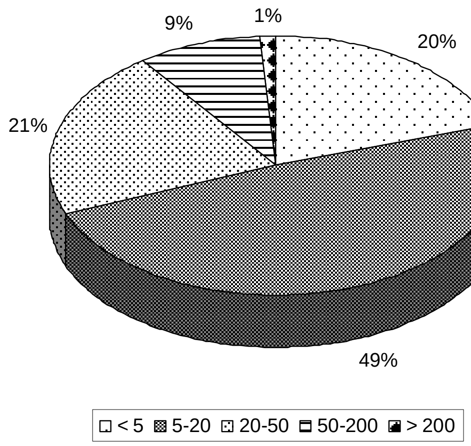

Fig. 3. The percentage of farms within the given farm size range (in hectares)

According to the CSO data, in 2007, grain accounted for 74% of the total sown area (grain mixtures of basic cereals and buckwheat, millet and other cereals, including maize grain) (CSO 2008). This overwhelming predominance of cereal was confirmed by the fact that such crops were preferred by the respondents. Wheat was the main winter grain, sown on over 5 thousand ha, which constituted almost 25% of the sown area. Subsequently, spring barley (about 15%) and winter rye (13%) were very popular. Beside the main cereal crops the respondents sowed oilseed rape on 11% of the total area (Fig. 4).

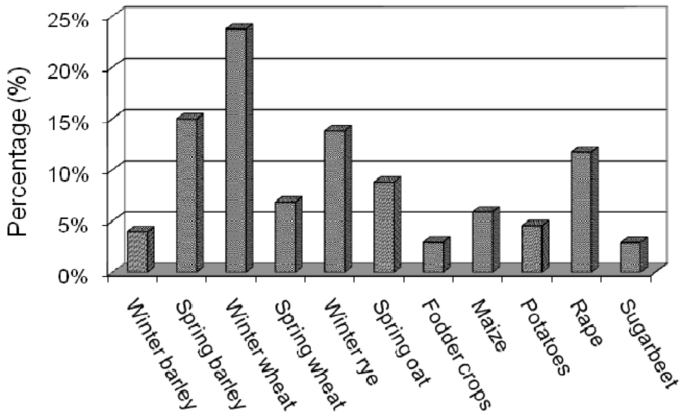

Fig. 4. The percentage of specific crop on the sown area in the respondents' farms

The survey also intends to determine what part of the crop is artificially irrigated, and what is operated by rain. The responses of the farmers clearly show that less than 1% of the crops were irrigated, and those were mainly potatoes, vegetables and strawberries.

FARMERS' KNOWLEDGE ABOUT CLIMATE CHANGES

The main source of information on climate changes, indicated by 90% of respondents, is television and radio. When asked about the extent to which they obtain information on climate change 55% of the respondents answered that they receive the average amount of information. Only 2% of them said that they receive no news on climate changes whatsoever. At the same time, farmers show a great confidence in the messages that they receive, because over 50% stated that they obtain reliable information (Fig. 5). The comments on questions regarding the accuracy of the information received included the following responses:

- *information is often mutually exclusive;*
- *reliability of the information depends on its source, but there is something to it;*
- *are not always confirmed by reality;*
- *incomplete and delayed information.*

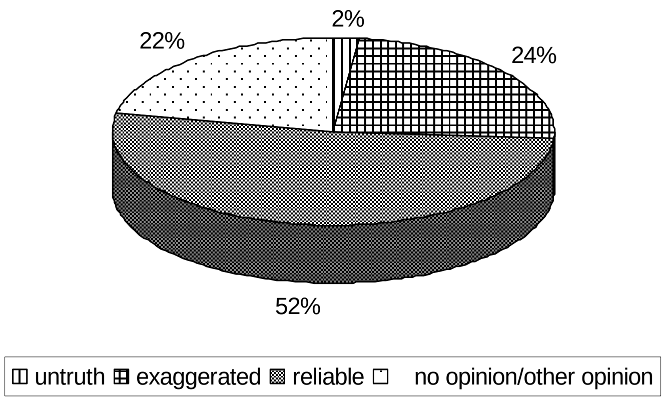

Fig. 5. The percentage of responses to the statement: *According to your opinion the information about climate changes, which you have received, is*:

Following the assumption that farmers have some knowledge about climate changes, they were asked, what impact these changes will have on agricultural production in their region. The vast majority answered that climate changes will have a medium or large impact on agriculture (Fig. 6).

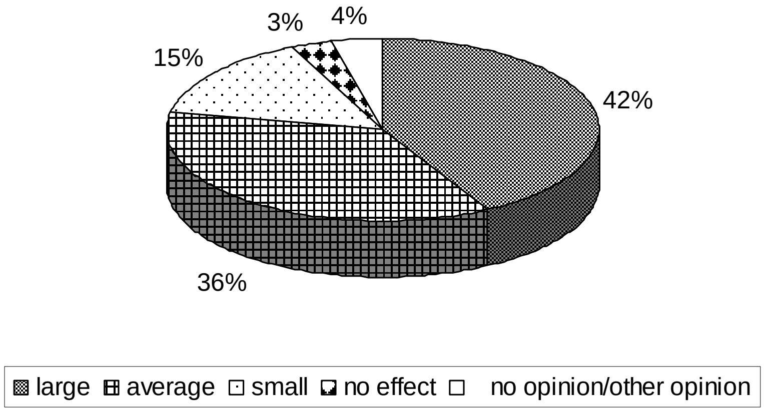

Fig. 6. The percentage of responses to the question: *According to the information about climate changes that you possess, what impact will they have on agricultural production in your region?*

At the same time, farmers indicate that future unfavorable climatic factors can significantly affect the amount of incurred losses. In particular, they indicate that more frequent droughts may result in heavy losses in crops (Fig. 7).

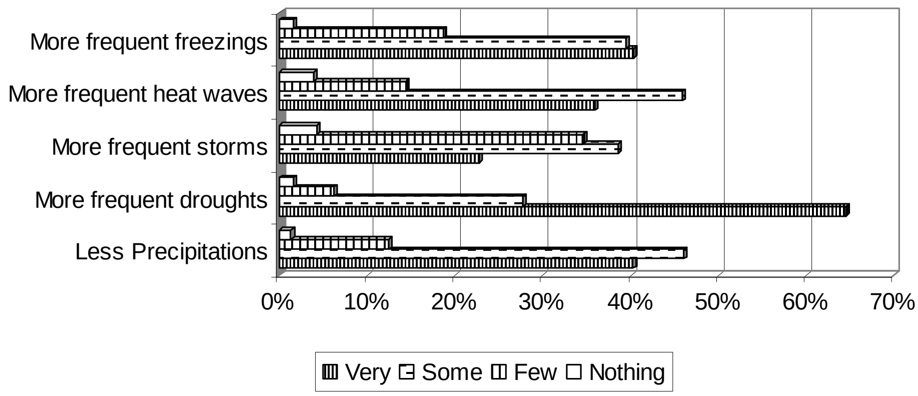

Fig. 7. The percentage of responses to the question: *To what extent may you suffer losses caused by the aforementioned climate changes?*

ADAPTIVE REMEDIES

Although farmers generally agree that climate changes will affect them, their approach to preventive actions bears a certain distance. Most of those surveyed said that one should first assess the degree of risk and review the potential adaptive measures (Fig. 8). At the same time 84% wanted to receive professional assistance on climate changes, and 76% expressed willingness to participate in the training/courses focused on finding the best adaptive strategies for farms.

The questionnaire included two questions about the feasibility of adaptive measures due to the future changes in temperature and changes in precipitation. From the answers of the farmers it was clear that the easiest method of adaptation is to introduce new plant varieties. Moreover, the surveyed perceived the introduction of the changes in terms of sowing performance, harvesting and changes in fertilization as equally easy. However, they are not willing to stop growing crops. The farm is the only source of livelihood for most farmers, and they have no other alternative such as finding another job. Comments on the survey indicate that the cessation of cultivation is out of the question. Also the introduction of irrigation was considered very difficult to implement (Fig. 9). In the commentary remarks farmers pointed out 3 primary obstacles that stand in the way of the increased use of irrigation in Poland; these are as follows:

- costs of irrigation installations and cost of water;
- lack of sufficient water amount;
- legal / administrative obstacles.

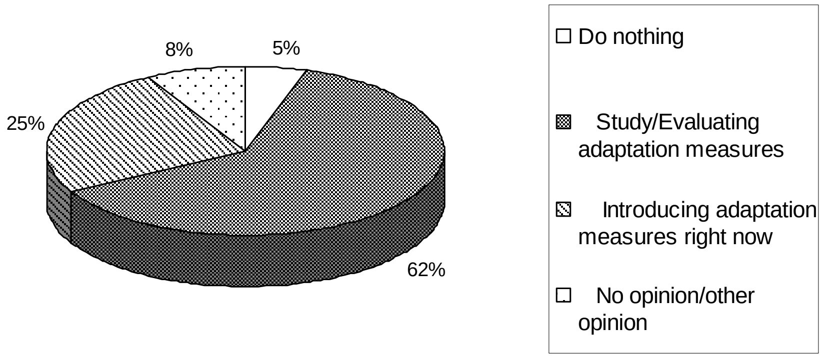

Fig. 8. The percentage of responses to the question: *In your opinion, what should be done about the potential impact of climate changes on agriculture in your region?*

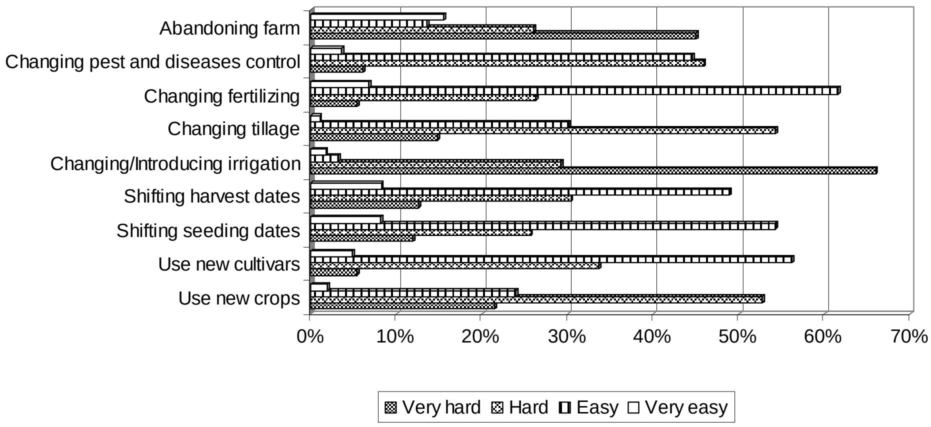

Fig. 9. The percentage of responses about the feasibility degree when asked: *Please indicate whether changes in temperature may induce you to undertake the following activities?*

In the case of adaptations, which require small financial outlays (i.e. changing the dates of field operations, changes in pest control), the support received from agricultural advisers should be sufficient to persuade farmers to introduce them. When it comes to the most of analyzed remedies, agricultural consultancy should go hand in hand with financial resources to convince farmers to the need of implementing adaptive measures. In the opinion of farmers, the introduction of irrigation is so expensive that fewer than 20% of the respondents could be convinced to introduce such adaptation based only on the agricultural consultancy. At the same time, the cessation of cultivation and abandoning the farm is also associated with high costs and agricultural consultancy would motivate farmers to do so only in the extreme cases (Fig. 10).

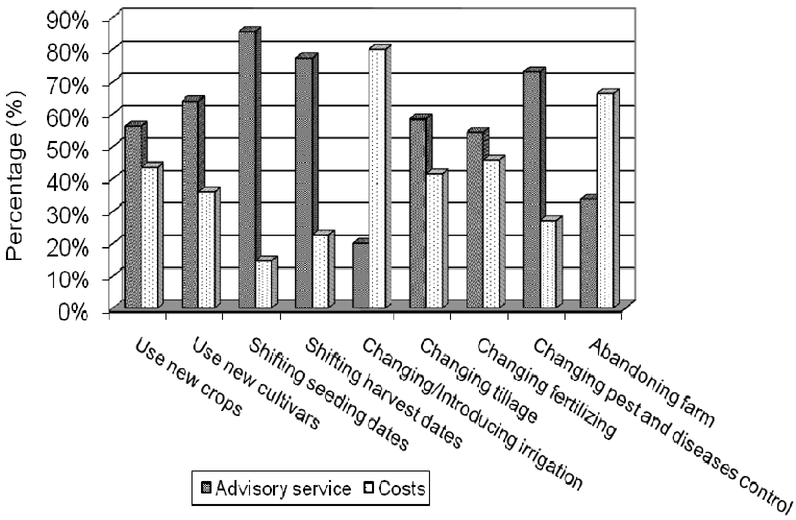

Fig. 10. The percentage of responses about the feasibility degree when asked: *Which of the factors may affect your decision to introduce adaptation measures to climate changes?*

DISSCOUSION AND CONCLUSIONS

Analyzed responses come from a group of farmers with higher education than an average Polish farmer, additionally, the surveyed also actively cooperate with agricultural advisory centers. It seems that this is not a shortcoming of the survey because actually this group of better educated and active farmers will be deciding on the further development of agriculture in Poland. Majority of farmers were certain that the information which they receive regarding climate changes is reliable.

At the same time, since television is the most frequent source of the information for the farmers, one should ask a question about the quality of this information. In the comments added to several surveys, the farmers asked for more information on the impact of climate changes on agriculture, for example in the form of brochures. Therefore, according to the authors' opinion the education of farmers and agricultural advisers is absolutely necessary. This way, farmers will be able to introduce the simplest methods of adaptation by themselves, while greater knowledge will enable them to verify the information which they receive. At the same time, the implementation of regional guides which will help to refine the adaptation strategies for the different areas of Poland, is recommended (Stuczyński *et al*. 2000, Sadowski *et al*. 2009).

The vast majority of farmers are convinced that the future adverse climatic factors will cause some losses on their farms. The respondents clearly indicated that the most serious threat may be posed by the increased frequency of droughts and less rainfall. Such conclusions are most likely drawn by farmers from their own observations and experience. In 2006, several weeks of heat and lack of rainfall in June and July, affected most severely such crops as spring cereals, maize, potatoes and sugar beets, and pasture. According to assessments of the Ministry of Agriculture and Rural Development, the biggest losses occurred on meadows and pastures, mainly regarding II and III swath (40-100% loss), spring cereals (20-60%), winter cereals (15-50%), rape (15-45%,) potatoes and sugar beet (20-60%), vegetables (30-60%) (Leśny *et al*. 2008).

According to the answers given by the respondents, adaptive measures can be divided into 3 main groups. The first group of activities are those that farmers are able to do themselves, or with the support of agricultural advisory centers, which do not require large financial outlays, they are as follows:

- change of the date of sowing,
- change of the date of harvest,
- change in the way of controlling pests and diseases.

The second group includes activities that farmers would be able to do after obtaining relevant knowledge, for instance from the agricultural advisers and with some financial support, or appropriate adaptive policy, they are as follows:

- the introduction of new crops,
- introduction of new varieties,
- change in the ways of growing,
- change in the way of fertilization.

The last group involves activities that farmers considered unrealistic, primarily due to costs, and these are following:

- cessation of cultivation / finding another source of income,
- introduction of irrigation.

Following the pattern of responses, it can be concluded that farmers are ready to introduce the majority of adaptations on the basis of knowledge provided by the agricultural consultancy.

According to farmers, the main threat for the Polish agriculture in the future climatic conditions will be droughts and water shortages. At the same time, farmers indicate that they would not be able to introduce modern irrigation systems as adaptive measures, mainly due to high investment costs. Therefore, in order to improve water management at farming level, farmers should be convinced to undertake such actions as increasing local water resources and their availability, improve the efficiency of water use, reduction of crop water demand (Łabędzki 2009). Such actions could be performed by the farmers themselves, after prior trainings in Agricultural Advisory Centers. The introduction of irrigation on a large scale seems to be impossible in the current economic situation of Polish agriculture and will probably require some systemic solutions in the national agricultural policy in the future.

The results, which were obtained by analyzing the survey indicate that farmers are aware of the potential effects of climate changes on agriculture and are deeply concerned (interested in) about this topic. Therefore, the authors of this paper are convinced that the only effective way to develop adaptive strategies is a real bottom-up approach. The views of farmers on the implementation of the adaptive measures are necessary to be included in the creation of nationwide programs aimed at adapting Polish agriculture to climate changes.

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Annex 1.

QUESTIONNAIRE FOR FARMERS

1. In which extent do you consider you are informed about Climate Change issues?

☐ Very
☐ Some
☐ Few
☐ Nothing

2. According to your opinion the information about climate changes, which you have received, is:

☐ Untruth
☐ Exaggerated
☐ Reliable
☐ No opinion/other opinion

3. According to the information about climate changes that you possess, what impact will they have on agricultural production in your region?

☐ Large
☐ Average
☐ Small
☐ No effect
☐ No opinion/other opinion

4. In your opinion, what should be done about the potential impact of climate changes on agriculture in your region?

☐ Do nothing
☐ Study/Evaluating adaptation measures
☐ Introducing adaptation measures right now
☐ No opinion/other opinion

5. Factors that have affected the agricultural production in your farm:

	Often	Sometimes	Never
Freezing	☐	☐	☐
High temperatures	☐	☐	☐
Droughts	☐	☐	☐
Storms	☐	☐	☐
Pests and/or diseases	☐	☐	☐

6. Factor incidence by crops

	Freezing	High temperatures	Droughts	Storms	Pests and/or diseases
Winter barley	☐	☐	☐	☐	☐
Spring barley	☐	☐	☐	☐	☐
Winter wheat	☐	☐	☐	☐	☐
Spring wheat	☐	☐	☐	☐	☐
Winter rye	☐	☐	☐	☐	☐
Spring rye	☐	☐	☐	☐	☐
Winter oats	☐	☐	☐	☐	☐
Spring oats	☐	☐	☐	☐	☐
Fodder	☐	☐	☐	☐	☐
Corn	☐	☐	☐	☐	☐
Potatoes	☐	☐	☐	☐	☐
Rape	☐	☐	☐	☐	☐
Sugar beet	☐	☐	☐	☐	☐
Sunflower	☐	☐	☐	☐	☐
Vegetables	☐	☐	☐	☐	☐
Vineyard	☐	☐	☐	☐	☐
Orchards	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

7. To what extent may you suffer losses caused by the aforementioned climate changes?

	Very	Some	Few	Nothing
Less Precipitations	☐	☐	☐	☐
More frequent droughts	☐	☐	☐	☐
More frequent storms	☐	☐	☐	☐
More frequent heat waves	☐	☐	☐	☐
More frequent freezing’s	☐	☐	☐	☐

8. Please indicate whether changes in temperature may induce you to undertake the following activities?

	No	Yes	Feasibility			
			Very hard	Hard	Easy	Very easy
Use new crops	☐	☐	☐	☐	☐	☐
Use new cultivars	☐	☐	☐	☐	☐	☐
Shifting seeding dates	☐	☐	☐	☐	☐	☐
Shifting harvest dates	☐	☐	☐	☐	☐	☐

Changing/Introducing irrigation	☐	☐	☐	☐	☐	☐
Changing tillage	☐	☐	☐	☐	☐	☐
Changing fertilizing	☐	☐	☐	☐	☐	☐
Changing pest and diseases control	☐	☐	☐	☐	☐	☐
Abandoning farm	☐	☐	☐	☐	☐	☐

9. Please indicate whether changes in precipitation patterns may induce you to undertake the following activities?

	No	Yes	Feasibility			
			Very hard	Hard	Easy	Very easy
Use new crops	☐	☐	☐	☐	☐	☐
Use new cultivars	☐	☐	☐	☐	☐	☐
Shifting seeding dates	☐	☐	☐	☐	☐	☐
Shifting harvest dates	☐	☐	☐	☐	☐	☐
Changing/Introducing irrigation	☐	☐	☐	☐	☐	☐
Changing tillage	☐	☐	☐	☐	☐	☐
Changing fertilizing	☐	☐	☐	☐	☐	☐
Changing pest and diseases control	☐	☐	☐	☐	☐	☐
Abandoning farm	☐	☐	☐	☐	☐	☐

10. Which of the factors may affect your decision to introduce adaptation measures to climate changes?

	Advisory service	Costs	Other Which?
Use new crops	☐	☐	
Use new cultivars	☐	☐	
Shifting seeding dates	☐	☐	
Shifting harvest dates	☐	☐	
Changing/Introducing irrigation	☐	☐	
Changing tillage	☐	☐	
Changing fertilizing	☐	☐	
Changing pest and diseases control	☐	☐	
Abandoning farm	☐	☐	

11. Would you like to receive technical assistance regarding climate-change adaptation options in your farm?
- ☐ Yes
- ☐ No

12. Your favourite information sources regarding climate-change adaptation options are:
- ☐ Radio and TV
- ☐ Internet
- ☐ Journals, Books and Newspapers
- ☐ Agricultural Research Services
- ☐ Cooperatives and Agribusiness
- ☐ Friends and neighbours
- ☐ Local administration

13. Would you like to participate in demonstration proposals aimed to find the most suitable climate-change adaptation options in your farm?
- ☐ Yes
- ☐ No

14. If you have no objection please give us your personal details and way to contact (name, surname, address, phone number, e-mail)
…………………………………………………………………………
…………………………………………………………………………

15. Voivodeship
…………………………………………………………………………

16. Sex
- ☐ Male
- ☐ Female

17. Age
- ☐ < 35
- ☐ 36-45
- ☐ 46-59
- ☐ >60

18. Number of hectares (approximate) under irrigation: ________________

19. Farm size (ha)
- ☐ < 5
- ☐ 5-20

☐ 20-50
☐ 50-200
☐ >200

20. Education:
☐ Higher education
☐ Post secondary school
☐ Secondary technical
☐ Secondary school
☐ Vocational
☐ Primary
☐ Without education

21. Please announce approximate area of your farm ……. and area occupied by aforementioned crops.

	Rainfed		Irrigation	
	ha	Average production	ha	Average production
Winter barley				
Spring barley				
Winter wheat				
Spring wheat				
Winter rye				
Spring rye				
Winter oats				
Spring oats				
Fodder				
Corn				
Potatoes				
Rape				
Sugar beet				
Sunflower				
Vegetables				
Vineyard				
Orchards				
Other				

22.Additional remarks
…………………………………………………………………………………
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8. METEOROLOGICAL PROTECTION OF THE AGRICULTURAL ECONOMY UNDER CONDITIONS OF CLIMATIC CHANGE

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INTRODUCTION

According to various sources (Preś 2007), about 2/3 of companies around the world are dependent on the weather in their operations in such a way which results in fluctuations in sale of goods and services caused by adverse, though not disastrous, weather phenomena. The US Trade Department has calculated that the weather risk accounts for 40% of the country's GDP. European data are not so precise and it has even been suggested that weather does not affect the EU economy (positive and negative effects of weather conditions offset each other in such a large and diverse climatic space), but with respect to individual countries and seasons, the part of GDP value affected by weather conditions varies but it does not exceed 1% (McWilliams 2004). However, if the relationship was illustrated with the results achieved by sensitive enterprises, the significance of weather conditions would prove very high in some cases. The most weather-affected industries include: power engineering, agriculture, the food industry, building construction, tourism and leisure services, transport, cleaning companies, road services and retail trade. Because business activities are very sensitive to trade fluctuations financial liquidity is particularly necessary. A company may collapse due to its temporary breakdown, even though it may be very effective otherwise. Hence, weather fluctuations may be a serious problem and they have to be taken into account in the company strategy. What can an entrepreneur do when faced with inevitable weather risk? There are several possibilities (Preś 2007):

- Avoidance – this is possible owing to weather forecasts, actions may be effective in agriculture with respect to technological operations; it is effective only to a limited extent in other industries because weather forecasts are not perfect. In many areas, long-term risk avoidance is impossible.

- Absorption – it involves covering losses with the use of one's own resources; it is applied especially in agriculture on a one-year scale; it is effective only in rather extensive production systems.
- Decreasing – changing the production profile whenever adverse weather conditions occur; it is impossible in most companies, (practicable in agriculture, but only to a limited extent).
- Transfer – risk transfer to another object (sometimes it is a customer; that is nearly always the case in agricultural production) or to the capital market as insurance or a derivative financial instrument.

WEATHER-RELATED RISKS IN AGRICULTURE

The effects of weather on agricultural production is an area studied by a specialist branch of meteorology, called agrometeorology. The importance of this science can be shown in different ways, one thing is certain though: the benefits it gives can be reduced to a single, economic dimension. Thales of Miletus, who lived in the 7^{th} century BC, known mainly as the author of the principles of geometry, became rich thanks to his intuition as a weather observer. Forecasting it to be beneficial, he bought olive oil extracting machines in the neighbourhood and was able to dictate prices during a season of good crops; note – he bought equipment rather than olive groves (Sorbjan 1996). According to historical research, weather phenomena in Western Europe used to be responsible for 1/3 to 2/3 of the variability of agricultural production (Solomou, Weike 1999).

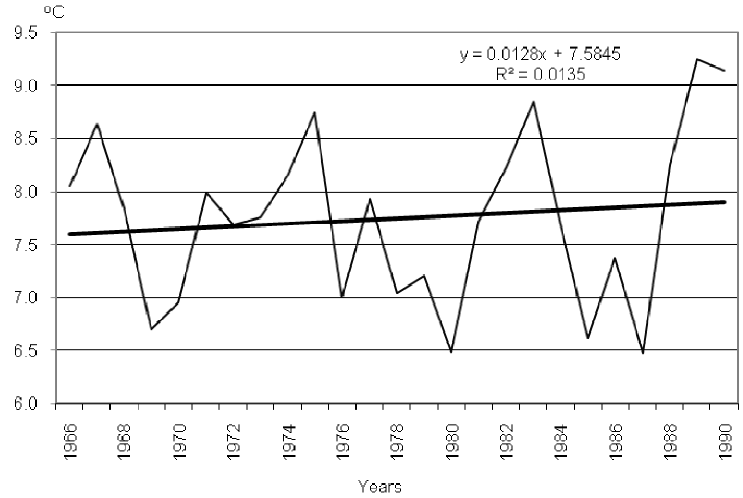
Nowadays, the condition of agriculture is heavily dependent on weather conditions, and sometimes the relationship translates further onto the entire economy, even affecting the political sphere (the severe winters of 1969/70 and 1978/1979 played a part in triggering a series of events leading to the political transformations in Poland).

Short-term weather variability and long-term climatic changes are a source of considerable risk in agricultural production. With the current level of knowledge of agrometeorology, which is the basis for production technologies, there are a lot of achievable effects which alleviate the impact of adverse weather conditions, but the existence of the buffer area only reduces the risk of agricultural activities; it does not eliminate it altogether. The situation may become aggravated in the face of upcoming climatic changes. Although it is difficult to estimate their impact in the perspective of fifty or a hundred years, and to predict the average global and local temperature, especially with respect to expected total rainfalls and rainfall distribution (IPCC Fourth Assessment Report. 2007), one thing is certain: weather variability will increase. It can therefore be claimed that with the inevitability of climate changes, the issue of weather risk estimation and modes of future enterprise activities, with particular emphasis on agriculture, is becoming extremely important. Agricultural production which actively takes into account weather-related risk will have to make use of decision-making support tools based on properly prepared information about weather and climate (Hansen 2002, Sivakumar and Motha 2007, Sonka *et al.* 1986).

Agricultural policy in many countries has changed despite being subsidised and despite state interventions in the form of all sorts of regulations; this branch of production has to face adverse external conditions, mainly weather (Barry 1984, Hardaker 2004). The ability to manage the risk will become one of a farmer's most important skills (Babcock *et al.* 2003). Almost at every latitude there is a risk of disastrous phenomena, so-called weather extremes and climatic anomalies, which destroy the results of a farmer's work or reduce the crop and its quality. The greatest danger of this type occurs in countries at the lowest level of development, where shortage or excess of rainfall produces disastrous results (Sivakumar and Motha 2007). Drought in Poland is occurring more and more frequently, and the two recent floods (1997 and 2010) will be recorded as the most disastrous weather phenomena in history.

Weather conditions fluctuate from year to year, which manifest themselves as variability of seasonal and annual factors and cause agricultural production output to reach different levels in its different segments. The situation in this respect can be analysed with the use of data from the past fifty years. According to analysis of data from 26 agrometeorological stations for the period between 1966 and 2005, the value of standard deviation of temperature in Poland was equal to 0.8ºC, with the variability factor was equal to 10.1%. However, the greatest variability was recorded in winter and spring (Szwejkowski 2009). Standard deviation during those periods was equal to 2.3 and 1.1ºC, respectively. The average temperature variability during the vegetation period was the same as that of annual temperatures. Annual atmospheric precipitation fluctuates similarly to temperature – its variability index was 12.5% and the standard deviation was 75.8 mm. The winter and autumn precipitation variability was 25.8 and 24.0%, while the variability during the vegetation period was nearly equal to that for the entire year, i.e. 14.6%.

Although the average annual temperature in the years 1991-2005 was higher by about 0.5ºC as compared to the average value for the forty years between 1966 and 2005 (Fig. 1), its annual and seasonal recorded variability was even slightly lower. It was the same with precipitation (Fig. 2). Variability of weather conditions frequently shows some temporal regularities (Szwejkowski *et al.* 2009).



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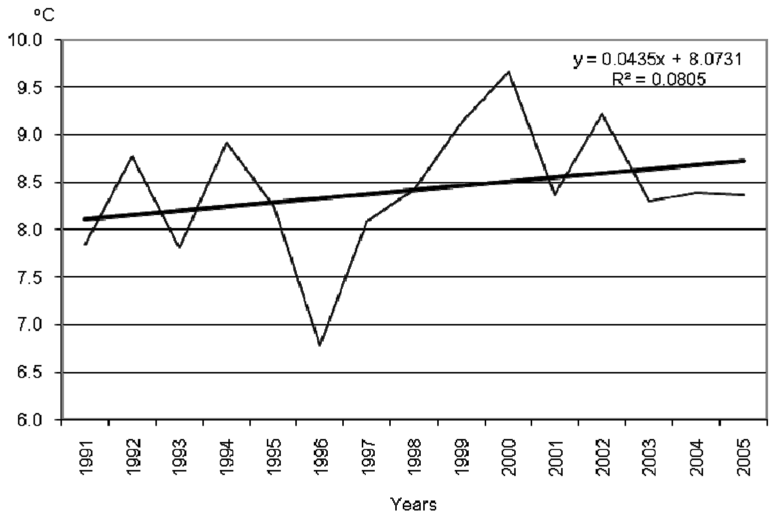

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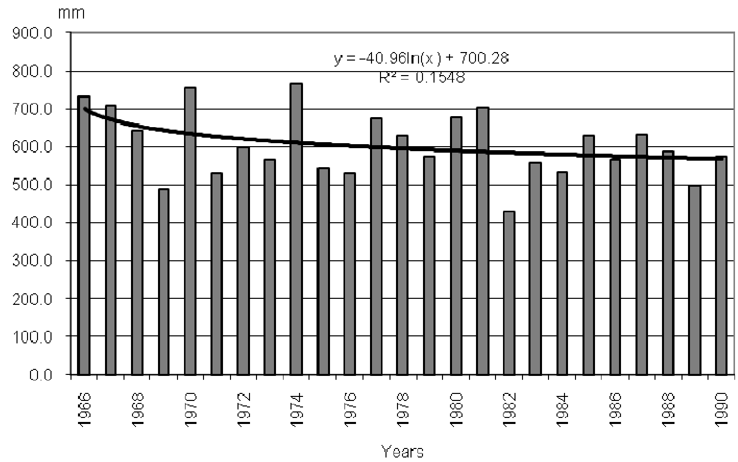
Fig. 1. Mean annual temperature (^oC) and trends of change of temperature in Poland in years 1966-1990 (a) and 1991-2005 (b). Source: Szwejkowski *et al*. 2009

An analysis of the methods that a farmer has to secure himself against weather fluctuations should emphasise that regular periodicity would make it much easier to take proper decisions, both in terms of technology and financial management. According to study results, there has been a certain order in the past 40 years, which can be described as an 8-year regular periodicity of annual temperatures and 4-year periodicity of atmospheric precipitation (Fig. 3).



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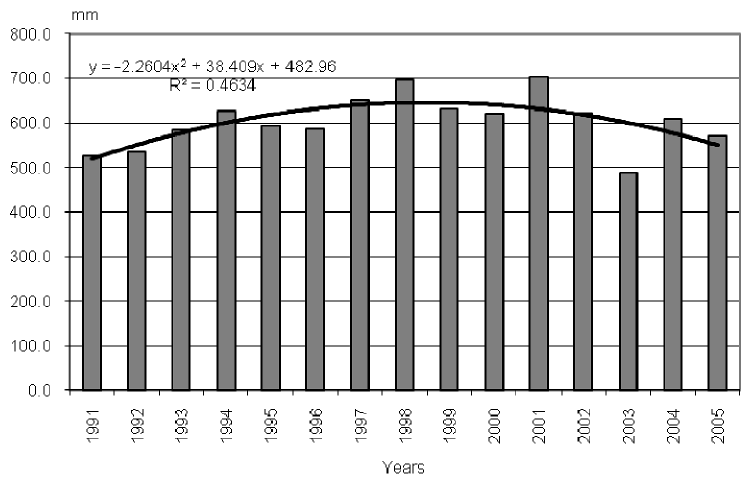

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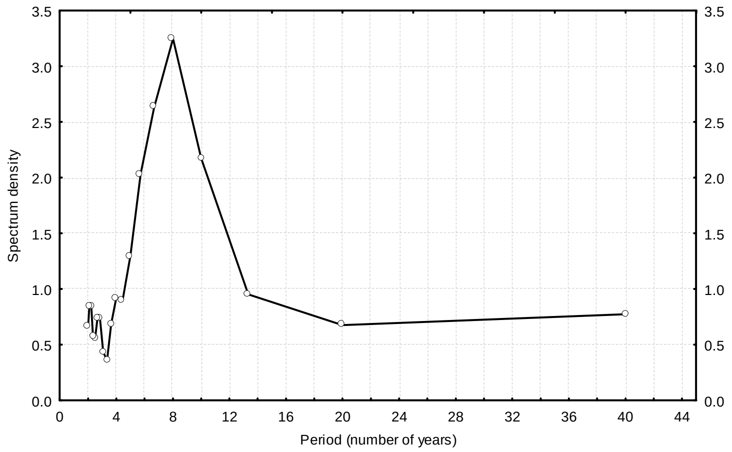
Fig. 2. Sums of annual precipitation (mm) and trends of change on the territory of Poland in years 1966-2005 (a) i 1991-2005 (b). Source: Szwejkowski *et al.* 2009

The variability of crop yield in Poland is a typical feature, which is manifest in the data provided by the Central Office of Statistics and compiled by authors. It has been determined based on that source that during the period between 1966 and 2005 variability was observed in every crop yield, combined with a linear growing trend. The thesis is illustrated by the main cereal: winter wheat and by a fodder crop – maize (Fig. 4).



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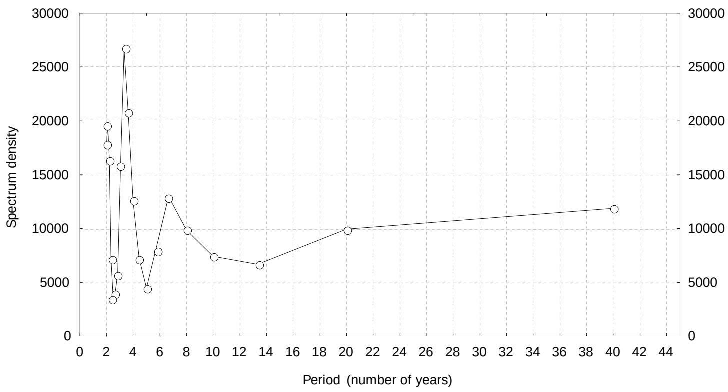

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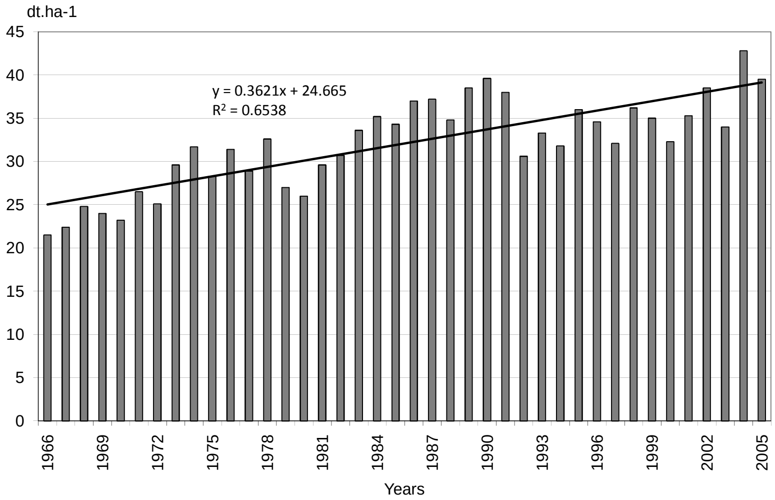
Fig. 3. Graph of spectrum density according to Fourier's analyze of mean annual temperatures (a) and precipitation (b) in years 1966-2005. Sources: Szwejkowski *et al.* 2009



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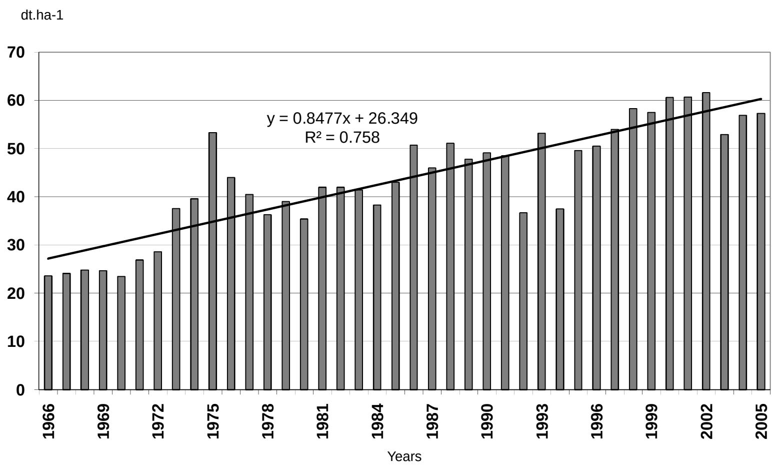

(b)

Fig. 4. Trends of change of mean yields on winter wheat (a) and maize (b) in Poland in years 1966-2005. Source: Szwejkowski and Dragańska 2008

Changes in crop yields were accompanied by price changes. The lack of crop price stability (Tab.1) is surely caused by various factors; however, it may have been largely caused by weather conditions. This especially concerns the prices of crops, potatoes, fruit and vegetables. The extent of changes of livestock prices was the largest, but the supply/demand relationship was the decisive factor in this case. It might seem that the price of milk as an agricultural product does not depend on the weather fluctuations, but this is not so, because fodder, produced from grain, is the main item of its production cost.

Table 1. Coefficients of change of prices of chosen agricultural products in years 1990-2005. Sources: Authors compilation on a base of data from Institute of Agricultural and Food Production Economics (IERiGŻ)

Product	Years: 1991-2005	Years: 2000-2005
Cereals grain	52.4%	25.1%
Potato	72.1%	36.5%
Fruits and vegetables	40,3%	36.7%
Pork	35.8%	22.3%
Milk	51.7%	21.1%

AGRICULTURAL RISK MINIMISATION BY TRANSFER TO THE CAPITAL MARKET

Although agricultural activities are considerably different from other spheres of production and services, there are certain solutions that can be applied to eliminate large fluctuations of management effectiveness – which means that a farmer need not be a producer who is totally dependent on factors beyond his control; he can also, as an entrepreneur, take actions to minimise risk.

However, Polish farmers' awareness changes with difficulty, as even such an obvious way of securing oneself against the effects of natural disasters as insurance is not accepted without resistance, even despite being obligatory. Irrespective of this and bearing in mind the common nature of various forms of insurance in agriculture in the West, the issue should be examined, analysed and the effects of such analyses should be applied in agriculture in Poland, especially in the face of expected climate changes. Moreover, according to the procedures applied so far, all the risk related to extreme weather conditions is borne by the national treasury, which adversely affects prices, and – paradoxically – it is not particularly beneficial to farmers. Therefore, it is time for a change.

The issue of weather-related securities is much more simple in companies than in agriculture. For example, a power-supply company obviously incurs some loss when the temperature is low in summer and high in winter. In this case, the demand for power needed for air-conditioning in summer and for heating in winter is low and all the transactions which secure against the risk may be indexes with simple indexes. These are, for example, HDD (heating degree days) and CDD (cooling degree days). It is more complicated in agriculture. Weather-dependence of crop yield is evaluated with the use of similar indexing systems, but they always refer to specific development periods of various species and are calculated for a variable numbers of days. According to American studies, a preliminary approach to weather-related derivatives has to assume a certain level of knowledge of the situation, so that the optimum package of securities can take into account both the specificity of crop species and the regional characteristics; moreover, weather-related variables should have the form of complex indexes rather than simple meteorological data (Vedenov and Barnett 2004). This shows that it is more difficult in agriculture to devise a good index which can be used to settle transactions, if weather-related financial instruments are not to be regarded as a mere form of profiteering.

As has already been said, financial instruments applied in order to minimise the risk of production can be divided into two groups: insurance and derivative financial instruments.

In the first group of financial securing instruments, compensation is paid for damage done by natural disasters. Price is the only criterion of selection of the insurance company and the type of insurance (apart from the obligatory insurance), which should also be considered within the context of all contractual regulations. In such cases, the insurer must exercise extreme prudence because proper risk estimation will affect the effectiveness of the enterprise. The insurance company has to consider weather and climatic trends so that its activities should not result in insolvency. This is why it is so important to evaluate the temporal and spatial risk of crop cultivation, which is performed in some departments which deal with agrometeorology (Atlas….. 2001). Risk has to be evaluated permanently because it is changing and, considering any upcoming significant climatic change, it will be different than it is now. Precise studies devoted to the issue will provide an opportunity to lower policy prices, which is usually beneficial to the insurance company and to the insured. An insurance company will always be willing to charge an insurance premium based on an estimated risk level higher than the real one. However, this is disadvantageous to everyone because high insurance premiums restrict the scope of insurance. Moreover, insurance is a kind of activity with a large load of moral risks. The market of agricultural insurance is susceptible to rule violations, which involves fraud or lowering the amount or even refusing to pay damages.

Less known ways of reducing weather-related risk in agriculture include making use of derivative financial instruments, offered by financial market institutions (Sokołowska 2008). The scope of the application of such securities is different than those previously discussed because their aim is to relieve the effects of natural weather variability, which is – as has been shown before – perfectly common and permanent. A farmer takes a risk every year, and agricultural production output varies from year to year because of weather fluctuations, as there is no such weather system which would be optimal for all plant species as well as for all branches of production. No insurance covers such circumstances, but it is possible to minimise the risk in cases of adverse weather. The dissimilarity of this form of risk minimisation lies in that it considerably reduces the moral risks, although the growing market attracts profiteers. Therefore, it comes as no surprise that parties to weather-indexed transactions include companies with real exposure to unexpected weather changes, but also hedge funds, investment banks, insurance companies and individual investors. What, then, is a derivative financial instrument and what is its importance in minimising the risk for agricultural production? Economists define a derivative instrument as one whose value depends on the value of another financial instrument, referred to as the base instrument (Preś 2007). However, a derivative financial instrument is mainly a form of transaction on the base instrument, taking into account an element, which may be conventionally referred to as an index. Common base instruments include shares, stock market indexes, interest rates, currencies and, obviously, commodities, and more specifically – their prices. Therefore, the definition does not indicate any relationship to agriculture, but it rather refers to pure finance. The essence of a weather-related derivative instrument in agriculture can be reduced to a commodity transaction based on a weather-indexed commodity price.

Weather-related indexes are naturally based on atmosphere parameters, such as temperature, total precipitation (rain or snow), wind velocity, clouding, insulation or thickness of snow cover and combinations of these parameters. The weather parameter itself, arising from measurements made at a selected weather station or their network, e.g. the average monthly temperature in Poland, can be a contractual index. A weather-related index is selected from a set of elements which describe weather conditions, considering its impact on a commodity (agricultural product) price. Such impact is always indirect because the weather directly determines only the production output (yield, cultivation area for a specific species, quality of agricultural material). And this is the fundamental issue – the choice of indexes for derivative weather-related instruments. Parties which negotiate an agreement aim at achieving specific results and it can be assumed that both have a pragmatic approach to the issue – transfer of weather-related risk of agricultural product price change. On the other hand, it may be speculated that the same approach is possible with pure profiteering in mind, and a weather-related index could be regarded as one of the possible elements of a – somewhat exotic – bet.

When explaining the essence of derivative instruments, one should emphasise that they are OTC instruments and can be offered by financial institutions, mainly banks. Being a commodity producer, a farmer secures himself against price changes, in such cases forward contracts are applied, which are determined not by a commodity fixed price, but by factors which may affect the price. This is because the price can be foreseen. Before appearing on the market, an agricultural commodity is produced in a process which is largely affected by external natural random processes. Such factors suggest the price level long before the product appears on the market. If conditions prove to be beneficial, the commodity supply is high and the price is low; conversely, if the conditions are disadvantageous, the supply is low and the prices are high.

Weather-related derivatives are offered in Poland only by foreign insurance companies (frequently in cooperation with Polish brokers), which operate on the OTC market in the European Union. Consus sp. z o.o. organises the trade in weather-related derivates and CO_2 emission rights in Poland. Consus sp. z o.o. cooperates with Galileo Weather Risk Management Ltd (Perś 2007), which is an international insurance company and the leader in derivate and weather-related insurance in Europe. Owing to cooperation with such a serious and reliable partner (A rating), Consus s. z o.o. can offer the best terms and conditions in Poland and in Europe. Although the global market on weather-related derivates is growing, a certain resistance can be observed in insurance companies against offering such insurance for agricultural production due to excessive risk of lack of financial liquidity. The problem could be solved by changing the approach to the risk evaluation from individual evaluation for each farm to a spatially aggregated evaluation (Woodard and Garcia 2007).

STRATEGIES ON THE MARKET OF WEATHER-RELATED DERIVATIVES

Large industrial and service providing companies transfer their risk to the capital market through the stock exchange. There are specific types of transactions on all the possible base instruments whose weather-related indexation is based on previously mentioned HDD and CDD indexes, calculated from the data provided by selected weather stations at certain locations (e.g. Berlin, London, Chicago). However, the practical side of securing agricultural transactions is different. They are conducted mainly on the OTC market, with banks and brokers being elements of the market; it is difficult to envisage in the agricultural sector (unlike in other sectors) that such financial instruments should be provided by farmers. Farmers are end users who use those instruments to secure themselves financially against weather variability. Such a market must involve a regulatory institution, the International Swaps and Derivatives Institution (ISDA), which is responsible for observing the rules.

The essence of derivatives application cannot be reduced to securing the prices of agricultural products against adverse weather. The measures offered by the market today involve actions which indirectly provide such security, although transactions are indexed by weather conditions. Let us consider one simple example, whose form is understandable to an average farmer. The derivative in such a case is a “forward” contract, which specifies the price of an agricultural product in relation to the weather conditions during a specified period of time. Therefore, the conditions of such a contract will specify the time framework and the weather station, data from which will be used; moreover, it will adopt the value of a weather feature or weather index calculated from the data, the product unit price as referred to the index base value (performance level) and the index unit price. For example, let the average daily July temperature of 30ºC be the transaction index, with the performance price of PLN 400 and the index unit price of 20 PLN/1^{o}C. Therefore, if there are 3 days in July with the average daily temperature of 31, 34 and 33ºC, the transaction will be calculated as follows: the total temperature excess was equal to 8^{o}C x 10 = 80 PLN. The transaction price will be equal to the performance price 400 PLN + 80 PLN = 480 PLN. Therefore, potential loss caused by very high temperature will be compensated for by an addition to the price. But this is not the end of the analysis: a farmer will earn a higher price, but he will profit only if the transaction price is higher than the market price at that moment; otherwise it is the buyer who will gain the profit. Although forward contracts are usually concluded in agricultural raw material trade between agents, farmers should still be interested in such solutions.

Another form of security could be provided by options. The relationships between factors in this case is much more complex. Leaving aside the technical details: an option is an arrangement which gives a buyer – "long" position – a right (but not an obligation) to buy – "call" – or sell – "put" – a commodity at a previously specified price. The right can be exercised on the day when the option expires (European option) or on any day between the date of concluding the option contract and the date of its expiration (American option), or on several precisely specified dates (Bermudan option). The seller takes the "short" position (Preś 2007).

If "forward" contracts may not raise particular emotions as being more "natural" and understandable to the parties, it is different with the option trade. Options as secondary financial institutions have become notorious in Poland. Using them requires one to apply certain strategies of action and choice as well as to have considerable economic knowledge. But one must first of all bear in mind that it is not a way of becoming rich or a kind of gambling game. Examples of action strategy provided in the literature assume a possibility of securing one's activities against loss caused by weather conditions by means of financial protection, but this is not a tool for an average farmer – although it has been suggested that action strategies with respect to it may be very simple (Sokołowska 2008).

A swap contract could be an object of interest in agriculture. The essence of such a contract is the exchange of risk by the parties to the transaction. One of the parties gains when a selected weather parameter reaches a value above an agreed level, while the other loses, and vice versa. If such a contract is concluded, variable weather conditions do not cause economic disturbance, in particular, they allow a company to maintain financial liquidity, because if adverse weather conditions occur, it gets payment from the other party to the contract; otherwise, its profit is slightly reduced to the advantage of the partner. To date, such financial engineering has been applied in premium business, but the simplicity of the "swap" contracts principles could make it usable – after the principles have been made more specific – in agriculture.

SUMMING-UP

According to Jajuga (2007), skills and experience are among the most important qualities of an investor who wants to minimise the risk of activities on the financial market. To date, only economists possess such knowledge, especially about typical derivatives, such as swap, option or forward contracts.

As we assume that transactions secured with derivative instruments should be treated seriously and have a single goal of risk transfer, a question arises as to whether a knowledge of agrometeorology is useful or useless in making decisions about the financial market where a farmer operates. The answer is obvious: the greater the farmer's knowledge of the weather-crop yield relationship, the better. Owing to such knowledge, it is possible to implement an appropriate investment strategy. Therefore, if it is assumed that the purpose of the transactions is different than just pure profiteering, we must assume that the other party should have the same level of knowledge. Therefore, there is no reason to provide farmers with additional instruments which arise from progress in agrometeorology to reduce the risk by operating in a securities market. Having gained any advantage, the secured party would not benefit from it because the derivative market would soon cease to exist. It is the same with the capital market, which would not gain much if there were great disparity in knowledge and skills to its advantage. However, it must be pointed out that financial activities of this kind are based on estimating the risk of adverse weather conditions, therefore, the ability to estimate such risk based on in-depth agrometeorological knowledge is important mainly to capital institutions. It stems from the simple fact that they are profit-oriented and they will not take any actions which prevent them from achieving it. Therefore, it may be claimed that financial institutions are interested in progress in agrometeorology, especially in precise definitions of adverse phenomena in agriculture (Woodard and Garcia 2008). It is very important to capital security companies to establish relationships between a specific weather system and reaction of plants which may have the form of increase or decrease in quantity or quality of the crop. Mathematical models of the weather-yield relationship may be very helpful in situation evaluation before taking any action. Equipped with specific tools and possessing the proper knowledge of the object being secured, financial institutions may be willing to enter the market of weather-related securing of agricultural production. Hence, one obvious conclusion is that – on the whole – agriculture can only lose. However, if actions are taken by a farmer who is aware of his risk, who has the knowledge of agrometeorology and one who can use it to precisely control technological processes, this might create a chance to gain financial benefit which, in extreme cases, may mean reduction of an otherwise inevitable loss.

Apart from the proper selection of indexes and the knowledge about their effect on production, other important factors include access to information about weather and reliability of current data, especially weather forecasts. In such cases, an important role can be played by infrastructure and methods of meteorological protection of agriculture provided, however, that they will act as independent services rather than being dependent on producers. The existing network of weather stations is not too suitable for the purpose, because a number of weather indexes should be regarded as showing high spatial variability, which is impossible to picture based on the data from the stations. Leaving out the problem of representativeness and accuracy of meteorological data pushes the issue of financial security towards the undesired development of gambling and profiteering.

Agriculture in the EU (including Poland) is an industry of low efficiency, but the degree of its regulation is high because of its social importance. If the practice of financial reduction of weather-related risk is established in our economic area, the charge on national budgets would considerably decrease.

Research conducted with the participation of agrometeorologists which should be carried out for the market of weather-related securities in agriculture should include:

- devising new or adapt old models (mathematical functions) of the weather-yield relationship, especially during periods of special weather-sensitivity of groups of plants and species,
- performing simulations and establishing the principles of derivative valuations based on universal models,
- establishing the usability of well-known, simple and comprehensive weather-related indexes for the price indexing of production risk security derivatives,
- exploring the operation of weather-related risk security instruments, depending on the scale of area aggregation (individual farm, commune, province, country) of weather-related indexes,
- ascertaining the representativeness and uniformity of data acquired at available measuring sites for use in insurance activities in agriculture.

Owing to comprehensive studies, not only in economics, but also in the principles of processes which affect weather-related risk, it will be possible to promote this form of management more effectively to improve production efficiency on farms, especially medium-sized and large ones.

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9. THE OCCURRENCE OF GROUND FROST IN THE MAZURSKIE LAKELAND BETWEEN THE YEARS 1966 AND 2005

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INTRODUCTION

Planned and intensive farming, as well as a growing market demand for agricultural produce of high value, requires precise knowledge of habitat conditions for crop production. The central location of Poland in Europe is the reason for various air masses to frequently flow over our country, bringing about the variability of vegetation conditions. Cool masses of air during the vegetation period result in the occurrence of frosts, which belong to unfavourable weather conditions, causing significant damage to field crops (Madany 1971, Hutorowicz *et al.* 1990). The later they occur in the spring and the earlier in autumn, the threat to crop plants, particularly to thermophilic ones, is higher. The same applies to higher and more frequent air temperature drops.

The various regions of Poland, depending on local climatic conditions, type of soil and lay of the land, are characterized by uneven occurrence of spring and autumn frosts, and consequently, the length of the frost-free period.

Plantations are most exposed to the risk of frost in the areas where the vegetation period begins at the earliest, as well as in the areas of high physiographic land diversification.

In the Mazurskie Lakeland, as compared to other regions of Poland, spring frosts occur at the latest, and the autumn frosts at the earliest (Koźmiński 1974, Koźmiński *et al*. 1987). On average, frosts recorded on the standard level (2 m above the ground level) occur until the mid-May and at the latest, by the end of May. Nevertheless, ground frosts can occur until the mid-June (Koźmiński 1974). During the vegetation period, 60% of days with frost occur, on average, in spring, while the others occur in autumn. The first autumn frosts in the Mazurskie Lakeland are recorded about 20 September, and ground frosts were observed even earlier (Koźmiński *et al.* 1987).

The aim of this study is to analyse the dates of frost (at 5 cm abore a ground level occurrence and to determine the number of days with ground frost in the Mrągowo Lakeland in 1966-2005.

MATERIALS AND METHODS

The present study uses the results of meteorological observations carried out in Kętrzyn (54°05'S, 21°22'N, 108 m above sea level.) and in Mikołajki (53°47'S, 21°35'N, 127 m above sea level). Those towns are situated in the Mazurskie Lakeland, and located 34 km apart. The period of research covers the years of 1966-2005. The research has been carried out with the application of the input data originating from the Department of Meteorology and Climatology of the UWM in Olsztyn.

On the basis of the above meteorological data, the following values were analysed:

- average dates of the beginning and the end of thermal vegetation periods, assuming the threshold value of the mean 24h air temperature of 5.0°C (Koźmiński and Michalska 2001),
- average dates of the occurrence of the last spring and the first autumn ground frosts (5 cm above ground level),
- the length of the frost-free period,
- the number of days with ground frost,
- number of frosts, according to the rate of temperature drop: mild (0 to –2.0°C), moderate (–2.1 to –4.0°C), strong (< –5.0°C),
- the number of days with frosts in spring and autumn months.

RESULTS AND DISCUSSION

An analysis of the meteorological data presented in Figures 1 and 2 shows that the beginning of the vegetation period in Kętrzyn began, on average, on 3 April and ended on 31 October, and in Mikołajki – on 2 April and 30 October, respectively. The length of the period under discussion during the forty years under analysis amounted in Kętrzyn, to 212 days, on average, and in Mikołajki – to 210 days. Although those towns are situated near each other, differences in the dates of the beginning and the end were still observed, as well as differences in the length of the vegetation period. This is caused by the physiographic diversity of the entire Mazurskie Lakeland. The meteorological station in Kętrzyn is situated in the vicinity of the town, to its south site, at an altitude of 108 m above sea level, far from large water bodies, while in Mikołajki, it is situated at an altitude of 127 m above sea level (to the south-east of the town) among the complex of great Mazurian Lakes, such as Mikołajskie, Tałty, Śniardwy, Bełdany, Łuknajno and Inulec. The influence of these large water bodies is probably the reason for the diversity of climatic conditions in the adjoining areas.

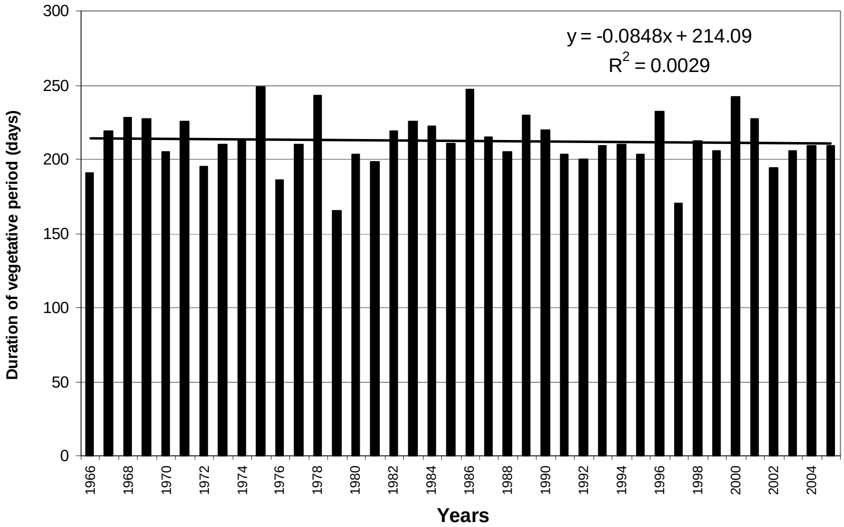

Fig. 1. Duration of vegetative period in Kętrzyn in years 1966-2005

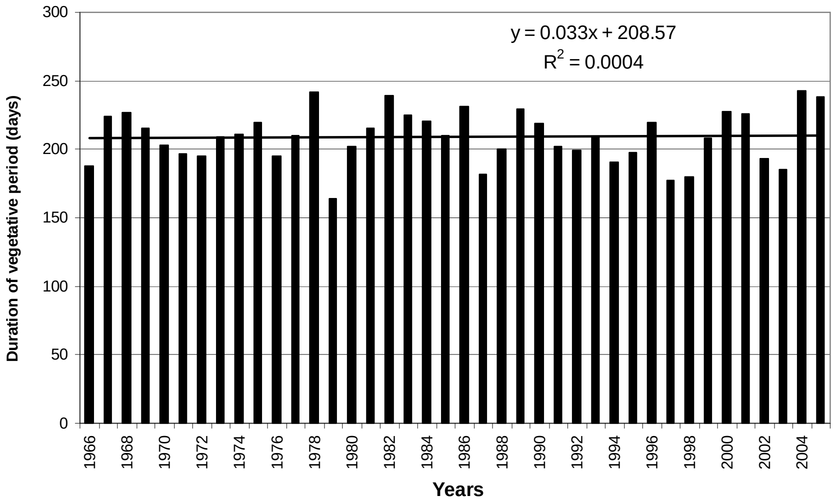

Fig. 2. Duration of vegetative period in Mikołajki in years 1966-2005

Figure 1 also shows that the earliest beginning of the vegetation period occurred on 6 March 1975. Additionally, in the same year, this period was the longest in the forty years under analysis – 249 days. The latest beginning of the period under discussion was recorded on 21 April 1979. That year was also characterized by the shortest vegetation period in the multi-year period under analysis – 165 days.

In Mikołajki, the earliest beginning of the vegetation period occurred on 16 III 2004 (Fig. 2); it was also the longest period in the forty years under analysis – 243 days. The latest date for this period to begin was on 28 April 1987 and 21 April 1979. The vegetation period ended at the earliest in Mikołajki on 1 October 1998 and on 2 October 1979. In these years, vegetation periods were also the shortest in the multi-year period under analysis and amounted to 182 and 164 days, respectively.

Differences between the longest and the shortest vegetation periods were brought about by circulation and physiographic factors (Hutorowicz *et al*. 1990, Kapuściński and Zabielski 2008).

The last spring ground frost in Kętrzyn, during the period of the forty years under analysis, occurred on average on 17 May (Fig. 3), and the first autumn frost occurred on 30 September (Fig. 4). Spring frosts disappeared at the earliest on 16 April and at the latest – on 22 April 1983. The variability range concerning the dates of the last spring frost was 68 days. The earliest autumn frosts occurred already on 3 September 2003, and the latest – on 22 October 1993.

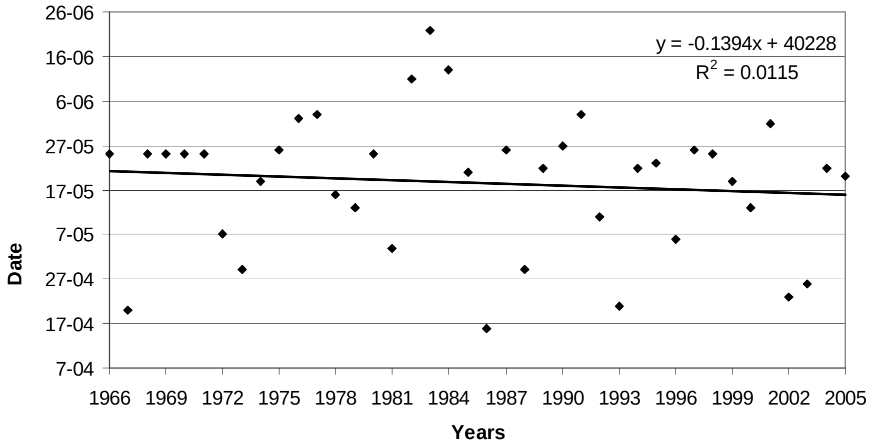

Fig. 3. Dates of the most recent spring ground frost in Kętrzyn in years 1966-2005

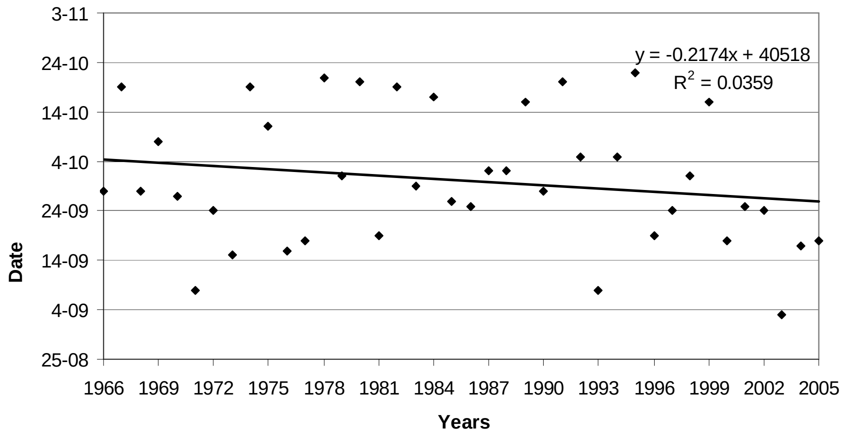

Fig. 4. Dates of the most recent autumn ground frost in Kętrzyn in years 1966-2005

The average length of the frost-free period (Fig. 5) in Kętrzyn was 135 days and ranged from 98 days in 1983 to 181 in 1986.

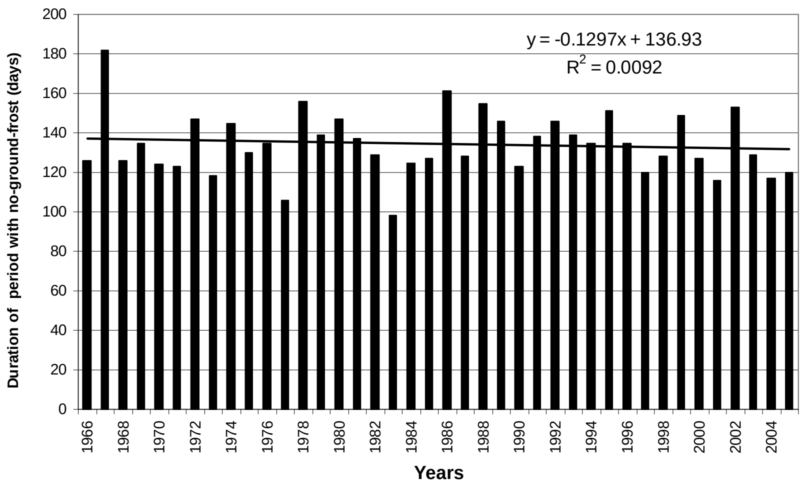

Fig. 5. Duration of period with no ground frost in Kętrzyn in years 1966-2005

15 May was determined to be the average date of the last ground spring frost in Mikołajki (Fig. 6), and 9 October – for the first autumn frost (Fig. 7). Figure 6 also shows that the earliest spring ground frosts were recorded on 17 April 1983,

and the latest – on 3 June 1991. The variability range for the occurrence of the earliest and the latest spring frosts amounted to 51 days.

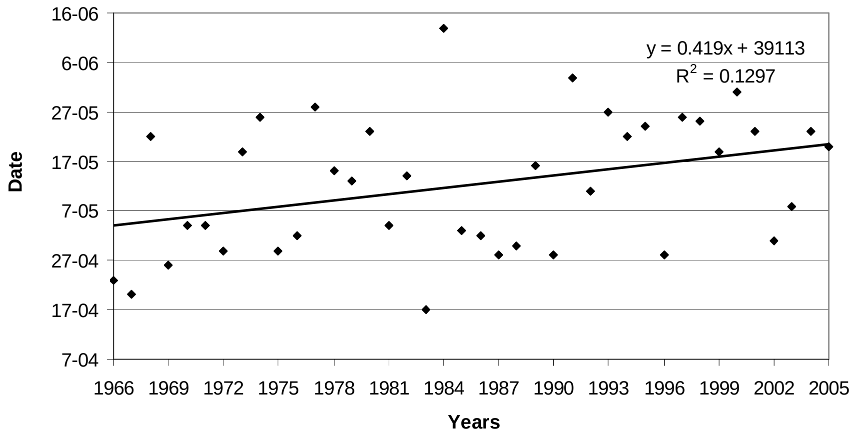

Fig. 6. Dates of the most recent spring ground frost in Mikołajki in years 1966-2005

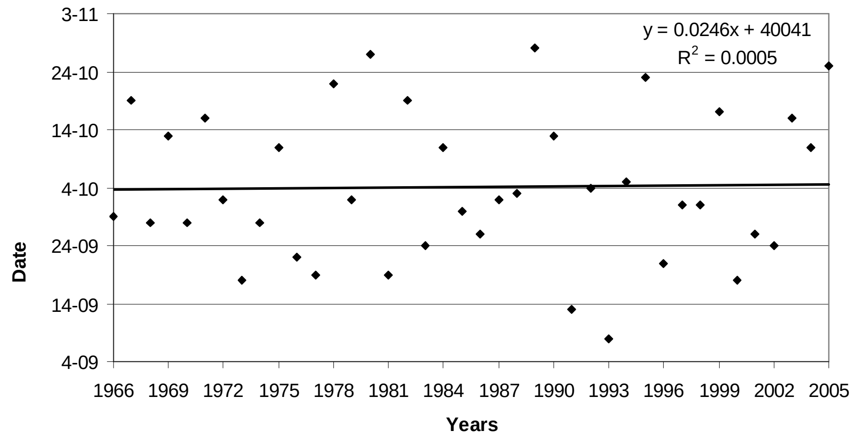

Fig. 7. Dates of the most recent autumn ground frost in Mikołajki in years 1966-2005

The earliest autumn frosts in the locality under analysis occurred on 8 September 1993, and the latest – on 28 October 1989. The variability range for these dates was 50 days – which is eighteen days shorter than in Kętrzyn. Trends calculated for the last spring and the first autumn frosts proved to be insignificant. A significant trend concerns only the last spring frosts in Mikołajki ($r = 0.360$, $p = 0.05$).

The average length of the frost-free period in Mikołajki in the forty years under examination was 144 days (Fig. 8) and it was nine days shorter than in Kętrzyn. The shortest frost-free period was in 1991 – 102 days, and the longest was 165 days in 1975 and 1989.

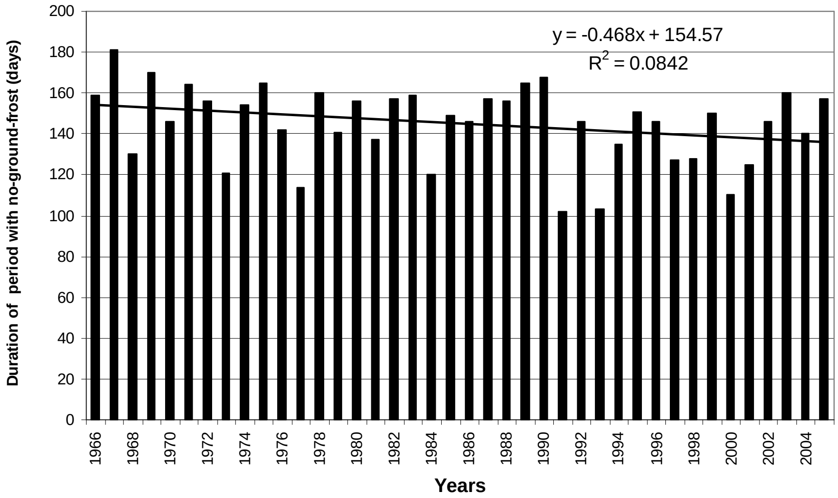

Fig. 8. Duration of period with no ground frost in Mikołajki in years 1966-2005

Average and extreme dates of the occurrence of spring and autumn frosts in the localities under examinations, despite their close vicinity, significantly differ. Spring frosts in the area of Warmia and Mazury last longer than in other regions of Poland (Koźmiński *et al*. 1987). In comparison to the corresponding multi-year period (1966-2005), in central Mazovia – in the vicinity of Warsaw – the last spring ground frosts occurred at the end of April and the first autumn ones – in mid-October. Additionally, in the period under analysis, the tendency of lengthening the frost-free period can be observed for both north-eastern Poland and its central part (Kolasiński 2008).

The highest number of days with spring and autumn frosts in the 40-year period under examination was recorded in Kętrzyn in 1971 and 1975: 37 and 39 days, respectively, and the lowest in 1966 and 1977 – eight and seven days (Fig. 9). The average number of days with ground frost was 31.5 (Tab. 1).

Table 1. Number of days with spring and autumn ground frost in Kętrzyn and Mikołajki during the evaluated forty years

Locality	Kętrzyn		Mikołajki	
Spring ground frost				
Month	Number of days with ground-frost	Percentage	Number of days with ground-frost	Percentage
March	60	6.8	30	5.8
April	625	71.3	368	72.0
May	178	20.3	111	21.7
June	13	1.4	2	0.4
Total	876		511	100
Average in spring	21.9		12.8	
Autumn ground frost				
September	67	17.4	33	14.8
October	238	61.8	124	55.6
November	80	20.8	66	29.6
Total	385		223	100
Average in autumn	9,6		5.6	
Total of spring and autumn	1261		734	100
Average of spring and autumn	31,5		18.3	

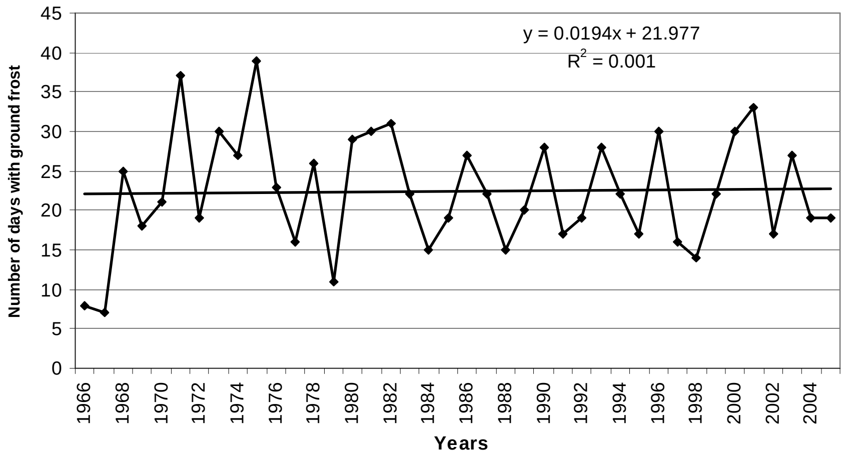

Fig. 9. Number of days with ground frost (5 cm above ground level) in Kętrzyn in years 1966-2005

In Mikołajki, the greatest number of days with ground frost (Fig. 10) occurred in 1982 and 1981: 34 and 32 days, respectively, and the lowest in 1966, 1967, 1969, 1979, 1987, 1997 and 1998: 4, 7, 9, 8, 3, 9 and 8 days, respectively. The average number of days with frosts in the locality under examination was 18 (Tab. 1). In Mikołajki, in the multi-year period under analysis, there were seven years with frosts lasting from three to nine days during the vegetation period, while in Kętrzyn there were two such years.

In Kętrzyn, in the 40-year period under analysis, there were eight years recorded with at least 30-day frosts in the vegetation period, while in Mikołajki there were only four such years.

Trends for the number of days with ground frost in Kętrzyn were insignificant, while in Mikołajki they were significant ($r = 0.313$, $p = 0.05$), from the perspective of verifying statistical hypotheses.

Figure 11 presents changes in the number of spring and autumn frosts in the ranges of the temperature drop: 0-2.0°C, –2.1-4.0°C, <–4.0°C. In the multi-year period under analysis, 1966-2005, both in Kętrzyn and Mikołajki, light frosts (0 to –2.0°C) occurred most frequently: 660 and 433 days, respectively, while strong frosts (<–4.0°C) were the least frequent: 238 and 123 days, respectively.

Table 1 presents the number of days with frosts ground in individual months of the vegetation period. As results from the presented data concerning the period under analysis, spring frosts in Kętrzyn and Mikołajki most frequently occurred in April, amounting to 652 and 368 days, respectively, which accounted for 71 and

72% of spring frosts. On average, the number of days in this month was 15 in Kętrzyn, and 9 in Mikołajki. Autumn frosts most frequently occurred in October: in Kętrzyn – 238 days in total, and in Mikołajki – 124 days. This accounted for 62 and 56% autumn frosts, respectively. On average, the number of October ground frosts per year in Kętrzyn was six, and in Mikołajki it was three.

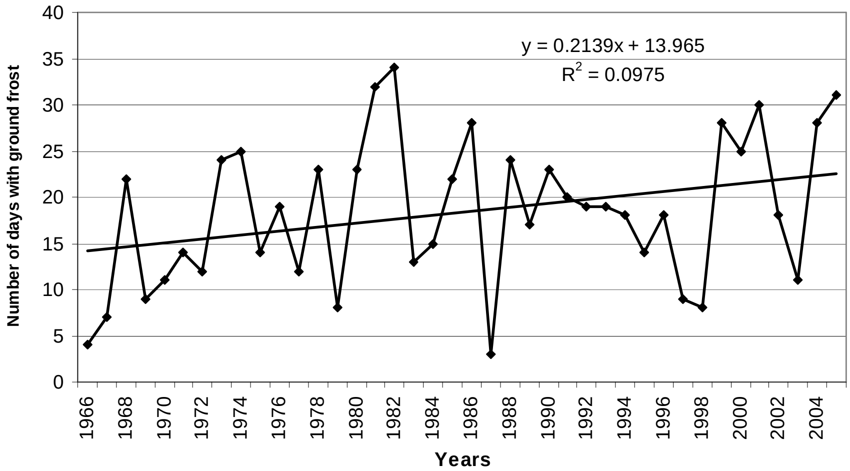

Fig. 10. Number of days with ground frost (5 cm above ground level) in Mikołajki in years 1966-2005

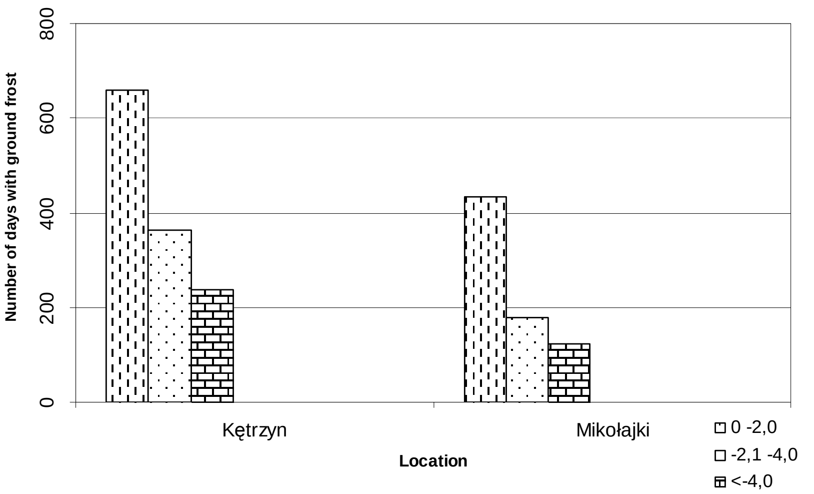

Fig. 11. Numbers of days with ground frost in three temperature spans in Kętrzyn and Mikołajki

In the 1966-2005 vegetation periods under analysis, in the Mazurskie Lakeland, both in Kętrzyn and in Mikołajki, spring frosts accounted for 70%, and autumn ones – for 30% of all frosts. Significant differences occurred in the localities under examination as regards the dates of occurrence, the number of days with frosts and the length of the frost-free period. In Mikołajki, the number of days with frosts was by thirteen days lower, on average, than in Kętrzyn and it amounted to 31.5 and 18.3 days, respectively. These values were higher in the case of Kętrzyn and lower in Mikołajki, in comparison to the 30-year period of 1951-1980 and the 10-year period of 1963-1972 (Koźmiński 1974,; Koźmiński *et al.* 1987). The reason for these changes could be the greenhouse effect, and therefore, climate warming. Consequently, the process of winter shortening is observed, along with the lengthening of early winter and early spring. On the other hand, the length of summer and autumn did not reveal any important trends of changes. Additionally, the existing climate changes are of a linear nature, and apart from that, a significant variability of climatic elements, caused by fluctuations, can be observed (Kossowska-Cezak 2003). The distribution of differences as regards frost occurrence parameters could result from the geographical location of the towns under analysis. Mikołajki is situated more southwards than Kętrzyn, and a prevailing circulation of south-east air masses is observed there (Kapuściński 2008), while in Kętrzyn – circulation from the north-west is recorded. It should be mentioned that Mikołajki is situated among large water bodies, which show a mitigating effect on the development of meteorological elements on the adjacent areas (Grant 2004).

CONCLUSIONS

1. The length of the vegetation period in the forty years under analysis amounted in Kętrzyn, on average, to 212 days, and in Mikołajki – to 210 days.
2. The range of variation for the dates of spring frost occurred at 5 cm abore ground level occurrence in Kętrzyn was 68 days, and in Mikołajki – 51 days.
3. In the examined period of 1966-2005, the length of the frost-free period in Mikołajki was longer than in Kętrzyn by nine days, on average.
4. In the localities under examination, mild frosts – 0-2.0^{o}C occurred most often, while strong frost, of more than –4.0^{o}C, were the least frequent.
5. Spring frosts accounted for about 70% of all frosts. They occurred slightly more often in Kętrzyn than in Mikołajki.

6. Autumn frosts were reported mainly in October and amounted to 62% in Kętrzyn and to 56% in Mikołajki.

7. The average number of days with ground frost in Mikołajki was by thirteen days shorter than in Kętrzyn and amounted to 31.5 and 18.3 days, respectively.

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10. WEATHER CONDITIONS VS. AGROPHENOLOGY AND YIELDING OF LUPINUS ANGUSTIFOLIUS IN NORTH-EASTERN POLAND*

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INTRODUCTION

The importance of leguminous plants, i.e. pea, lupine and faba bean, began to decline in the 1970s due to the intensification and chemization of agriculture and the greater availability of cheap, solvent-extracted soy cake. However, in recent years, an increase in the areas of their cultivation has been observed, resulting from the possibility of obtaining additional subsidies for agricultural and environmental programmes, as well as from trends in agrotechnology toward promoting ecological and sustainable agriculture (Księżak 2000, 2001), since the negative results of the lack of proper crop rotation are becoming increasingly perceptible, particularly on light soils, while the cultivation of leguminous plants has a favourable effect on the physical, chemical and phytosanitary properties of soil. Consequently, the interest in their cultivation, including lupine, is increasing in Poland and in other countries of the European Union (Podleśny 2004). Research into the nutritive use of lupine is being conducted on most continents and in some countries (e.g. Chile, Peru) and is already added to basic alimentary products in order to increase the amount of protein consumed in governmental programmes. Among the three species of lupine cultivated in Poland, narrow-leaf cultivars are characterized by the shortest period of vegetation, higher resistance to anthracnose and increased yielding capacity (Jasińska and Kotecki 2001). Root nodule bacteria of lupine, *Rhizobium lupini*, in favourable conditions of the habitat, can fix up to 200 kg N/ha, of which about 80-90 kg of nitrogen remains in the soil for successive crops. Due to its deep root system, lupine is able to uptake the nutrients washed inside, which are unavailable for many cultivated plants. It can leave up to 40 kg of phosphorus and 45 kg of potassium per hectare in post-harvest remains.

The literature to date on the subject of lupines has mainly focused on agrotechnology, while papers dealing with the determination of the plant dependency

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on weather conditions are scarce (Andrejko and Grochowicz 2003, Podleśny and Podleśna 2008, Strobel and Pszczółkowski 2007, Szwejkowski *et al*. 2001, 2002). Therefore, an examination of the relationship between the yielding of blue lupine (Emir cultivar) and selected meteorological factors in north-eastern Poland has been selected as the aim of this study.

MATERIALS AND METHODS

Source materials concerning yielding and conditions for the cultivation of *Lupinus angustifolius* of the EMIR cultivar come from 1987-2002 and originate from the COBORU experimental stations for variety assessment located in Głodowo and Marianowo, while for Wrócikowo the available data concerned 1994-2002. Experiments were conducted in soils of very good, good and weak rye complex (class IIIb, IVa and IVb), and spring crops – wheat or barley – were most frequently used as the forecrop. The data provided by COBORU also included the dates of sowing and the appearance of basic phenological phases, as well as the data concerning weather conditions in the form of 24h values of mean temperature and precipitation. Due to the lack of records for the total radiation, its 24h values were estimated following the equation provided by Hunta *et al*. (1998), based on maximum and minimum temperatures, sums of precipitation and radiation in upper layers of atmosphere, from 1998-2000, originating from meteorological stations conducting actinometric measurements. With this aim in view, the data from Mikołajki were used in Wrócikowo and Marianowo, while the data from Toruń were applied for Głodowo.

Bearing in mind the importance of individual elements in the life of plants as well as the availability of meteorological data, the authors assumed total radiation, mean temperature and precipitation to be basic independent variables in the statistical assessment of the weather-yield relations which, in further calculations, were determined as follows:

SR1	TSR1	P1
SR2	TSR2	P2
SR3	TSR3	P3
SR4	TSR4	P4

where:

SR – sums of total radiation (MJ m^{-2}),
TSR – sums of mean air temperature (°C),
P – sums of precipitation (mm),

The figure occurring at the variable indicates the period:

1 – sowing – germination,

2 – germination – the beginning of flowering,

3 – beginning of flowering – end of flowering,

4 – end of flowering – technical maturity.

The calculations applied the multiple regression method (linear and quadratic) with step-wise selection of variables. The equations considered only those variables for which the coefficients of regression were significant at the level of at least $\alpha = 0.1$. The equations were evaluated first on the basis of determination coefficient R^2, applied in most research of this type, and afterwards, the adjusted determination coefficient R^2_{adj} was applied, and then R^2_{pred}, which was determined through the Cross Validation procedure (Kuchar 2001). It is used as a very rigorous criterion of evaluation to avoid over-parametrization of the model, i.e. unsuitable description of the phenomenon, particularly when sets of input data are not numerous. When the value of R^2_{pred} was significant and slightly departed from R^2 statistics, it was assumed that its predictive value was high and when it was close to zero a model was disqualified. The significance of entire equations was examined by testing the significance of determination coefficients by applying the F-Snedecor test; the equations were created for each period of cultivar growth; therefore, the amount of yield can be determined with certain probability during the vegetation, by using basic meteorological factors (Kuchar 1993, Faber 1996).

RESULTS AND DISCUSSION

As follows from the comparison of data concerning yielding (Tab. 1, Fig. 1) the highest yields of *Lupinus angustifolius* of the Emir cultivar were obtained under the conditions of Wrócikowo, where it amounted, on average, to 3.2 t ha^{-1} for the multi-year period. In Marianowo, the cultivar yielded an average level of 2.7, and in Głodowo – 2.6 t ha^{-1}. The yield was much diversified in individual years and it ranged from 1.0 to 4.9 t ha^{-1}. The results from Głodowo in 1989 were eliminated from the research period. This was because the yield obtained was very low (0.4 t ha^{-1}) as a result of the simultaneous occurrence of many external factors that are unfavourable for lupine cultivation (low pH of the soil (4.3), April and May ground frosts, high deficiency of humidity in these months and consequently, the occurrence of fusarium diseases). It was considered if the entire experiment should be disqualified.

Table 1. Basic statistic parameters of Lupine Emir variety

Station	Average ($t\ ha^{-1}$)	Min ($t\ ha^{-1}$)	Max ($t\ ha^{-1}$)	SD ($t\ ha^{-1}$)	CV (%)
Głodowo (ϕ 52° 50′, λ 19° 14′)	2.57	1.32	4.31	0.89	34.47
Wrócikowo (ϕ 53° 50′, λ 20° 41′)	3.23	1.75	4.90	1.11	34.36
Marianowo (ϕ 53° 13′, λ 22° 06′)	2.70	1.02	4.36	0.96	35.55

Explanations:
SD – standard deviation   Max – maximal
CV – coefficient of variation   Min – minimal

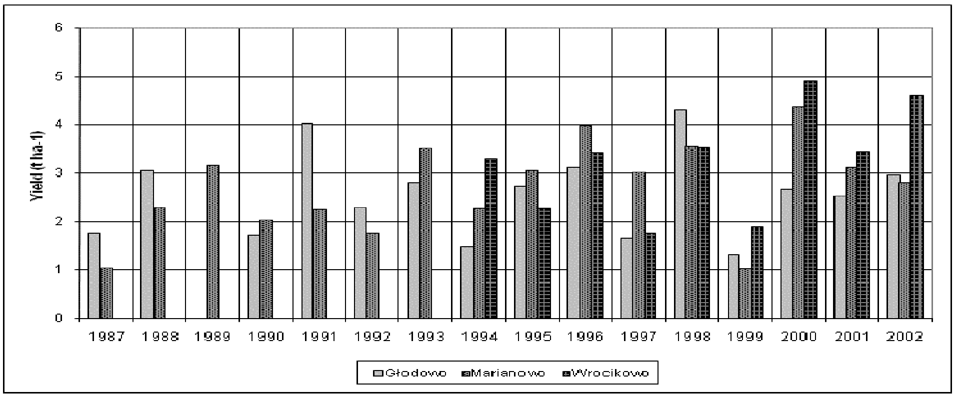

Fig. 1. Yielding of *Lupinus angustifolius Emir* variety in the years 1987-2002

The cultivar showed a poorer yield in 1987, 1990 and the poorest in 1999, probably as a result of heavy rainfall in the period of germination – the beginning of flowering, which was the reason for the extended interphases. On the other hand, the highest yields, exceeding 4.0 $t\ ha^{-1}$, were characteristic for 1991 and 1998 in Głodowo, 1996 and 2000 in Marianowo and 2000 and 2002 in Wrócikowo (Fig. 1).

The mean and extreme dates of sowing and phenological phases of the Emir cultivar in individual stations are presented in Table 2, descriptive statistics of the lengths of interphase periods in Table 3, and meteorological factors for growing periods are presented in Table 4.

Table 2. Terms of sowing and phenological phases of Lupinus angustifolius *Emir variety*

Term		Sowing	Germination	Beginning of flowering	End of flowering	Complete maturity
Average	G	7.04	26.04	6.06	2.07	6.08
	W	9.04	27.04	8.06	11.07	11.08
	M	16.04	30.04	10.06	3.07	7.08
The erliest	G	27.03	16.04	23.05	19.06	17.07
	W	29.03	15.04	26.05	22.06	23.07
	M	2.04	18.04	28.05	17.06	24.07
The latest	G	20.04	4.05	22.06	21.07	25.08
	W	25.04	9.05	22.06	5.08	25.08
	M	4.05	17.05	28.06	23.07	7.09

G – Głodowo, W – Wrócikowo, M – Marianowo.

Table 3. Description statistic of interphases duration of Lupine-EMIR /days/

Period	Mean duration			Max			Min		
	G	W	M	G	W	M	G	W	M
1	19	18	14	29	29	21	10	9	10
2	41	42	41	52	53	52	36	34	35
3	26	33	23	45	51	36	20	19	17
4	36	32	36	37	44	32	18	20	12

Period: 1 – sowing-germination,
2 – germination-beginning of flowering,
3 – beginning of flowering-end of flowering,
4 – end of flowering-technical maturity.

Table 4. Basic statistic parameters of meteorological factors in growth period Lupinus

Variable	Average	Min	Max	SD	CV
		Głodowo			
SR1	260	167	341	59	23
SR2	779	632	879	69	9
SR3	454	230	663	106	23
SR4	591	400	846	116	20
TSR1	148	96	207	28	19
TSR2	552	479	597	34	6
TSR3	418	218	612	107	26
TSR4	603	426	888	129	21
P1	20	0	57	17	85
P2	62	10	157	39	63
P3	69	18	154	39	57
P4	88	30	143	29	33
		Wrocikowo			
SR1	237	158	341	63	27
SR2	833	673	991	94	11
SR3	610	427	853	128	21
SR4	589	365	748	144	24
TSR1	135	100	161	19	14
TSR2	561	505	627	37	7
TSR3	529	319	754	126	24
TSR4	567	388	691	121	21
P1	26	1	51	18	69
P2	80	37	174	41	51
P3	83	23	118	41	49
P4	57	0	122	43	75
		Marianowo			
SR1	232	150	332	52	22
SR2	819	700	982	92	11
SR3	418	288	721	109	26

SR4	642	452	816	117	18
TSR1	136	80	171	24	18
TSR2	574	483	668	39	7
TSR3	373	271	700	108	29
TSR4	641	501	796	87	14
P1	14	1	52	16	114
P2	68	8	125	34	50
P3	54	14	119	30	56
P4	77	8	144	40	52

Explanations CD, CV, Max, Min, period 1-4 as in Tables 1 and 3

Variable:

SR – sums of global radiation (MJ m^{-2}),

TSR – sums of average temperature of air (°C),

P – sums of precipitation (mm).

Lupine seeds in Głodowo and in Wrócikowo were sown earlier (usually on 7 April and 9 April, respectively) than in Marianowo (16.04), and the number of days between sowing and germination ranged from 14 in Marianowo to 18 in Wrócikowo and 19 days in Głodowo. According to Sadowski *et al*. (1996), the length of this period is shortened along with the growth in temperature, and the plants should be subject to a short period of coolness, i.e. vernalization, which influences the further course of development periods. Podleśny and Strobel (2006) report that the beginning of April is the best date for sowing, in order to obtain a high yield of blue lupine. Calculated mean sums of total radiation amounted at that time between 232 and 260 MJ m^{-2}, the sums of mean temperatures – 135-148°C, and precipitation – 14-26 mm.

Germination was observed in the last pentada of April (26-30.04), and the beginning of flowering in the second pentada of June (6-10.06). The length of the germination-beginning of flowering period in stations was very even, amounting to 41-42 days. In that time, the cultivar needed, depending on the station, total radiation ranging from about 780 to 830 MJ m^{-2}, total mean temperature of 550-570°C and 60-80 mm of precipitation. The end of the flowering period fell usually on the first decade of July; flowering lasted, on average, between 23 days in Marianowo and 33 days in Wrócikowo, and the examined meteorological factors amounted to 418-610 MJ m^{-2}, 370-530°C and 54-83 mm, respectively. The Emir cultivar obtained its technical maturity at the turn of the first decade of August, and the length of the last development period (the end of flowering-technical maturity) lasted from 32 to 36 days. During that period, sums of radiation reached values from about 590 to 640 MJ m^{-2}, average temperature – 570-640^oC and total precipitation ranged from 57 to 88 mm. In individual agrophases, their extreme values greatly departed from the mean, while minimum values were often equal to zero.

The sowing-technical maturity period lasted, on average, 114 days in Marianowo, 112 days in Głodowo and 125 in Wrócikowo, and sums of the examined factors amounted, in individual stations (in the same order) to: SR – from 2084, 2112 to 2268 MJ m^{-2}, TSR 1721-1792^oC and P – 213, 239, 243 mm, respectively.

An analysis of the relations between meteorological factors (SR, TSR, P) and yielding (presented by means of correlation factors of selected variables (Tab. 5) and regression equations (Tab. 6) shows that the impact of meteorological factors on yielding of lupine of the Emir cultivar was varied depending on the location of the station. In Marianowo, the values of determination coefficient R^2 significantly grew along with the progress of vegetation: from 0.40 (in the 1st agrophase of growth) to 0.74 in the period of plant maturity. R^2_{adj} amounted to 0.36-0.68, respectively. All equations passed a CV test and the scope of fluctuations of R^2_{pred} indicators ranged from 0.29 to 0.59. Yielding did not significantly depend on the sums of precipitation and total radiation calculated for the sowing-germination period, while values below the averages for those factors favoured high yielding. It should also be explained that these were quadratic relationships with small regression factors; therefore, their quite moderate impact on yield should be assumed. In Wrócikowo (as in Głodowo), no regression equations at all were created for the sowing-germination period; probably thermal-solar conditions and humidity reserves after winter were satisfactory in these areas.

In significant models, created for the consecutive development periods of this cultivar, the yielding was significantly and negatively affected by the sums of precipitation calculated for the germination-beginning of flowering period (linear and quadratic relations) and in an equation created for the third agrophase – also by precipitations of the flowering period. According to Ceglarek (2000), the best conditions for plant growth include sufficiently high humidity together with a moderate temperature – which corresponds to the results obtained. High determination coefficients, R^2 and R^2_{adj}, exceeding even 90% of total variability, were obtained in the research, but none of the equations passed a CV test, which showed the lack of significance of the models due to their over-parametrization (small sample size).

Table 5. Coefficient of correlation (R^2, R^2_{adj}, R^2_{pred}) for selected of variables in equations regression

Period	Variables (in regression equation)			N	R^2	R^2_{adj}	R^2_{pred}	S_{yx}
				Głodowo				
1	–							
1-2	KSR2				0.29**	0.24*	0.10	0.8
	KSR2	P1		15	0.41**	0.32*	0.08	0.7
1-3	KSR2	P1	KTSR3		0.60***	0.49**	0.23	0.6
1-4	lack of better							
				Wrócikowo				
1	–							
1-2	P2				0.65***	0.60**	0	0.7
	P2	KP2		9	0.84***	0.78**	0	0.5
	P2	KP2	KSR2		0.94***	0.90***	0.46	0.4
1-3	P2	KP2	P3		0.94***	0.91***	0	0.3
1-4	lack of better							
				Marianowo				
1	KP1				0.40***	0.36**	0.29**	0.8
	KP1	KSR1			0.67****	0.62***	0.56***	0.6
	KP1	KSR1	P1	16	0.71***	0.63***	0.43*	0.6
1-2	KP1	KSR1	SR2		0.73****	0.66***	0.59**	0.6
1-3	lack of better							
1-4	KP1	KSR1	P4		0.74****	0.68***	0.54**	0.5

*.**.*** denote significance levels μ = 0.1. 0.05. 0.01.
N – number of observations.
S_{yx} – standard error of estimation.
K – square function.
Explanations SR. TSR. P. period 1-4 as in Tables 3 and 4.

Table 6. Selected regression equations taking into account the results of CV test

Period	Regression equations
	Głodowo
1	–
1-2	y = 5.33***– 0.0001**KSR2
	y = 5.43***– 0.0001**KSR2 + 0.02 P1
1-3	y = 6.53***– 0.0001***KSR2 + 0.03**P1 – 0.0001**KTSR3
1-4	lack of better
	Wrócikowo
1	–
1-2	y = 4.95*** – 0.02***P2
	y = 7.34*** – 0.08**P2 + 0.0003**KP2
	y = 6.25*** – 0.09***P2 + 0.0003***KP2 + 0.0001 KSR2
1-3	y = 7.63*** – 0.07***P2 + 0.0002**KP2 – 0.01**P3
1-4	lack of better
	Marianowo
1	y = 3.05*** – 0.0008***KP1
	y = 4.25*** – 0.0009***KP1 – 0.0001***KSR1
	y = 4.08*** – 0.003** KP1 – 0.0001***KSR1 + 0.04 P1
1-2	y = 6.57*** – 0.0009***KP1 – 0.0001***KSR1 – 0.003 SR2
1-3	lack of better
1-4	y = 3.74*** – 0.0009***KP1 – 0.0001***KSR1 + 0.006 P4

Explanations as in Tables 2 and 5.

Similarly in Głodowo, despite obtaining relatively high values of R^2, reaching 0.60 and 0.49 R^2_{adj}, no model was selected for the cultivar in the CV test. Its yielding was significantly negatively affected by sums of radiation from germination to the beginning of flowering, while in an equation created for the third agrophase, sums of mean temperature of the flowering period were also included (in this case, because the relation was quadratic, moderate values were desirable), along with sums of precipitation calculated for the sowing-germination period. According to Poulain *et al*. (1990), during the vegetative growth of plants, mean values of solar radiation were negatively correlated with yield. Similar results were obtained for some cultivars of *Pisum sativum* (e.g. Karat in Radostowo) by Grabowska (2004), but in individual stations and for the majority of cultivars (e.g. in Wrócikowo), a favourable effect of higher sums of radiation on yield was revealed. Podleśny and Strobel (2006) found the configuration of weather conditions during individual years of research had a negative effect on lupine yield in 1991-1993.

CONCLUSIONS

1. In the years of research (1987-2002), a clear differentiation of weather conditions, i.e. solar radiation, average temperatures and precipitation, was observed in individual periods of growth and development of *Lupinus angustifolius* of the Emir cultivar, which significantly affected the yield (2.6-3.2 t ha^{-1}), dates of phenological appearances and the length of interphase periods.
2. Obtained statistical models of yield, as most statistical models, have limited implementation to the point (area) and time for which were fixed. For the aim of evaluation their universality was conducted the verification on the independent material. The implementation of the cross-validation procedure, showed that good yield evaluation (R^2_{pred}>50%) could give regression equations built only for Marianowo station. Factors significantly affecting the yield of the cultivar included total radiation and precipitation in the sowing-germination period. For the experimental stations in Głodowo and Wrócikowo, the regression models created (despite the high determination factors R^2 and R^2_{adj} that are commonly applied in this type of research) did not pass a verification procedure using a CV test.

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11. QUALITY VERIFICATION OF WIELKOPOLSKA INTERNET AGROMETEOROLOGICAL INFORMATION SERVICE (WISIA) OPERATION AS WELL AS SUITABILITY AND FORECAST ACCURACY ASSESSMENT

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INTRODUCTION

Changing climatic conditions necessitate the need for adaptive changes of many branches of agricultural production in order to optimize production conditions and to minimize losses (Eitzinger *et al*. 2009, Ratajkiewicz 2009). Variability of agrometeorological conditions may determine even up to 80% variation in quantity of the obtained yield (Petr 1991). Therefore, the demand for agrometeorological forecasts, that will provide information on the weather conditions projected for the next day, the expected impact of these conditions on growth, development and yield of crops, as well as the likelihood of certain diseases and pests of plants, is increasing from year to year (Hoogenboom 2000, Rijks and Baradas 2000, Stigter *et al*. 2000, Strand 2000, Weiss *et al.* 2000). Results of the survey conducted among farmers in Wielkopolska Region in the years 2001-2002 clearly indicated the urgent need for creation of an agrometeorological decision support service in this region (Geppert 2002, Urbańska 2002). As many as 97% of farms, among 180 surveyed households, indicated the need to obtain agrometeorological information and 91% would like to know what is the probability of pests gradation and crop diseases. The need to obtain agrometeorological forecasts was so strong that vast majority (i.e. 82%) of farmers declared the possibility of unpaid placement of agrometeorological stations on their farm, and in the future, if the forecasts meet their expectations, they would be willing to bear the costs of the received agrometeorological advice.

Agrometeorological forecasts have undoubtedly become a key component of any decision support systems in agriculture, allowing one to optimize the conditions of crop production on the scale of a single farm, the entire region and even the country (Hoogenboom 2000, Sivakumar *et al.* 2000). This optimization is based primarily on adjusting the dates of plant chemical protection treatments, protection against frost and wind, irrigation, fertilization, and even sowing and harvesting, to the meteorological conditions in a given period. Such actions are connected with the need to develop the models that would predict the occurrence of specified events and threats depending on the meteorological conditions. What is more, these activities can improve the yield quality, increase its quantity and thus, in consequence, bring economic benefits (Jones *et al.* 2000, Rijks and Baradas 2000).

In Poland, the creation of agrometeorological stations network was already initiated in the 60s (Molga 1970). Due to financial shortages and deep political and economic changes, this project was never fully implemented. Another attempt to create agrometeorological information service was made in the current Zachodniopomorskie Voivodship in 1998. Agricultural Consultancy Center in Bonin near Koszalin, in cooperation with the Institute of Hydrology and Agrometeorology in Padua, using the PHARE funds created a network of four automatic weather stations, which were the primary source of agrometeorological information in the region (Bac *et al.* 1998). The agrometeorological information was prepared and made available to farmers in the region through various media. It was based on the Polish Institute of Meteorology and Water Management (IMGW) weather forecasts, measurement data coming from the above mentioned stations and field observations. This service, as well as the created network of stations, ceased to operate in 2003.

A particularly valuable source of agrometeorological information supplementing the decision support systems in Poland with issues related to the plant protection are mainly the Institute of Soil Sciences and Plant Protection (IUNG) in Puławy and the Institute of Plant Protection (IOR) in Poznań. As a result of cooperation between these institutions and IMGW the Internet Decision Support System in the Integrated Plant Protection was created in the years 2000-2002. This website presents the results of modeling prediction dates indicating the occurrences of certain cereal and potato diseases.

In the years 2004-2006, the Wielkopolska Region Internet Agrometeorological Information Service (WISIA) was created. This service was established at the Faculty of Land Reclamation and Environmental Engineering by the Meteorology Department of Poznan University of Life Sciences (PULS), in cooperation of the Meteorology Department of PULS with the Interdisciplinary Center of Mathematical Modeling (ICM) at Warsaw University. These works were the final result of the research project (financed by the Polish Ministry of Science (KBN)) carried out by the Meteorology Department under the following title: "*The use of digital weather forecasts for the construction of local agro-meteorological forecasts and* *the assessment of the quality of their applications in the agrometeorological protection of agriculture*" (Project KBN (Polish Ministry of Science) No. 013 3P06R 25). The website of the WISIA service is available from April 2005 in a free version at *www.agrometeo.pl.*

The purpose of this paper is to present the structure and functioning of Wielkopolska Region Internet Agrometeorological Information Service (WISIA) three years after completion of the project financed by Polish Ministry of Science, which resulted in creation of this service. The paper presents the results of the survey conducted on users of the website, which were the basis for the evaluation of the service quality and the accuracy of the presented forecasts.

The information used to create WISIA service

Weather forecasts

The basic element of agrometeorological information on WISIA website is the weather forecast. The source of the meteorological information used in for the preparation of agrometeorological information for the farmers in Wielkopolska Region is the Interdisciplinary Centre for Mathematical Modeling (ICM) at the Warsaw University. The digital ICM weather forecasts are available on the Internet in a graphic form on the page http://new.meteo.pl/. These are 84-hour forecasts, updated every six hours and determined for 3-hour time intervals. The ICM forecasts used presently on WISIA website are a product of the numerical COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System) model. This model was developed by the U.S. Marine Meteorology Division (MMD) of the Naval Research Laboratory (NRL). COAMPS model works on a 13-km grid.

The network of automated agro-meteorological stations

The network of automatic weather stations of the Meteorology Department of PULS was created at the turn of November and December 2004 and consists of four stations (Leśny *et al.* 2004, Juszczak *et al.* 2005). Stations in Złotniki near Żnin, Wieszczyczyn near Śrem, and Stare Miasto near Wronki are located in cultivated fields about 100-250 meters from the farm buildings. The fourth station located in Rzecin near Wronki is located in the central part of 140 hectars of wetlands surrounded by a forest. Detailed information on the equipment and operations of the stations are included in the work Juszczak *et al.* (2005).

The structure of WISIA website

The user of WISIA website obtains information about the weather conditions for a given day and the weather forecast for 2 days in advance, agrometeorological forecast and the forecast of wind chill temperature (Fig. 1, bookmark FORE-CAST-PROGNOZA). Additionally, in METEO DATA (DANE METEO) bookmark, there are available meteorological data from weather forecast model (for any specified period of time), and meteorological data measured at the stations (Złotniki, Wieszczyczyn, Stare Miasto, Rzecin). Also the list of most important website addresses of the institution and portals dedicated to the problems of agriculture and weather forecasting (bookmark LINKS-LINKOWNIA) can be quite useful.

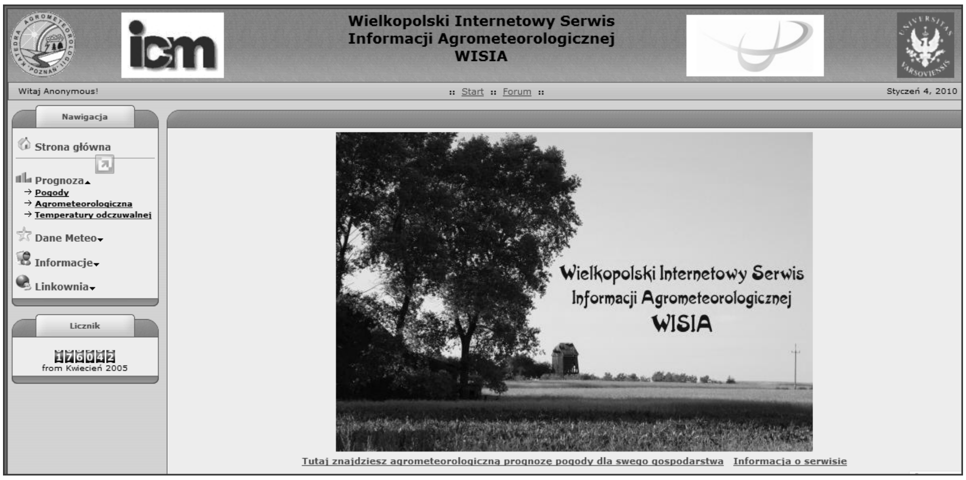

Fig. 1. The view of the main page of WISIA website (www.agrometeo.pl)

Meteorological and agrometeorological forecasts

Meteorological and agrometeorological forecasts are developed for the communities located in Wielkopolska Province, the eastern part of the Lubuskie Province, the south-eastern part of Zachodnio-Pomorskie Province and the southern parts of Kujawsko-Pomorskie Province. A website user taking interest in these forecasts must choose the county, then the municipality, for which he wants to obtain the forecast. The selection is done by clicking on the appropriate area of the displayed map (Fig. 2). Weather forecasts are available in a graphic form. A forecast includes the following meteorological elements: air temperature at the ground level and at 1.5 m height, soil temperature at 5 cm depth, the relative humidity of the air at 1.5 m and soil moisture, atmospheric pressure and wind speed, direction, cloudiness, precipitation and total radiation (Fig. 3).

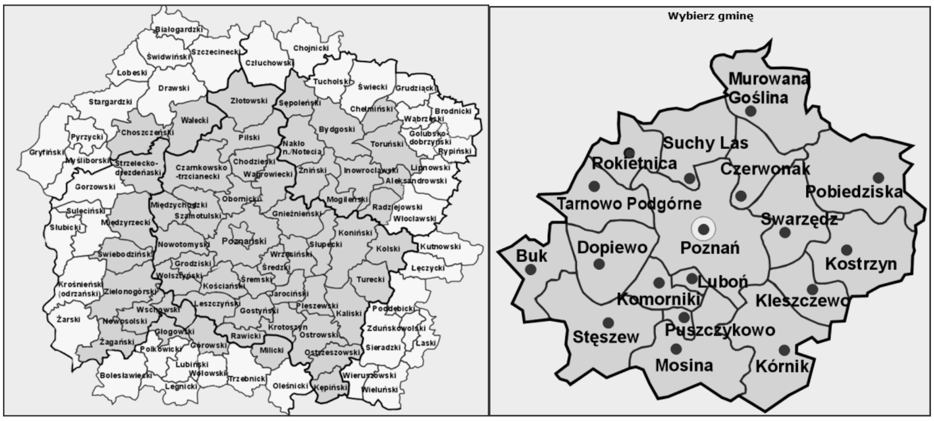

Fig. 2. The map of counties and municipalities for which one can select the weather forecast presentation

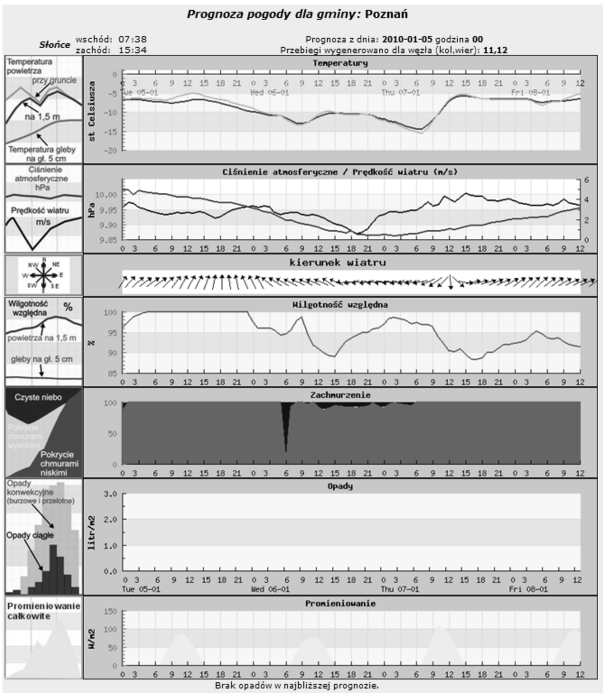

Fig. 3. The sample of weather forecast for Poznan municipality

Agrometeorological forecasts – detailed selection

Choosing the "agrometeorological forecast" bookmark and defining the municipality for which the forecast is to be prepared, one receives a display of the list with the elements of the agrometeorological forecast (Fig. 4).
A service user obtains the following information:

- sum of degree days (3 days back, for a given day and two days forward, there is available a degree-day calculator to calculate the degree days for any period of time and any threshold temperatures); calculated on the basis of the data from COAMPS weather model for any community,
- precipitation (the daily sum and cumulative monthly rainfall as well as from January and November), the data obtained from the Meteorology Department stations and calculated on the basis of data from COAMPS weather model for any community,
- potential evapotranspiration (using Penman-Monteith formula, the daily sums and accumulated for different time intervals) calculated on the basis of the data from COAMPS weather model for any community,
- actual evapotranspiration (from the Heat Balance Model (Leśny 1998), the daily sums and accumulated for different time periods and different crops: beets, canola, corn, winter and spring cereals), calculated on the basis of the data from COAMPS weather model for any community,
- signaling the occurrence of dew (3 days back, for a given day and two days forward), calculated on the basis of the data from COAMPS weather model for any community,
- total radiation and insolation (daily sums and cumulative, three days back, for a given day and two days forward); calculated on the basis of the data from COAMPS weather model for any community,
- dates of the occurrence of pests threatening crops and fruit (e.g. colorado potato beetle, apple codling moth, plum fruit moth, peach and apple aphids), modeled on the basis of the data from COAMPS weather model for any community, (details Juszczak *et al.* 2008, 2009)
- potato blight warning (IUNG Puławy),
- conditions for chemical plant protection treatments, for different chemical agents separately (systemic, contact and plunge) (prepared for a given day and two days forward; counted on the basis of the data from COAMPS weather model for any community),
- Deutsche WetterDienst agrometeorological forecast (available until June 2009).

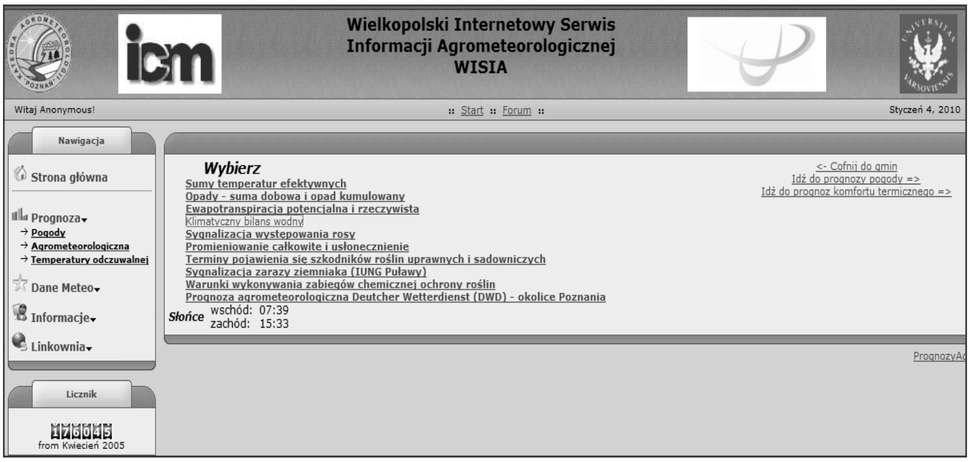

Fig. 4. Options available by selecting the agrometeorological forecast bookmark

Quality verification of WISIA service operation

The assessment of the quality of WISIA service operation was conducted on the basis of a survey group of farmers from Wielkopolska Province. Farmers were selected from those who were surveyed in the years 2001 and 2002, during the preparatory work for the project (Geppert 2002, Urbanska 2002) and declared access to the Internet. At that time 180 farms were examined, including 83 large-scale farms (50 to 2000 ha), 28 small farms (50 ha) and 69 specialized farms (from 0.5 to 1000 ha). 52% of the farmers had a computer with the internet access (most among the specialized farms – more than 60%).

The survey of farmers was launched in 2006 (Waraczewski 2007). Prior to the surveys, a telephone contact was made with over 90 farmers having access to the Internet, during which they were familiarized with WISIA service offer and potential benefits possible to obtain after taking into consideration the agrometeorological information in their daily work. In addition, after a farmer became positively interested in WISIA service, they were asked a question regarding the planned trial surveys. The question was: "*Do you agree to participate in a survey, which will serve to assess the quality of the agro-meteorological service operation*?"

Most of 90 farmers mentioned above declared their willingness to cooperate with WISIA service providers. Those farmers were provided with the survey rules and after their acceptance the prepared surveys were sent to each of them, three months ahead, including the addressed and stamped return envelopes. Unfortunately, only some of them continued the cooperation until the end of 2006. Although the quantity of collected material was different from the expectations of the project authors, it constituted the basis for the preliminary analysis of the quality of WISIA forecast service. Surveys were distributed to all farmers at the same time. It was assumed that each of the farmers would send completed questionnaire at the end of each month.

Age characteristics of the surveyed farmers

50% of the surveyed farmers were from 50 to 60 years old. The elderly accounted for only 10% of all farmers (Fig. 5). Farmers in this age group accounted for a relatively large percentage of people, assuming that they are people running the farm on their own. Intriguingly, a relatively small percentage of young people were under 25 years of age (5%) and there were no persons aged 25-35 years. Next largest group of farmers were those between 36 and 49 years old. They represented 35% of the surveyed farmers.

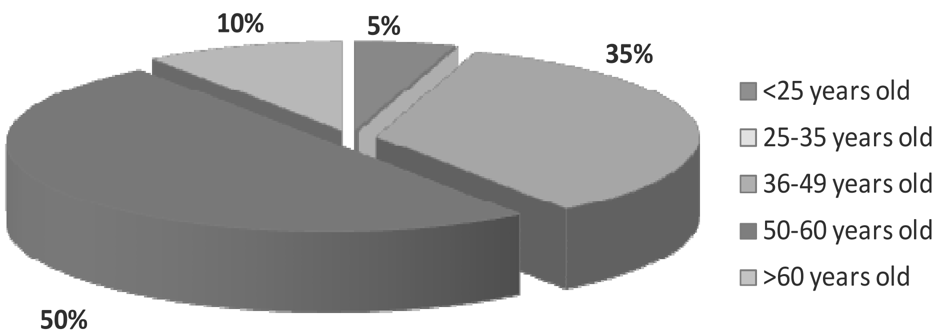

Fig. 5. Age of the surveyed farmers

Farms area

Most of the farms, up to 45%, ranged in the size between 50 and 100 hectares (Fig. 6). Farms with the area of 100-300 hectares accounted for 20% of the total number of farms. Larger farms, with the area exceeding 300 ha were owned by about 10% of the surveyed farmers. Among small and medium-sized farms, of up to 50 hectares, the largest number were those smaller than 20 ha, which accounted for 15% of all farms. These are mostly specialized farms (e.g. gardening). Approximately 10% of farmers had a farm with the area in the range of 10-50 ha.

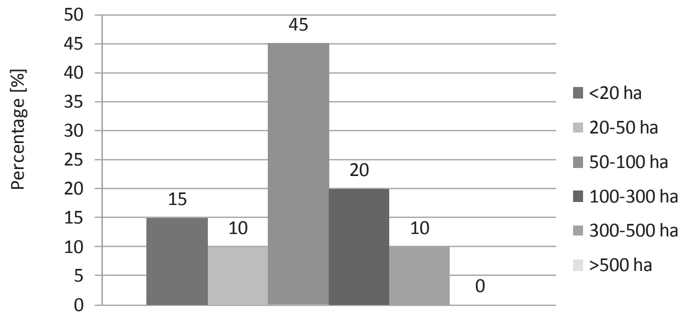

Fig. 6. Farmland area of the surveyed farmers

Types of farms and agricultural activity

The largest number of the surveyed homesteads were those that focus on cultivation of cereals and root crops. They accounted for 27% and 24% of farms (Fig. 7). The main source of livelihood for 16% of the farmers' were pig livestock farms. The poultry farming was the basic maintenance for 11% of the farms, and the cattle only 2%. Fruit-growing and horticulture were the basic production of the 20% of the surveyed farms.

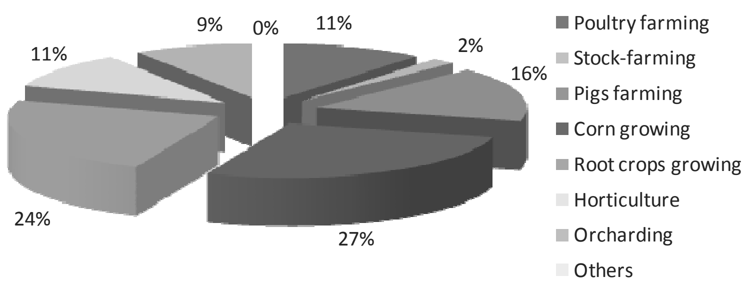

Fig. 7. The breakdown of farms by the type of farming activities

Evaluation of WISIA usage frequency by the farmers

The obtained results of the analysis suggested that the surveyed farmers used the website quite often, but with variable regularity (Fig. 8). Approximately 46% of the farmers used the service during the survey period from 5 to 7 times a week. 20% of the farmers in this group used it five times a week, while over 13% of the farmers visited the website 6 and 7 times a week. Most farmers, that is 28% of them, used the agrometeorological service twice a week. Approximately 13% of the farmers used the service from 1 to 3 times per week.

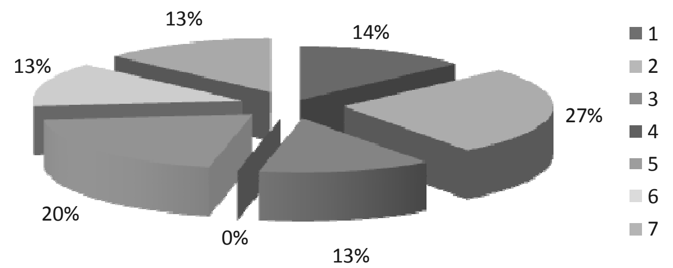

Fig. 8. The percentage estimation of WISIA service usage frequency by the farmers during the week

Frequency of WISIA service usage by the farmers in the period of one month is much lower than it might seem basing on the analysis carried out for one week (Fig. 9). Since as many as 46% of the farmers used the website 5-7 times a week, it could be expected that the same number of farmers would be using the service more than 20 times per month. Meanwhile, only 36% of the farmers (29% – 20 times per month and 7% – 25) used the service with such frequency. Most of the farmers, that is 36%, used the service 10 times per month, and 28% of them 3 to 5 times per month. Thus, the group of farmers regularly using the service was relatively small.

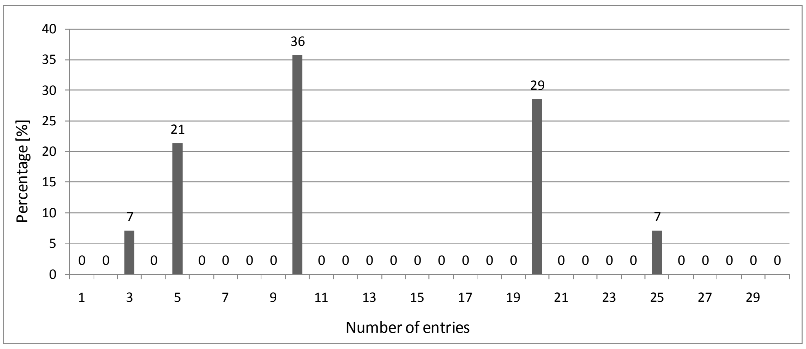

Fig. 9. The percentage estimation of WISIA service usage frequency by the farmers during the month

Evaluation of the usage frequency of different elements of WISIA service

From all elements of WISIA website, the meteorological forecasts were used most frequently (Fig. 10). The most important meteorological element of the forecast was for a farmer the precipitation (20%). The wind speed forecasts were used slightly less frequently (12%). Whereas the information on the air temperature (4%) and the wind direction (1%) was used much less frequently.

As far as the agro-meteorological forecasts are concerned, the most often used information regarded the occurrences of plant pests (11%) and the summary of precipitation and cumulative precipitation values (8%). The forecast of the dates for performing chemical plant protection were used slightly less frequently (7%). The remaining elements of agrometeorological forecasts were virtually not used. The elements of the service such as occurrence of dew, potato blight, total radiation and insolation forecasts were used in the marginal range of 1%.

As far as the remaining service elements are concerned, the links to the websites of institutions involved in agriculture and meteorology were used most often. However, in comparison to other elements of this service, the links to other websites were used relatively rarely. Service elements such as wind chill forecasts and dictionary were used most infrequently (1%).

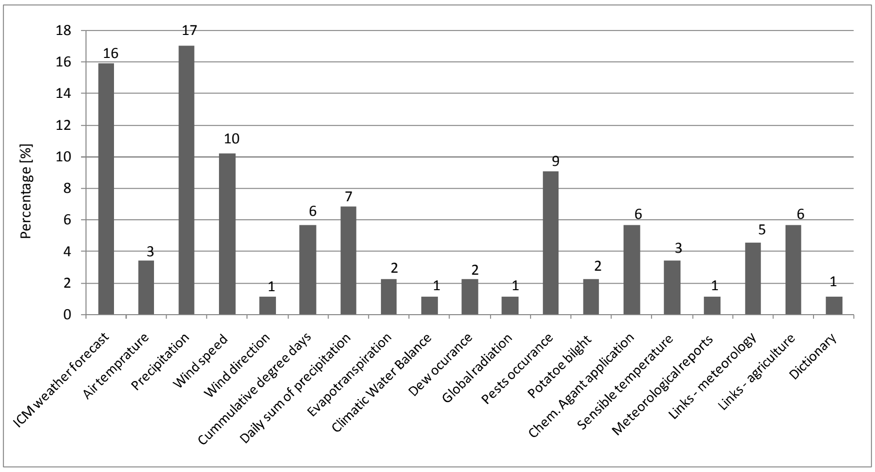

Fig. 10. The percentage estimate of the usage frequency of the individual service elements by the farmers

The evaluation of the 'usefulness' of the individual elements of WISIA service

The usefulness of individual items in WISIA website was assessed by means of a point scale from 0 to 5 (0 – completely useless, 1 – very little useful, 2 – little useful, 3 – moderately useful, 4 – useful and 5 – very useful).

The highest score of 5 was awarded by 100% of surveyed farmers to the occurrences of dew forecasts and the negative forecasts of potato blight (Tab. 1). Thus, it can be concluded that although these elements of agrometeorological forecasts are used very rarely, in the opinion of the service users, they are necessary and useful. Also the ICM meteorological forecasts were considered very useful. As many as 92% of respondents rated the usefulness of this element of the service as 4 or 5. The most useful elements of this forecast were the precipitation forecasts (74% of respondents gave scores of 4 or 5) and wind speed (73% – rating 4 or 5). When it comes to assessing the elements of the meteorological forecast, 100% of the respondents found the wind direction forecast to be moderately useful. Other elements of this forecast were moderately helpful for 15-33% of the surveyed farmers.

Table 1. The evaluation of the 'usefulness' of the individual WISIA service elements in the percentage of incidence of granting a certain number of points on the scale from 0 to 5

	Elements of WISIA service																		
Scores	ICM weather forecast	Air temperature	Precipitation	Wind speed	Wind direction	Cumulative degree days	Daily sum of precipitation	Evapotranspiration	Climatic water balance	Dew occurrence	Global radiation	Dates of pests occurrence	Potato blight	Chemical agent application	Sensible temperature	Meteorological reports	Links - meteorology	Links – agriculture	Dictionary
0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0		0	0	25	0	20	100	0	0	0	0
3	8	33	15	25	100	0	0	0		0	100	0	0	20	0	0	50	0	100
4	25	0	15	13	0	0	80	0		0	0	13	0	0	0	0	0	75	0
5	67	67	69	63	0	0	20	0		100	0	63	100	60	0	0	50	25	0
Average scores	4.6	4.3	4.5	4.4	3	0	4.2	0		5	3	4.2	5	4	2	0	4	4.3	3

Estimations of the sum of degree days and evapotranspiration were the elements of agrometeorological forecasts used very rarely. Most likely, farmers were unable to interpret correctly the results presented in this part of the website. High utility of forecasting of dew and potato blight dates has been mentioned above. In addition to these elements, the list of daily precipitation sum and cumulative precipitation (100% of respondents), the projections of appearance dates of plants pests (76%) and the forecast of the conditions for the performing of the chemical plant protection treatments (60%) were rated as very useful (grade 5) and useful (4). Forecasts of the occurrence dates of plants pests and the forecast of the conditions for performing chemical plant protection treatment were assessed as moderately helpful or slightly helpful by 25-40% farmers.

The enclosed links to websites containing the information about the institutions and portals related to agriculture (100% of respondents gave scores of 4 or 5) and to websites related to meteorology (50% of respondents gave scores of 5 and 50% gave 3) were rated as the most useful of all from the remaining service items. The dictionary utility was rated as moderate.

The evaluation of the 'prediction accuracy' of individual WISIA service elements

Precision of prediction of individual WISIA service elements was rated in the scale from 0 to 5 (0 – completely inaccurate, 1 – very vague, 2 – not very precise, 3 – moderately accurate, 4 – precise and 5 – very accurate).

The precision of the ICM meteorological forecasts was judged very differently, as the points given ranged from 1 to 5 (Tab. 2). Only 17% of farmers found the ICM forecast to be very precise (score 5) and 25% to be precise (grade 4). Vast majority of the farmers (42%) considered, however, that this is a forecast of moderate accuracy (grade 3). For about 16% of the farmers ICM forecast presented low or very low accuracy. One of the elements of the meteorological forecasts favorably evaluated was the precision of the wind speed forecast. For 66% of respondents this forecast was accurate or very accurate. At the same time, 100% of the farmers evaluated the wind direction forecast to be precise. Evaluation of precipitation forecasting accuracy is very vague and probably this element influenced the judgment of the whole ICM forecast. Only 46% of the farmers considered the precipitation forecast to be accurate (score 4), or very accurate (score 5). At the same time, however, as many as 31% of the farmers felt that the precipitation forecast is moderately accurate (score 3). For 23% of the farmers this forecast was not very precise or hardly precise. The evaluation of air temperature forecasting accuracy was relatively good. In fact, as many as 50% of the farmers treated this forecast as very precise and for the remaining 50% it was moderately precise.

Table 2. The evaluation of the ‘prediction accuracy' of the individual WISIA service elements in the percentage of incidence of granting a certain number of points on the scale from 0 to 5

	Elements of the WISIA service																		
scores	ICM weather forecast	Air temperature	Precipitation	Wind speed	Wind direction	Cumulative degree days	Daily sum of precipitation	evapotranspiration	Climatic water balance	Dew occurrence	Global radiation	Dates of pests occurrence	Potato blight	Chemical agent application	Sensible temperature	Meteorological reports	Links - meteorology	Links - agriculture	Dictionary
0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0			
1	8.3	0	15	11	0	0	0	0		0	0	0	0	0	0	0			
2	8.3	0	7.7	0	0	0	0	0		0	0	17	0	25	0	0			
3	42	50	31	22	0	0	40	0		0	100	17	0	50	100	0			
4	25	0	31	33	100	0	60	0		0	0	67	100	25	0	0			
5	17	50	15	33	0	0	0	0		100	0	0	0	0	0	0			
Average scores	3.4	4	3.2	3.7	4	0	3.6	0		5	3	3.5	4	3	3	0			

As far as the agrometeorological forecasts elements are concerned, the sum of degree days and evapotranspiration were entirely overlooked in the evaluation. The precision of forecasting the occurrence of dew (100% of respondents gave score of 5) and the negative forecast of potato blight (100% of farmers gave score of 4) were evaluated most favorably. The precision of daily precipitation sums forecasting and cumulative precipitation was assessed as good (60% – rating 4) or moderate (40% –

rating 3). For most farmers, 67% of them, the forecast of dates of the pests occurrence was at a good level of precision, and for 50% of the farmers the forecast of the conditions for performing chemical plant protection treatments had moderate accuracy (score 3). In the latter case, 25% of the farmers thought that these forecasts had good or bad accuracy. The precision of forecasting the wind chill temperatures was rated as moderate (100% of farmers admitted scores 3).

The evaluation of the frequency of using the information contained in WISIA service for different agricultural treatments

Definitely most of the farmers, as many as 57%, used the agrometeorological information displayed in WISIA website for the correct determination of an optimal performance time of chemical plant protection treatments (Fig. 11). 22% of the farmers used this information to determine the time of grain harvesting and 17% of the farmers took it into account when spreading the fertilizers. Only 4% of the farmers determined the optimal time for grass mowing using the information contained in WISIA service. None of the farms used this information when deciding on hay drying.

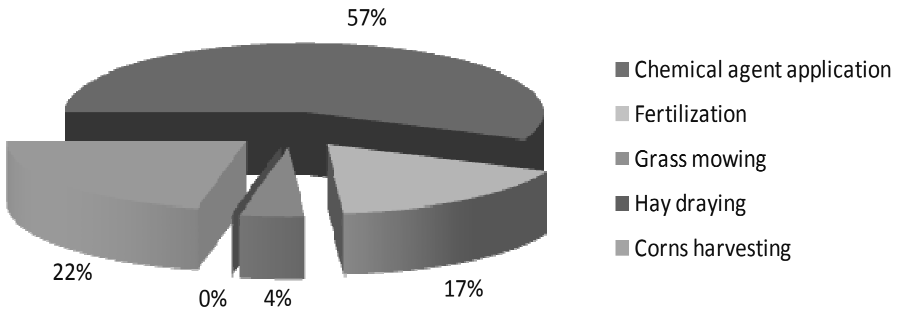

Fig. 11. The percentage evaluation of the frequency of using the information contained in WISIA service for different agricultural treatments

On the basis of the analysis of questionnaires and interviews with the farmers, it is clear that WISIA service fit in well with the farmers daily work schedule. The authors believe that one of the reasons why the service was not used as a whole, but only certain elements of it, was the inadequate understanding of its operation principles. Therefore, the publication directed to potential customers of WISIA service was issued in 2006, the purpose of which was to teach farmers how to use this website properly and efficiently. This publication has been distributed to the farmers using WISIA service.

SUMMARY AND CONCLUSIONS

Agrometeorological information services are a valuable tool in the hands of farmers who have ample knowledge and experience to interpret the information included in this service properly. This information can help one to determine the dates for performing of the most important agricultural activities, which in turn, can significantly optimize the work of a farmer and at least help to minimize the losses incurred as a result of improperly chosen date of performing the procedure.

Wielkopolska Region Internet Agrometeorological Information Service is a valuable source of agrometeorological information for the farmers in the region. It enjoys a growing popularity, which is confirmed by the number of visitors to the website. Since April 2005, more than 195,000 hits have been registered, which gives on average over 3,000 per month. Each day more than 100 users visit the website, which gives the evidence of high usefulness of the service. The dynamics of the number of service users is shown in figure 12. There were selected a few random dates with the registered number of hits on WISIA website.

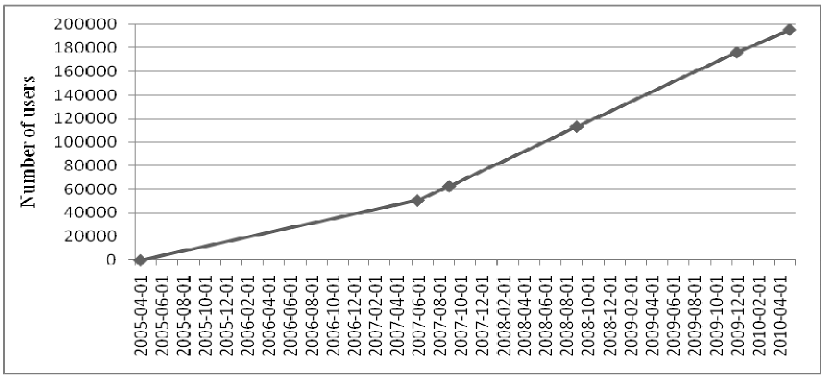

Fig. 12. The dynamics of the number of users of WISIA service in the period from April 2005 to May 2010

Adaptation of agriculture to changing agroclimatic conditions is urgently needed to monitor the situation in the field to determine, for example, the occurrences of pests, or a specific development phase of plants. Book-learned knowledge may prove to be insufficient in the light of the currently observed climate changes and its impact on the agro-ecosystem. Agrometeorological information services can help farmers to adapt production systems, or agricultural practices to the changing production conditions.

An essential condition to obtain absolute confidence of farmers in agrometeorological services is to present fair weather conditions and weather forecasts for the longest possible period of time. WISIA service has gained recognition among a wide range of users. Although the quality of the forecasts presented and verifiability do not always meet the expectations of the users. It is necessary to review regularly the presented meteorological and agrometeorological forecasts. This task is especially difficult, even if not impossible, without adequate funding and highly trained staff.

The project which led to creating WISIA service, was concluded with success in December 2006. In the course of the project realization and after its completion the analysis of the meteorological and agrometeorological forecasts quality was performed, however, on a limited basis, mainly due to lack of sufficient staff and modest project budget. Since then, the efforts have been underway aimed at funding and development of the service. The institutions wishing to undertake the cooperation on the commercialization of services and increasing the range of its operation are sought out and welcome. Despite some success and recognition among the representatives of local authorities, we regret to say that there are no clear decisions and willingness to cooperate. The authors of the service do hope that WISIA service will be developed in the future and will not share the fate of other similar projects implemented in Poland.

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12. CHANGES OF CUMULATIVE DEGREE-DAYS AS AN INDICATOR OF CLIMATE CHANGES IN THE MASURIA REGION

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INTRODUCTION

According to IPCC 2007 report, the global average temperature has increased by 0.74°C within the period of 1906-2005. The linear warming trends observed over the last few decades (0.13°C per decade) were twice as big as they were calculated for the whole twentieth century. The global warming is a fact and this process is having an essential effect on changes of environmental conditions over global, regional and local scales (IPCC, Climate Change Synthesis Report 2007), although a rate of these changes and their impacts on environment is different in various regions. For example in Poland, the average air temperature has increased by 0.25°C per decade within the period of 1966-2006. For summer period (June-August) the temperature has increased even with the rate of 0.33°C per decade (Mager *et al*. 2009). According to the IPCC Fourth Assessment Report (WG1) (2007) it is highly probable that the surface air temperature will increase from 1.8°C even up to 4.0°C dependently on the SRES scenario. A temperature rise of about 0.2°C per decade is projected for the next two decades for all SRES scenarios (IPCC, WG1 Report, 2007).

Temperature has a crucial impact on development rates of different organisms living on the Earth. For example, developmental rates of plants and invertebrates depends strongly on temperature (e.g. Kramer *et al.* 2000), or rather so called "heat units" (e.g. Gilmore and Rogers 1958). Concept of "heat units" was introduced first by Reaumur in 1735. Since that time different methods of calculating heat units have been applied in agricultural sciences for description and prediction of specific phenological development events of plants and poikilithermic invertebrate species (insects & nematodes) as well as building population dynamics models (e.g. Allen 1976, McMaster and Wilhelm 1997). Therefore, heat units expressed mostly as degree-days (*DD*), which are an accumulated product of time and temperature between developmental thresholds for each day, are commonly used to quantify physiological development of abovementioned organisms (Baskerville and Emin 1969, Roltsch *et al.* 1999, Synder *et al.* 2001).

The predicted temperature changes will definitely increase the cumulative degree-days *(DD)* values (Bergant *et al.* 2006, Juszczak *et al.* 2009). Therefore, the climate changes will most probably strongly affect the plants and insects' physiology and their spatial distribution (e.g. Strand 2000, Harrington *et al.* 2001, Root 2003, Yamamura *et al*. 2006, Juszczak *et al.* 2009). There are a lot of examples of responds of different plant and invertebrate species to warming conditions that have been occurred over the last century (Porter *et al.* 1991, Rosenzweig *et al.* 2001) Observed warming trends in Canada led, for example, to earlier spring activity of mountain pine beetle (Crozier and Dwyer 2006).

Considering above, the main goal of this paper is to estimate the trends of cumulative degree-days changes, as the result of climate changes occurred over the period of 1951-2005, for the north-east Poland.

MATERIALS AND METHODS

Study site

Analyses were carried out for the Region of Warmia and Masuria Lakeland, north-east part of Poland. A common feature of climate of this region is the variability of weather and even a few weeks shift in the calendar of whole periods, which can be characterized by specific thermal values. The cause of frequent changes are inflows and transfers of different air masses. Continental air masses from east caused a hot summer and strong cooling during winter. The same air masses in the late spring and early autumn cause the occurrence of frosts, extending the periods of cold weather. All of Poland, particularly its north-eastern part is an area where there is a clash between marine and continental air masses, which cause the above-mentioned variability of weather. In addition, with a varied landscape with variable topography, lakes and forests, we can distinguish a variety of local climates (Panfil *et al.* 2007).

Average annual air temperature in the region during 1951-2000 was 7.0^{o}C and was approximately equal to the average temperature of April (6.6°C), which is a typical feature of Polish climate. The annual sum of precipitation amounted to 599 mm (Szwejkowski *et al.* 2002).

Weather data

Degree-days values were calculated for ten selected weather stations of Polish National Weather Service (IMGW) located in Olsztyn, Suwałki, Elbląg, Białystok, Lidzbark Warmiński, Kętrzyn, Biebrza, Mława, Myszyniec and Toruń. For all stations, daily maximum and minimum temperatures from the period of

1951-2005 were taken for calculations and analyses. In the paper, the average daily temperature was calculated based on T_{max} and T_{min}, as an arithmetic average of both values. While, the yearly average temperature was calculate based on this daily average temperatures.

Degree-days calculations

One degree-day is achieved, when the air temperature is one degree above a lower temperature threshold for 1 day (Snyder *et al.* 1999) Degree-days are in most cases estimated based on daily maximum (T_{max}) and minimum (T_{min}) temperatures by approximating diurnal temperature curves (Snyder *et al.* 1999). Variety of methods with varying degrees of complexity have been developed to approximate diurnal temperature curves and to estimate *DD* (Cesaraccio *et al.* 2001). Several most commonly applied methods of degree-days estimation were compared and evaluated by Roltsch *et al*. (1999).

In the paper, degree-days values were calculated based on the single-sine method, which uses a daily minimum and maximum temperatures to produce a sine-wave curve for a 24-hours period, and then estimates degree-day for that day by calculating the area between the defined temperature thresholds and below the curve (Baskerville and Emin 1969, Allen 1976, De Gaetano and Knapp 1993, Roltsch *et al*. 1999). The single-sine method assumes that temperature curve is symmetrical around the maximum temperature. Dependently on a considered temperature thresholds and a place where the sine curve is intercepted by these thresholds, the formulas used for calculation of degree-days are different (Zalom *et al.* 1983). All formulas and detailed assumptions taken into calculations were described in the paper of Juszczak *et al*. (2009).

Degree-days were calculated for two defined lower temperature thresholds (T_{low}) of 0.0°C and 10.0°C. Temperature threshold of 10°C is most commonly used and applied for studies of developmental rates of some plants (e.g. corn) and invertebrates (e.g. Codling Moth). While, temperature threshold of 0°C is very often used for studies of agrometeorological parameters change over time. However, These two temperature thresholds were chosen as an example and should not be interpreted in relation to development of any plant or invertebrates, without complex analyses of key developmental thresholds which are specific for each species. In both cases, the upper thresholds were considered to be high enough to not limit calculation of *DD* (sine curve was not intercepted by an upper threshold).

Spatial analyses

Trends of cumulative degree-days changes estimated for all weather stations located within the considered region were presented graphically on maps, where the *a* parameters of linear equations representing the trends of *DD* changes for different T_{low} and stations, were extrapolated between these stations by using the SURFER 6.0 software. This software produces visually appealing contours and surface plots from irregularly spaced data.

RESULTS

Air temperature changes

The average yearly air temperature of the North-East Poland was 7.1^{o}C within the analyzed 55-years period from 1951 to 2005 (Tab. 1). While, the average yearly air temperature of considered stations ranged from 6.4 (Suwałki) to 8.0^{o}C (Toruń). Within the analyzed period the average yearly temperature changed in the whole region with the rate of 0.23^{o}C per decade. The rate of temperature changes was different for each station and although these differences were not very essential, it was observed that changes were the smallest in the coldest part of Poland

Table 1. Average yearly air temperature, minimum and maximum yearly average temperatures of weather stations located in the north-east part of Poland and trends of observed temperature changes (parameter "*a*") for the 55 years period from the year 1951 to 2005

Stations	T_{avg}	$T_{avg-min}$	$T_{avg-max}$	'a' parameter
Suwałki	6.4	4.4	8.1	0.019
Biebrza	6.6	4.8	8.4	0.019
Myszyniec	6.9	5.1	8.7	0.019
Mława	7.0	4.9	8.9	0.044
Białystok	7.0	5.2	8.7	0.013
Olsztyn	7.2	5.6	9.0	0.024
Kętrzyn	7.2	5.4	9.0	0.022
Lidzbark	7.2	5.5	9.0	0.024
Elbląg	7.9	5.9	9.5	0.025
Toruń	8.0	6.2	9.9	0.026
Average for all stations	7.1	5.3	8.9	0.023

(Białystok, Suwałki, Biebrza, Myszyniec). For example, the average yearly air temperature of Białystok station changed with the rate of 0.12°C per decade. On the other hand, the average yearly air temperature of Mława station increased even 0.44°C per decade. These temperature changes are assumed to have pronounced influence onto the rate of many plant species and pests development over the growing season, what can be expressed by changes of cumulative degree-days (Juszczak *et al.* 2009).

Degree-days values changes

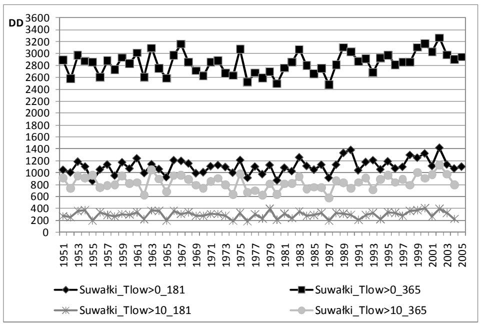
The average cumulative degree-days values calculated as 55-years average for T_{low}>0°C and for stations of north-east Poland ranged from 1109 *DD* (Suwałki) to 1296 (Toruń) when estimated for the half of the year (Tab. 2) as well as from 2839 *DD* (Suwałki) to 3246 *DD* when calculated for the whole year. Whereas, when T_{low}>10°C was considered, than the average *DD* estimated for the half of the year ranged from 296 *DD* (Suwałki) to 362 *DD* (Toruń) and from 834 *DD* (Suwałki) to 1020 *DD* (Toruń) for the whole year.

The courses of yearly cumulative degree-days values for each of a station, different time horizons and temperature thresholds are presented on Figure 1. For each of the year and each station there were observed essential fluctuations (DD_{max} – DD_{min}) of cumulative degree-days values and the range of this fluctuations for T_{low}>0°C was from 560 *DD* (Suwałki) to 738 *DD* (Olsztyn) for half of a year and from 712 *DD* (Mława) to 1151 *DD* (Mława) for a whole year (Tab. 2). The range of this fluctuations is obviously much smaller when T_{low}>10°C is considered. In this case, the *DD* fluctuations within the whole analyzed period are within a range of 204-279 *DD* for the middle of a year (stations Myszyniec and Mława, respectively) and within 459-706 *DD* for the whole year and the same stations.

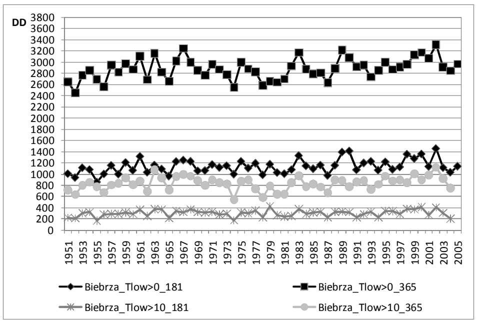
The fluctuations of cumulated degree days values are of course related to changes of yearly average temperatures. There is strong, statistically very essential relationship between an average yearly air temperature and cumulative values of degree-days, what is expressed on Figure 2. This relationship is much better when *DD* are estimated for T_{low}>0°C (R^2 = 0.82). The average yearly air temperature calculated for the whole 55-years period has differed from 4.5°C to ca. 10.0°C whichever station is considered. The corresponding degree-days values cumulated at the end of a year has differed within this range of yearly average temperatures from about 2400 *DD* to 3700 *DD* for T_{low}>0°C and from about 550 *DD* to 1250 *DD* for T_{low}>10°C.

Table 2. Statistics related to changes of cumulative values of degree-days calculated for two lower temperature thresholds >0°C and >10°C for half (DOY181) and the end (DOY365) of a year for the 55 years within the period from 1951 to 2005 for selected weather stations of north-east Poland

	Suwałki	Biebrza	Myszyniec	Mława	Białystok	Olsztyn	Kętrzyn	Lidzbark	Elbląg	Toruń	Region average
DD> 0°C_ DOY 181											
DD_{avq}	1109	1140	1166	1181	1197	1183	1185	1176	1249	1296	1188
DD_{min}	860	861	918	824	915	811	906	868	921	961	884
DD_{max}	1420	1456	1483	1561	1499	1549	1537	1571	1618	1684	1538
'*a*'	2.7	3.2	3.0	6.1	2.0	4.1	3.8	4.6	4.4	4.3	3.8
DD> 0°C _ DOY 365											
DD_{avq}	2839	2880	2955	2980	2999	3015	3029	3014	3173	3246	3013
DD_{min}	2477	2448	2648	2389	2622	2642	2630	2641	2764	2823	2608
DD_{max}	3264	3311	3360	3540	3405	3436	3477	3508	3662	3707	3467
'*a*'	3.2	4.3	4.0	11.0	1.7	5.8	5.2	5.8	6.0	6.5	5.4
DD>10°C _ DOY 181											
DD_{avq}	296	302	312	320	336	312	313	307	330	362	319
DD_{min}	182	173	209	175	224	164	201	188	194	233	194
DD_{max}	408	427	414	455	446	426	454	446	468	511	445
'*a*'	0.3	0.7	0.3	1.7	-0.2	0.8	0.9	1.1	0.9	1.1	0.8
DD> 10°C _ DOY 365											
DD_{avq}	834	835	872	894	917	888	897	884	949	1020	899
DD_{min}	577	545	664	545	664	659	622	655	720	796	645
DD_{max}	1126	1124	1123	1252	1178	1161	1223	1200	1289	1292	1197
'*a*'	0.8	1.8	0.9	5.0	-0.4	2.0	2.2	2.2	2.2	2.8	2.0


DD
Suwałki_Tlow>0_181
Suwałki_Tlow>0_365
Suwałki_Tlow>10_181
Suwałki_Tlow>10_365

a)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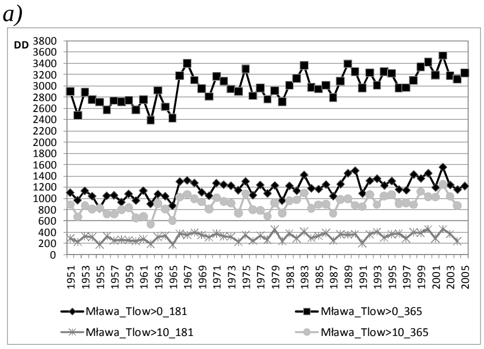
b)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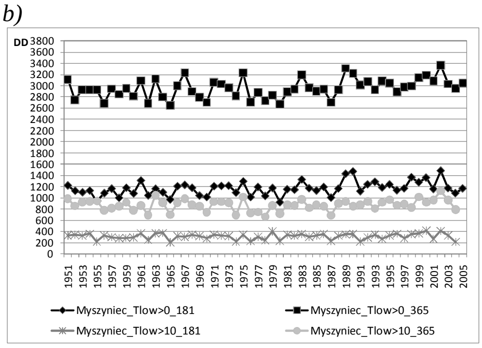
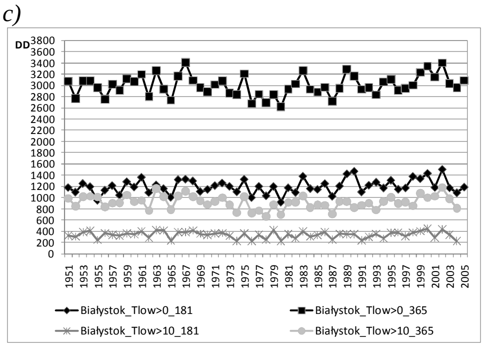
c)


DD
Myszyniec_Tlow>0_181
Myszyniec_Tlow>0_365
Myszyniec_Tlow>10_181
Myszyniec_Tlow>10_365

d)


DD
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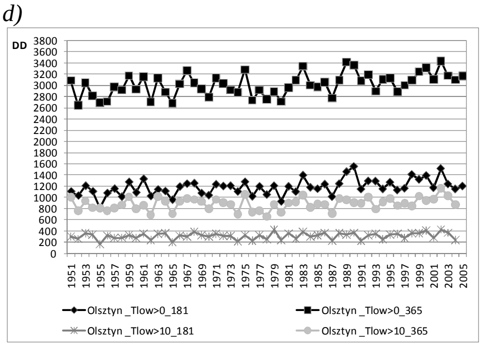
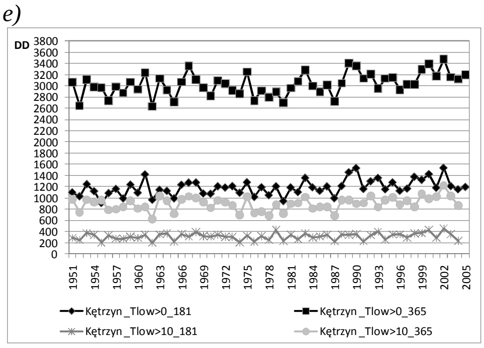
Białystok_Tlow>0_365
Białystok_Tlow>10_181
Białystok_Tlow>10_365

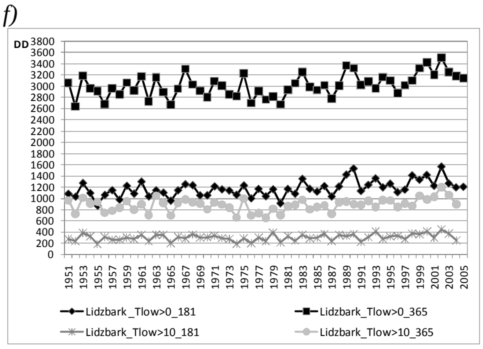
e)


DD
Olsztyn _Tlow>0_181
Olsztyn _Tlow>0_365
Olsztyn _Tlow>10_181
Olsztyn _Tlow>10_365

f)


DD
Kętrzyn _Tlow>0_181
Kętrzyn _Tlow>0_365
Kętrzyn _Tlow>10_181
Kętrzyn _Tlow>10_365

g)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Lidzbark_Tlow>0_365
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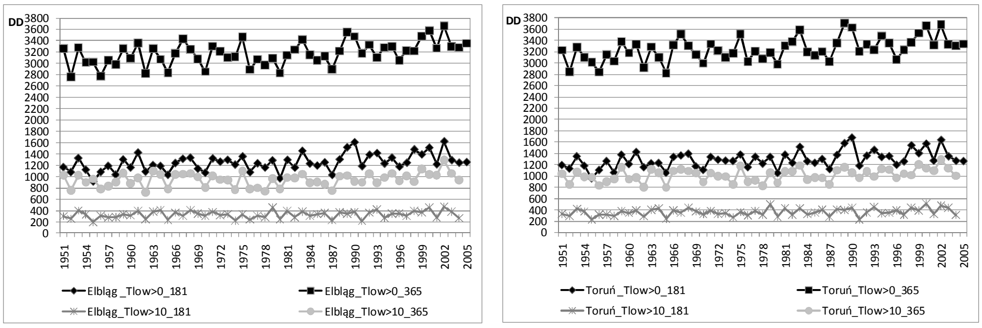
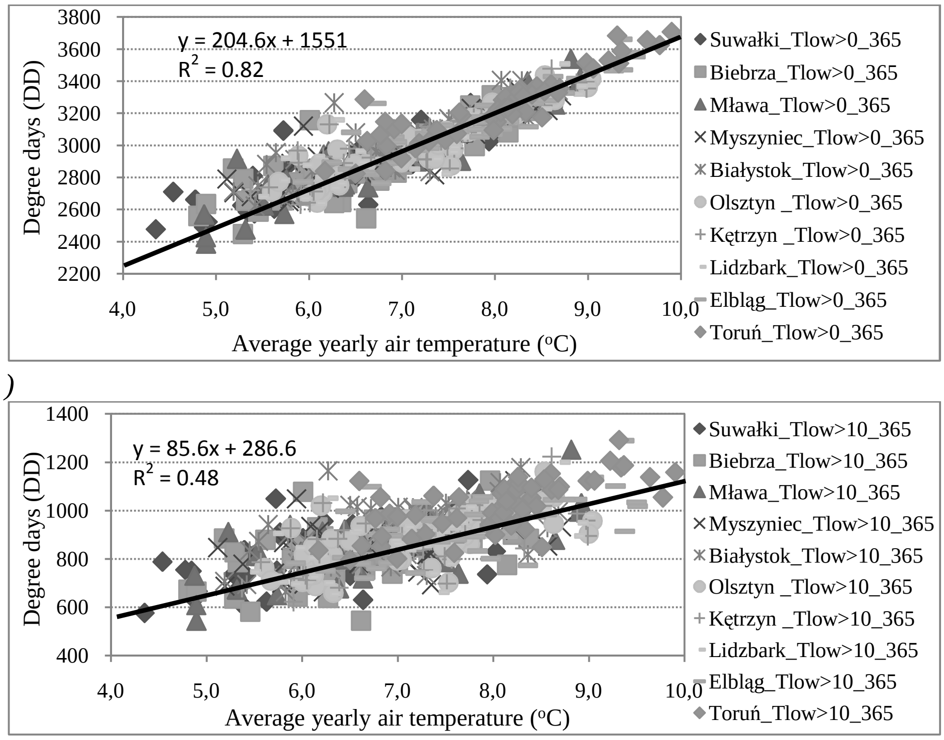
h)



i) *j)*

Fig. 1. Trends of degree-days changes for selected stations of north-east Poland. Degree-days were calculated for two different lower temperature thresholds (0^{o}C and 10^{o}C) and two yearly time-horizons of middle (181-182 day of a year) and end of each year (365-366 day of a year). Weather stations: *a* – Suwałki, *b* – Biebrza, *c* – Mława, *d* – Myszyniec, *e* – Białystok, *f* – Olsztyn, *g* – Kętrzyn, *h* – Lidzbark Warmiński, *i* – Elbląg, *j* – Toruń



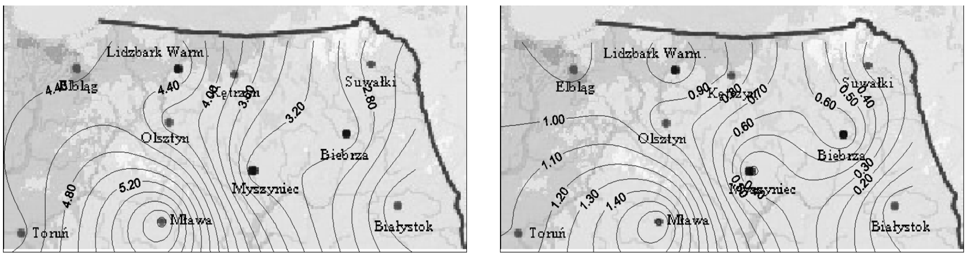
a
)
b)

Fig. 2. Relationship between cumulated yearly degree-days and an average yearly temperature. *DD* were calculated for temperature thresholds a) 0^{o}C and b) 10^{o}C for each of a year within the period of 1951-2005 for selected weather stations of north-east Poland

The cumulated yearly values of degree days can change even by 205 *DD* per 1.0°C difference of yearly average temperature when T_{low}>0°C, and 86 *DD* when T_{low}>10°C.

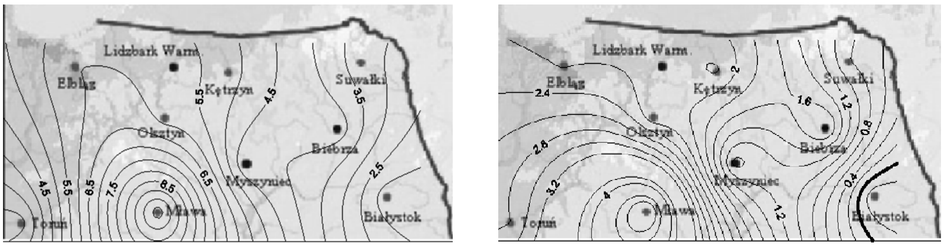
The cumulated degree days values has increased within the analyzed 55-years period with an increased yearly average temperatures. The trends of such changes were statistically very essential in both cases whichever station is considered. The cumulated yearly *DD* values have increased in average with the rate from 1.7 *DD* (Białystok) to 11.0 *DD* (Mława) per year, when T_{low}>0°C is considered (Tab. 2). The yearly *DD* values increased in average with the rate of 5.4 *DD* per year for the whole region. For T_{low}>10°C, not all trends were positive. In nine from ten station the trend was positive and yearly cumulated *DD* increased with the rate from 0.8 *DD* (Suwałki) to 5.0 *DD* (Mława). The only exception was Białystok station where observed trends were negative, when *DD* were calculated for T_{low}>10°C (*DD* decreased with a rate of 0.4 DD per year). However, the average yearly cumulated degree-days values has increased in the whole region within the 55-years period with a rate of 2.0 *DD* per year.

Spatial distribution of "*a*" parameter of linear equations representing the trends of cumulative *DD* changes over the analyzed 55-years period is presented in Figures 3 and 4. Maps shows the distribution of *DD* for two time horizons – half and end of a year, and two temperature thresholds. Generally it can be seen, that values of "*a*" parameter are decreasing from west into east part of Poland for both T_{low}>0°C and T_{low}>10°C (although changes have more complex behavior). This is a typical feature of continental climate, which is more pronounced during cold parts of a year.



a) b)

Fig. 3. Spatial distribution of "*a*" parameter of linear equations representing the trends of cumulative *DD* changes over the analyzed 55-years period for the middle of a year within the period 1951-2005; a) for T_{low}>0°C and b) T_{low}>10°C



a) b)

Fig. 4. Spatial distribution of “*a*” parameter of linear equations representing the trends of cumulative *DD* changes over the analyzed 55-years period for the end of a year within the period 1951-2005; a) for T_{low}>0^{o}C and b) T_{low}>10^{o}C

CONCLUSIONS

1. Analyzes carried out within our studies confirm a globally observed climate warming trend. However, the observed temperature changes are getting about 2-times bigger per decade in the north-east Poland, than the average global linear warming trend reported in the IPCC for the last few decades (IPCC, WG1 Report, 2007). The rates of temperature changes were related to the average yearly air temperature and it seems that the smaller average temperature, the smaller rate of changes estimated per year or decade.

2. Cumulative degree-days values calculated based on daily extreme temperatures reached higher and higher values with an increased average yearly air temperature. The analyses carried out based on that data showed spatial differences in distribution of yearly values of degree-days and indicate the parts of the north-east Poland were these changes happened faster over the analyzed 55-years period and most probably will happen faster in future. The rate of this degree-days changes can be estimated to be close to even 205 *DD* per each 1.0^{o}C average air temperature change when T_{low}>0^{o}C and 85 *DD*, when T_{low}>10^{o}C. These changes can have essential influence onto length of growing season, appearance of new plants and invertebrates (e.g. pests) as happened in other parts of Poland (e.g. Walczak and Tratwal 2009), as well as can have an effect on physiology and phenology of different insects what have been already reported and predicted for example by Porter *at al.* (1991) and many others.

3. The analyses of temperature changes for that region were done only in a scale of the whole year. Most probably these analyses should be done also for shorter periods, e.g. growing season, or quarterly, as was done by Juszczak *et al*. (2009). After that, the understanding of impact of such temperature changes on plants and invertebrates would be better and this effect would be more pronounced.

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13. SUMMARY

The first chapter of the monograph analyses the effect of precipitation and fertilization on yields and sugar content of sugar beet in the south of Poland. The data were obtained from the Station of Cultivar Evaluation in the south of Poland. Sugar beet was grown on soils of a very good and good wheat complex in the years of 1989-2005. Using the regression method, variation in the roots and foliage of the beet was studied, and so was the percentage content of sugar in the roots as dependent on the following factors: rainfall in the period of April-June, rainfall in July-September, fertilization with nitrogen, phosphorus and potassium, year of cultivation. The variation in sugar beet root yield caused by precipitation in April-June (in 140-240 mm range) was 30 dt ha^{-1}, the optimum value being 223 mm. Precipitation from July to September (in 150-310 mm range) modified the yield by 29 dt ha^{-1}. The highest yields were achieved with 310 mm rainfall. Fertilization with nitrogen and potassium in the range studied, i.e. 110-160 and 120-180 kg ha^{-1}respectively, affected the beet root yield positively. Phosphorus doses in excess of 60 kg ha^{-1}caused a decrease in sugar beet root yield. The yield of foliage increased with increasing precipitation both in the April-June and July-September periods, while precipitation in the first period modified the yield by 45 dt ha^{-1} and by 130 dt ha^{-1} in the second period. An increase in nitrogen and potassium fertilization caused a decrease in yield, while increased phosphorous fertilization induced increased yield of beet foliage. Sugar content in beet roots expressed in percentage reacted strongly to the increased precipitation. The increased precipitation in April-June resulted in 2.8 pp. fall in sugar content, and in the July-September period the fall was even 5.5 p.p. Sugar content increased as a result of potassium fertilization, and no changes could be found in the content caused by the increased nitrogen and phosphorus fertilization.

In second chapter the analysis of sugar beet yields was continued but for the data from the eastern Poland. In this region sugar beet was cultivated on soils of a very good, good and faulty complex in the years 1991-2005. For the highest yields of roots and leaves the optimum set was as follows: rainfall April-June 119 mm (the lowest recorded) and rainfall July-September 266 mm (the highest recorded). The least favorable for root yield was the set with the highest rainfall in IV-VI (215 mm) accompanied by the lowest rainfall in VII-IX (124 mm), and for leaves – the lowest rainfall of both periods (119 mm and 124 mm). Sugar content was the highest when rainfall in the two periods was minimum, and the lowest when the rainfall approached maximum quantity.

Next chapter characterizes frost occurrence space variability in two spring months, April and May, in the eastern Poland, in the period of 1988-2007. The analysis is based on the air temperature measurements at the height of 200 cm a.g.l., which were made in 17 meteorological stations. Average number of days with spring frosts in the eastern Poland increased towards the north (besides the area between Rzeszów and Zamość). In April there were six times more such days in Podlaska Lowland than in Sandomierz Hollow and the surroundings of Przemyśl (in May almost 2 days). In all meteorological stations 1-day frosts dominated. Most frequently mild frosts occurred (–2.0ºC ≤ tmin ≤ 0.0ºC), on average from 2.8 days in Tarnów to 6.0 days in Białystok. Since the end of the 80 s of the 20th century, frosts most often have occurred in April with advanced high pressure system over the Central Europe and during arctic air masses advection from the northern sector. In May, frosts occurred often enough during a strong high appearance over the Scandinavian Peninsula, which determines arctic air masses advection from the north-east.

The content of chapter four investigates the spatial patterns of Sum of Active Temperatures (SAT) and Growing Degree Days (GDD) in Poland, in the context of the general, thermal suitability of the region for vine cultivation. The warmest and the coldest years of the 1999-2008 period are spatially analyzed, and changes in spatial extend and location of areas with SAT and GDD conditions favorable for vine cultivation are discussed. The changes in spatial extend of the areas with favorable conditions in Poland are compared with other in the countries of Central Europe: Czech Republic, Slovakia and Hungary.

In the most favorable years prevailing areas of Poland are suitable for vine growing (in terms of GDD; 57% of the country area) and sufficient for cultivation of very late ripening varieties (in terms of SAT). However, if the least favorable year is analyzed, when not enough heat can be cumulated, there are extensive areas which are of questionable suitability (63% of the country area) for vine cultivation or suitable only for frost and disease resistant varieties.

The aim of the study in the next chapter was to evaluate the impact of weather conditions on the cultivation of maize grain in Poland. An analysis into the yield of maize was performed using statistical data from the Central Statistical Office between 1992 and 2008. An assessment of the impact of meteorological conditions on maize cultivation was performed using the weather-yield statistical model, with a *weather yield index* WI and partial weather index evaluating conditions during the vegetation of maize. For this analysis, meteorological data from Puławy (central Poland) between 1921 and 2009 were used. The result shows that the lowest variation in yield occurs in the south-eastern part of Poland, where there is more suitable climatic condition for maize cultivation than in the northern regions. This indicates that in the northern regions, a lack of heat is still a limiting factor for maize production. The analysis of weather maize yield index (WI) for Puławy between 1921 and 2009 shows an improved tendency of climatic condition for maize cultivation. There is an increase in the frequency of years with favorable conditions for maize cultivation with WI> 105, along with a decreasing number of years with adverse conditions with WI< 95. At the same time, years such as 2006 and 1994 were observed when a drought occurred in the spring and summer causing very low yields. An analysis of partial weather maize yield indexes shows that in recent years, weather changeability during June and July (WIJJ) has been increasing, whilst WIMJ and WIJA have had more stable and higher values than in previous years.

The aim of the next chapter is to present the application of low-altitude remote sensing, used in order to assess the impact of drought on the state of crops in different regions of Poland. The chapter describes the elaborated methodology and analysis of aerial photographs. Spatial analysis was carried out using geographical information systems (GIS). The result of the study is the assessment of drought impact on crops in different regions of Poland. The analysis was carried out in areas affected by drought as well as the areas outside which have been designated on the basis of climatic water balance (CWB). The Drought Monitoring System for Poland (ADMS) is provided by the Institute of Soil Science and Plant Cultivation - National Research Institute (IUNG-PIB) on behalf of the Ministry of Agriculture and Rural Development.

Chapter seven is devoted to the impact of climate changes on agriculture and possible adaptation activities in this field. Addressing the above problem 11 research teams established a consortium and prepared the project called ADAGIO. The purpose of the project was to gather information on potential threats to agriculture then, to determine adaptation activities and their diffusion. The main threats to agriculture in the future climatic conditions were identified as follows:

- increase of frequency and intensity of occurrence of extreme climatic events;
- intensification of problems connected with proper water supply for plants (increase of frequency of drought occurrences, bigger water drainage, decrease of ground water supply, etc.);
- more intense development of native phyto pathogens and the expansion of thermophilic species.

Considering the above mentioned threats the experts engaged in the implementation of the project in Poland proposed various adaptation activities. In their opinion climate changes will influence mainly water supplies and hydrological cycle therefore, the following measures should be taken:

- increasing water supply available for farming;
- increasing the efficiency of using water in agriculture;
- decreasing the intake of water by plants.

In the case of occurrence of new agrophages or intensification of the incidence of the native ones the following steps should be taken :

- adapting the farming technology in order to limit the incidence of agrophages;
- introducing efficient methods of preventing the development of new agrophages.

In the case of extreme meteorological phenomena the most effective preventive measure seems to be the development of special insurances for farmers.

Chapter eight addresses the problem of using weather derivatives in agriculture insurance. Progressing climate changes carry the risk of bad weather conditions. One might expect that in the future the number of disasters will increase together with the weather changeability in our country. Currently, when unfavorable weather conditions occur in a larger scale farmers usually expect support from the government. Usually in Polish conditions such help is granted however, it does not compensate for all losses. In the case of weather changes, in turn, the insurance seems of little efficiency. Modern economic instruments could help to avoid such situations. Polish traditional agriculture economy uses simple insurance systems with difficulty, can more complex solutions be applied here then? It may seem that implementing modern insurance solutions requires the engagement of people from banking or para-banking sector only. Surely the economist is the most important person in the process of management and development however, the estimate of weather risk and results of harmful phenomena belongs to agrometeorology. The following work is one of the few publications dealing with this problem and aims at explaining some basic issues at the same time emphasizing the necessity of undertaking concrete interdisciplinary research in this field. Particularly it explains the following issues:

- definition and description of a weather derivative instrument,
- instrument parameters;
- types of weather indexes which can be applied in creating the instruments,

- weather models and weather indexes as instrument parameters,
- comparison of the insurance with weather derivatives,
- policy and strategy of using weather derivatives, and particularly indicating the dangers resulting from using them by people who have little business experience.

In the ninth chapter vegetation seasons, as well as spring and autumn ground frosts, were measured on the basis of twenty-four-hour mean and minimum air temperatures recorded from 1966 to 2005 in Mikołajki and Kętrzyn, situated in the Mazurskie Lakeland. Ground frost was defined as the minimum air temperature falling below $0^{o}C$ in the vegetation season. The frequency of ground frost was established at 5 centimeters above the ground level, in particular spring and autumn months of the vegetation season. After ascertaining the mean dates of final spring ground frosts and initial autumn frosts, the duration of the frost-free period in the locations under analysis was established. The conclusions from the analysis of the data demonstrate that the duration of the vegetation season in the forty years under analysis was 212 days in Kętrzyn and 210 days in Mikołajki. The mean beginning of this season occurred on April 3rd in Kętrzyn, and on April 2nd in Mikołajki, while the end occurred on October 31st in Kętrzyn and October 30th in Mikołajki. The analysis of frequency of ground frost in particular months of the vegetation season showed that spring ground frost accounted for 70%, and autumn ground frost for 30%. The duration of the frost-free period was 135 days in Kętrzyn and 144 days in Mikołajki. The most days with ground frost in spring were recorded in April. With regard to autumn, the most days with ground frost were recorded in October.

Next chapter contains research aimed at determining the impact of meteorological factors on the growth, development and yielding of *Lupinus angustifolius* of the Emir cultivar in 1987-2002. The research material concerning yield and weather conditions originated from three experimental stations for various assessment, located in the north-eastern Poland. The analyses used the multiple regression method, with the application of linear and quadratic functions, with step-wise selection of variables and the created equations were evaluated by means of R^2 determination factor, adjusted R^2 and a Cross Validation test, by determining R^2_{pred}. In the years of research, a clear diversity of weather factors was established, i.e. solar radiation, mean temperature and precipitation in individual periods of growth and development of blue lupine, which significantly affected the rate of yield, dates of phenological stages and the length of interphase periods. Only in the experimental station in Marianowo all created equations passed verification procedures with the application of the Cross Validation tests. Factors significantly affecting the yield of the cultivar included total solar radiation and precipitation in the sowing-germination period; these were quadratic relations, demonstrating the moderate response of the cultivar to these factors.

Chapter eleven presents information on the quality verification of decision supporting system in agriculture. Agrometeorological information services are a valuable tool in the hands of farmers who have ample knowledge and experience to interpret the information included in this service properly. This information can help one to determine the dates for performing of the most important agricultural activities, which in turn, can significantly optimize the work of a farmer and at least help to minimize the losses incurred as a result of improperly chosen date of performing the procedure. Wielkopolska Region Internet Agrometeorological Information Service is a valuable source of agrometeorological information for the farmers in the region. It enjoys a growing popularity, which is confirmed by the number of visitors to the website. Since April 2005, more than 195,000 hits have been registered, which gives on average over 3,000 per month. Each day more than 100 users visit the website, which gives the evidence of high usefulness of the service.

Chapter twelve confirms the observation that trends in air temperature changes in the north-eastern Poland follow the world pattern. It allowed using non-observational methods to forecast the incidence of pests by means of the so called degree-days which were analyzed considering the changes which occurred in the period of 1951-2005.The rate of these degree-days changes can be estimated to be close to even 205 *DD* per each 1.0^{o}C average air temperature change when T_{low}>0^{o}C and 85 *DD*, when T_{low}>10^{o}C. These changes can have essential influence on the length of growing season, appearance of new plants and invertebrates (e.g. pests) as happened in other parts of Poland, as well as they can have an effect on physiology and phenology of different insects what have already been reported and many others predicted.

Keywords: yield of sugar beet, precipitation, fertilization, fertility of soil, sugar content, spring and autumn ground frosts, minimum air temperature, Sum of Active Temperatures, Growing Degree Days, wine-grapes growing, spatial interpolation, spatial analyse, vegetation season, frost-free period, yield of maize, weather index, agricultural drought, remote sensing, GIS, yield of blue lupine, meteorological factors, effect climate changes on agrophages risk

14. STRESZCZENIE

BADANIA AGROMETEOROLOGICZNE

W pierwszym rozdziale monografii analizowany wpływ opadów i nawożenia na plony buraka cukrowego i zawartość cukru w południowej Polsce. Dane pochodziły ze Stacji Oceny Odmian położonych w południowej Polsce. Buraki cukrowe uprawiane były na glebach kompleksu pszennego bardzo dobrego i dobrego w latach 1989-2005. Stosując model regresji zbadano zmienność plonu korzeni i liści buraka cukrowego a także procentowej zawartości cukru w korzeniach pod wpływem następujących czynników: opad w okresie kwiecień-czerwiec, opad w okresie lipiec-wrzesień, nawożenie azotem, fosforem i potasem, rok uprawy. Zmienność plonu korzeni buraka cukrowego pod wpływem opadu kwiecień-czerwiec (w badanym przedziale 140-240 mm) wynosiła 30 $dt \cdot ha^{-1}$, a optymalną wartością było 223 mm. Opad od lipca do września (w przedziale 150-310 mm) modyfikował plon o 29 $dt \cdot ha^{-1}$. Najwyższe plony osiągano przy 310 mm opadu. Nawożenie azotem i potasem w badanym zakresie, tj. odpowiednio 110-160 i 120-180 $kg \cdot ha^{-1}$, wpływało dodatnio na uzyskiwane plony korzeni buraków. Dawki fosforu przekraczające 60 $kg \cdot ha^{-1}$powodowały obniżenie plonu korzeni buraka cukrowego. Plon liści wzrastał w miarę wzrostu opadu zarówno w okresie kwiecień-czerwiec jak i lipiec-wrzesień, przy czym opad w pierwszym okresie modyfikował plon o 45 $dt \cdot ha^{-1}$a w drugim aż o 130 $dt \cdot ha^{-1}$. Wzrost nawożenia azotem i potasem powodował obniżenie, natomiast zwiększanie dawki nawożenia fosforem przyczyniało się wzrostu plonu liści buraka. Zawartość cukru w korzeniach buraka wyrażona w procentach silnie reagowała na wielkość opadu. Wraz ze wzrostem opadu w okresie kwiecień-czerwiec spadek zawartości cukru wynosił 2,8 p.p., a w okresie lipiec – wrzesień aż 5,5 p.p. Zawartość cukru wzrastała pod wpływem nawożenia potasem, natomiast nie stwierdzono zmian jej wartości pod wpływem nawożenia azotem i fosforem.

W rozdziale drugim kontynuowano rozpoczęty temat ale dla danych z terenów wschodniej Polski. Buraki cukrowe uprawiane były na glebach kompleksu pszennego bardzo dobrego, dobrego i wadliwego w latach 1991-2005. Optymalnym dla uzyskania najwyższych plonów korzeni i liści okazał się układ czynników: opad kwiecień-czerwiec 119 mm (najniższy badany) i opad lipiec wrzesień – 266 mm (najwyższy badany). Najmniej korzystny dla plonu korzeni był układ, w którym najwyższym opadom IV-VI (215 mm) towarzyszyły najniższe opady VII-IX (124 mm), a dla liści – najniższe opady obu tych okresów (119 mm i 124 mm).

Zawartość cukru była najwyższa, gdy opady dwóch okresów były w minimum, a najniższa, gdy osiągały wartości maksymalne.

W rozdziale trzecim monografii przedstawiono ogólną charakterystykę przestrzennej zmienności występowania przymrozków w dwóch miesiącach wiosennych (kwiecień, maj) we wschodniej Polsce (1988-2007). Analiza opiera się na pomiarach temperatury powietrza na wysokości 2 m n.p.g., na 17-tu stacjach meteorologicznych. Średnia liczba dni z przymrozkami wiosną we wschodniej Polska rosła w kierunku północnym (poza obszar między Rzeszowem, a Zamościem).). W kwietniu było sześć razy więcej takich dni na Nizinie Podlaskiej niż w Sandomierzu i w okolicach Przemyśla (w maju prawie 2 dni). Na wszystkich stacjach meteorologicznych dominują przymrozki 1 dniowe. Temperatura minimalna najczęściej występowała w przedziale od 0 do –2ºC (od średnio 2,8 dni w Tarnowie do 6 w Białymstoku). Od końca lat 80-tych XX wieku, przymrozki na analizowanym obszarze najczęściej występowały w kwietniu podczas zalegania wyżu nad Europą Środkową oraz podczas napływu powietrza arktycznego z północy. W maju przymrozki występowały dość często podczas silnych wyżów na Półwyspie Skandynawskim, które determinowały adwekcje mas powietrza arktycznego z północnego wschodu.

W kolejnym rozdziale przedstawiono rozkład przestrzenny Sum Temperatur Aktywnych (SAT) i Sum Temperatur Efektywnych (GDD) w Polsce w celu dokonania ogólnej klimatologicznej oceny przydatności regionu do uprawy winorośli. Lata ekstremalne pod względem termicznym z okresu 1999-2008 analizowano przestrzennie, oraz badano zmiany obszarów posiadających korzystne warunki termiczne (uwzględniając SAT i GDD) do uprawy winorośli. Zmiany przestrzennego zasięgu korzystnych warunków termicznych Polski zostały następnie porównane z wybranymi krajami Europy Środkowej: Czechami, Słowacją i Węgrami. W latach korzystnych termicznie 57% obszaru Polski posiada warunki dobre dla uprawy winorośli (klasyfikacja GDD) oraz wystarczające dla uprawy nawet późnych i bardzo późnych odmian winorośli (wg SAT). Jednakże, w wybitnie niekorzystnych termicznie latach, kiedy dostawa ciepła nie jest wystarczająca dla winorośli, obserwowane są rozległe obszary posiadające wątpliwe warunki do uprawy winorośli (63% powierzchni Polski) lub odpowiednie jedynie dla mrozo- i chorobo odpornych odmian winorośli (odmian rezystentnych)

Celem analiz prezentowanych w kolejnym rozdziale jest ocena wpływu warunków pogodowych na plon ziarna kukurydzy. W analizach wykorzystano dane Głównego Urzędu Statystycznego z lat od 1992 do 2008. Ocenę warunków klimatycznych plonowania kukurydzy wykonano za pomocą agrometeorologicznych statystycznych modeli prognoz plonów z indeksem pogodowym (WI). Do analizy wykorzystano dane meteorologiczne z lat 1921-2008 dla Puław. Wyniki pokazują, że najniższe zmienności plonów występują w południowo-wschodniej części Polski, gdzie warunki klimatyczne są bardziej odpowiednie dla uprawy kukurydzy niż w regionach północnych. Oznacza to, że na północy, brak ciepła jest nadal czynnikiem ograniczającym wzrost produkcji kukurydzy. Analiza pogodowego indeksu wydajności kukurydzy (WI) dla Puław między 1921 i 2009 pokazuje poprawę warunków klimatycznych uprawy kukurydzy. Nastąpił wzrost częstości lat o korzystnych warunkach dla uprawy kukurydzy (WI> 105), wraz z malejącą liczbą lat o niekorzystnych warunkach (WI <95). W tym samym czasie, w latach 2006 i 1994 susze, które wystąpiły w okresie wiosenno-letnim, spowodowały bardzo niską wydajność. Analiza pogodowego indeksu wydajności kukurydzy wskazuje, że w ostatnich latach, jego zmienność w czerwcu i lipcu (WIJJ) zwiększa się, podczas gdy WIMJ i WIJA przyjmują wyższe wartości i są bardziej stabilne niż w latach poprzednich.

W rozdziale szóstym przedstawiono zastosowania niskopułapowej teledetekcji lotniczej do oceny wpływu skutków suszy na stan upraw w różnych regionach Polski. W pracy scharakteryzowano opracowaną autorsko metodykę wykonywania i analizy zdjęć lotniczych. Pozwoliła to na wykonanie map indeksów wegetacji, a przy wykorzystaniu GIS scharakteryzowano kondycję roślin w różnych regionach Polski. Rezultatem badań jest przeprowadzenie oceny wpływu suszy na uprawy w różnych regionach Polski za pomocą metod zdalnych (map indeksów wegetacji). Analizy przeprowadzono w obszarach dotkniętych suszą i poza tymi obszarami, które zostały wyznaczone na podstawie wartości klimatycznego bilansu wodnego (KBW) i warunków glebowych. System monitoringu suszy w Polsce jest prowadzony przez IUNG-PIB w Puławach na zlecenie Ministerstwa Rolnictwa i Rozwoju Obszarów Wiejskich.

Rozdział siódmy poświęcono wpływowi zmian klimatycznych na rolnictwo i możliwym do podjęcia działaniom adaptacyjnym w tym zakresie. Odpowiadając na powyższy problem, 11 zespołów badawczych zawiązało konsorcjum i przygotowało projekt ADAGIO. Celem projektu było zebranie informacji na temat potencjalnych zagrożeń dla rolnictwa, identyfikacja działań adaptacyjnych a także rozpowszechnianie zaproponowanych działań przystosowawczych. Jako główne zagrożenia dla rolnictwa w Polsce w przyszłych warunkach klimatycznych zakwalifikowano:

- wzrost częstotliwości występowania oraz intensywności ekstremalnych zdarzeń klimatycznych;

- natężenie problemów związanych z zaopatrzeniem roślin w wodę (zwiększanie częstotliwości występowania suszy, zwiększenie odpływu, zmniejszenie zasobów wód gruntowych itd.);
- intensywniejszy rozwój rodzimych fito patogenów a także ekspansja nowych ciepłolubnych gatunków.

W związku z powyższymi zagrożeniami, eksperci zaangażowani w realizacje projektu w Polsce zaproponowali różne działania adaptacyjne. Ich zdaniem zmiany klimatyczne będą głównie oddziaływały na zasoby wodne oraz cykl hydrologiczny i dlatego w tej materii należy:

- zwiększać zapasy wód dostępnych dla rolnictwa;
- zwiększać efektywność wykorzystania wody w rolnictwie;
- obniżać zapotrzebowanie roślin na wodę.

W przypadku pojawienie się nowych agrofagów lub intensyfikacji wystepowania rodzimych należy :

- zaadoptować tak technologię uprawy aby ograniczyć występowanie agrofagów;
- wprowadzić efektywne metody zapobieganie pojawianiu się nowych agrofagow.

W przypadku ekstremalnych zdarzeń meteorologicznych najefektywniejszym środkiem zaradczym wydaje się rozwój specjalnych ubezpieczeń dla rolników.

W rozdziale ósmym poruszono problem zastosowania w ubezpieczeniu rolnictwa pochodnych instrumentów pogodowych. Postępujące zmiany klimatu wyraźnie podniosą stopień ryzyka pogodowego. Można się też spodziewać, że przyszłość w naszym kraju będzie oznaczała nie tylko wzrost liczby zjawisk katastrofalnych lecz przede wszystkim znaczną zmienność pogodową. Aktualnie, gdy sytuacja niekorzystnej pogody wystąpi w rozległej skali, to rolnicy najczęściej oczekują pomocy od rządu. Zwykle w polskich warunkach taka pomoc jest udzielana, jednak nie rekompensuje ona wszystkich strat. W przypadku wahań pogodowych z kolei, ubezpieczenia stają się mało skuteczne. Sięgnięcie po nowoczesne instrumenty ekonomiczne pozwoliłoby uniknąć takich sytuacji. Polska, tradycyjna gospodarka rolna z trudem wykorzystuje proste systemy asekuracyjne, czy zatem mogą znaleźć zastosowania rozwiązania bardziej złożone? Wydawać by się mogło, iż zaproponowanie nowoczesnych asekuracyjnych rozwiązań finansowych, wymaga jedynie zaangażowania ludzi sektora bankowego czy parabankowego. Z pewnością ekonomista jest w procesie kształtowania i managementu najważniejszy, lecz ocena stopnia ryzyka pogodowego, ocena skutków zaistnienia zjawisk szkodliwych, to już jednak domena agrometeorologii. Niniejsza praca stanowi, jak dotąd, jedną z nielicznych pozycji literaturowych zajmujących się tym zagadnieniem i stawia sobie za cel objaśnienie podstawowych kwestii, akcentując jednocześnie konieczność podjęcia konkretnych interdyscyplinarnych badań z tego zakresu. W szczególności zaś objaśnione są w nim:

- definicja i opis pochodnego instrumentu pogodowego,
- parametry instrumentów;
- rodzaje indeksów pogodowych mogących mieć zastosowanie w tworzeniu instrumentów,
- modele pogodowe a indeksy pogodowe jako parametry instrumentów,
- porównanie ubezpieczeń z pochodnymi instrumentami pogodowymi
- zasady polityki i strategii korzystania z pochodnych instrumentów pogodowych, a szczególnie wskazanie na niebezpieczeństwa wynikające z ich wykorzystywania przez osoby mające niewielkie przygotowanie biznesowe.

W kolejnym rozdziale na podstawie przebiegu średnich dobowych i minimalnych temperatur powietrza notowanych w latach 1966-2005 w Mikołajkach i Kętrzynie położonych na Pojezierzu Mazurskim wyznaczono okresy wegetacyjne oraz przymrozki wiosenne i jesienne. Jako przymrozki przyjmowano spadek minimalnej temperatury powietrza poniżej $0^{o}C$ w okresie wegetacyjnym. Częstość występowania przymrozków przygruntowych określono na poziomie 5 cm n.p.g w poszczególnych miesiącach okresu wegetacyjnego z podziałem na wiosenne i jesienne. Po ustaleniu średnich dat ostatnich przymrozków wiosennych i pierwszych jesiennych określono długość okresu bezprzymrozkowego dla badanych miejscowości. Z analizy danych wynika, iż długość okresu wegetacyjnego w badanym 40-leciu wynosiła w Kętrzynie 212 dni, a w Mikołajkach 213 dni. Średni początek tego okresu wystąpił 3 IV w Kętrzynie, a w Mikołajkach 2 IV, natomiast koniec 31 X. w Kętrzynie i 30 X w Mikołajkach. Z analizy częstości występowania przymrozków w poszczególnych miesiącach okresu wegetacyjnego 70% stanowiły przymrozki wiosenne, a 30% jesienne. Długość okresu bezprzymrozkowego wynosiła 144 dni w Mikołajkach i 135 dni w Kętrzynie. Najwięcej dni z przymrozkami w okresie wiosny notowano w kwietniu, w okresie jesieni w październiku.

Rozdział dziesiąty dotyczy badań nad określeniem wpływu czynników meteorologicznych na wzrost, rozwój i plonowanie łubinu wąskolistnego odmiany Emir w latach 1987-2002. Materiał badawczy o plonowaniu i warunkach pogodowych pochodził z trzech stacji doświadczalnych oceny odmian, zlokalizowanych w północno-wschodniej Polsce. W analizach zastosowano metodę regresji wielokrotnej z użyciem funkcji liniowej i kwadratowej z krokowym wyborem zmiennych, a utworzone równania oceniono za pomocą współczynnika determinacji R^2, poprawionego R^2 i testu Cross Validation, wyznaczając R^2_{pred}. W latach badań stwierdzono wyraźne zróżnicowanie czynników pogodowych, tj. promieniowania słonecznego, temperatury średniej i opadów atmosferycznych w poszczególnych okresach wzrostu i rozwoju łubinu wąskolistnego, co miało znaczący wpływ na wysokość plonowania, terminy pojawów fenologicznych i długość okresów międzyfazowych. Jedynie w stacji doświadczalnej w Marianowie, wszystkie utworzone równania pozytywnie przeszły procedury weryfikacyjne testem Cross Validation; wśród czynników wywierających istotny wpływ na plon odmiany znalazły się promieniowanie całkowite i opady okresu siew-wschody, przy czym były to zależności kwadratowe, świadczące o umiarkowanej reakcji odmiany na te wskaźniki.

W rozdziale jedenastym zawarto informacje na temat weryfikacji jakości system wspomagania decyzji w rolnictwie. Agrometeorologiczny serwis informacyjny jest cennym narzędziem w rękach rolników, którzy mają dużą wiedzę i doświadczenie do prawidłowego interpretowania informacji zawartych w tym serwisie. informacje Te mogą pomóc określić terminy wykonywania najważniejszych prac (zabiegów) w gospodarstwie, co z kolei może znacznie zoptymalizować działanie rolnika, a w ostateczności zminimalizować straty poniesione w wyniku nieprawidłowego wybrania terminu wykonania zabiegu. Wielkopolski Internetowy Serwis Informacji Agrometeorologicznej jest cennym źródłem informacji agrometeorologicznych dla rolników w regionie. Cieszy się rosnącą popularnością, o czym świadczy liczba odwiedzających stronę. Od kwietnia 2005 r., zostało zarejestrowanych ponad 195.000 odsłon, co daje średnio ponad 3000 miesięcznie. Każdego dnia ponad 100 użytkowni

ków gości na stronie internetowej, co dowodzi wysokiej przydatności tej usługi.

W rozdziale dwunastym potwierdzono, że trendy zmian temperatury powietrza w Polsce północno-wschodniej są zgodne z tendencją światową. Pozwoliło to na zastosowanie nieobserwacyjnych metod prognozowania wystąpienia szkodników za pomocą tzw. stopniodni, które przeanalizowano pod kątem zmian, jakie zaszły w latach 1951-2005. Stopień zmiany wartości stopniodni można określić na około 205 DD na każdy 1.0°C zmiany średniej temperatury powietrza dla progu T_{min}>0°C i blisko 85 *DD* dla progu T_{min}>10°C. Zmiany te mogą mieć istotny wpływ na długość okresu wegetacyjnego, pojawianie się nowych roślin i bezkręgowców (np. szkodników), jak to miało miejsce w innych częściach Polska. Mogą mieć także wpływ na fizjologię i fenologię różnych owadów, co zostało już ogłoszone i przewidziane oraz wiele innych.

Słowa kluczowe: plony buraków cukrowych, opad, nawożenie, zasobność gleby, zawartość cukru, przymrozki wiosenne i jesienne, temperatura minimalna, sumy temperatur efektywnych, uprawy winorośli w Polsce, interpolacja przestrzenna, analiza przestrzenna, sezon wegetacyjny, długość okresu bez przymrozków, plonowanie kukurydzy, indeks pogodowy, susza rolnicza, teledetekcja, GIS, plonowanie łubinu wąskolistnego, wpływ zmian klimatycznych na zagrożenie agrofagami