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IMPACT OF EXTREME CLIMATE CHANGES ON THE PREDICTED CROPS IN POLAND*

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Abstract. The paper presents general characteristics of resources and outputs of agriculture in the Kujawsko-Pomorskie and Lubelskie Regions, based on statistical databases and literature review. Some specific features of the regions, with special consideration for the predicted extreme climate changes, are also included. Next, some statistically significant dependencies between the climatic parameters and yields of selected important crops in the abovementioned regions were worked out on the basis of empirical survey conducted in the University of Technology and Life Sciences, Bydgoszcz, and the Institute of Agrophysics in Lublin. Creating an appropriate method of forecasting long series of ten days without precipitation was necessary to find the desired dependencies. Third, some efforts were taken to make integrated assessments of forecast agricultural outputs influenced by climate extreme phenomena on the basis of the yield-precipitation relations obtained and on the data coming from wide area model regional outputs such as prices of farmland and produce.

Keywords: agricultural economics, agriculture, climate change, crop production, integrating assessments

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INTRODUCTION

Socio-economic scenarios form an important instrument for exploring the long-term consequences of anthropogenic climate change and the available response options. Major challenges include a more consistent use of socio-economic scenarios that would enable the integration of perspective on the impact of mitigation, adaptation and residual climate. A number of authors face the challenge of producing regional and sub-national scenarios over long spans of time (Gaffin *et al.* 2004, Theobald 2005, Britz 2008, Hallegatte *et al.* 2011, Van Vuuren *et al.* 2010). There are local scenarios, in which a global environmental change could be represented. Given these challenges and prospects for relating impact, adaptation and vulnerability, more and more often research seems to depend directly on certain factors within climate change scenarios. One of them is developing a scenario of information that is relevant to the concerns of this research, such as information about extreme weather events or improved information about precipitation changes (Bojar *et al.* 2001, Leśny 2009, Braunmiller and Köchy 2013).

For regional case studies in Poland, two important regions for agricultural production in Poland as a part of Central Europe, were selected, which is justified by the essential contribution of Poland to the European food supply, e.g. Poland is the 5th largest grain producer in Europe (with approximately 10% share) and 20th in the world (FAO). Some crops in those regions are especially important, e.g. grains as a group, wheat, barley, potatoes. Predicted extreme climate deviations will influence yields and outputs of such crops in the future. Some statistically significant dependencies and models were employed to forecast the effects of such climatic changes on the volume and values of outputs of selected crops, which can help shape a more appropriate agricultural and food trade policy in terms of calculation of the necessary food raw materials in store because the risk of an unstable output increases in terms of food supply and an imbalance in demand. To find the desired dependencies, an appropriate method of forecasting long series of ten days without precipitation was worked out. Applying some integrating assessments of analysed phenomena allows one to calculate some important measures for the abovementioned forecasting aims.

Taking into account the formulated goal of this approach, one can submit a hypothesis that the precipitation level and its distribution in the Kujawsko–Pomorskie and Lubelskie Regions, including other specific regional conditions, can influence the yields and outputs of surveyed crops, essentially differing from the average forecasted trends in this scope, defined according to the wide area spatial analysis models assumptions. A positively verified hypothesis can contribute to completing the socio-economic scenarios in a more comprehensive way.

MATERIALS AND METHODS

General characteristics of resources and output of agriculture in Kujawsko-Pomorskie and Lubelskie regions

Kujawsko-Pomorskie is situated in the central part of Poland while Lubelskie is in the south-eastern part (Fig. 1). Kujawsko-Pomorskie and Lubelskie are very important regions in terms of agricultural production in Poland due to essential resources and outputs in relation to other regions (BDL GUS, 2014). Synthetic measures of the value of regions in agriculture are very high as compared to other regions in Poland (Tab. 1).

Fig. 1. Location of surveyed regions in Poland. Explanation: 1. Kujawsko-Pomorskie 2. Lubelskie

For both regions, low possibility of water retention for agricultural production needs is a problem (Tab. 1). Hence, improvement of the infrastructure for more effective small retention of water is a challenge for both regions.

In Lubelskie, farming is more extensive than in the Kujawsko-Pomorskie Region because the market value of the agricultural output is much lower in the Lubelskie Region than in Kujawsko-Pomorskie - in 2011, 2778 PLN/1 Ha and 3906 PLN/1 Ha, respectively. That means that the Lubelskie region has a greater growing potential of farming output, which can be reached through production intensification and land consolidation.

In the Lublin region and, to some extent, in the Kujawsko-Pomorskie, activities (at the CAP or domestic and regional policy level) towards agricultural land consolidation will be also important. Some irrigation investments and/or different methods of their stimulation can be also one of the solutions for adapting regional agriculture to climate change.

Table 1. Comparative analysis of agricultural parameters of Kujawsko-Pomorskie and Lubelskie regions

Item	Feature	Kujawsko-Pomorskie	Lubelskie
		Data	Data
1.	Area (thousand hectares)	1797.1	2512.2
2.	Location	Central part Poland (the valley of Vistula, Brda, Drwęca and Notec)	South-Eastern Poland (region between Vistula and the Bug)
3.	Population (people)	2,096,404.0	2,165,651.0
4.	Landscape	Moraine uplands	Differentiated e.g. uplands, lowlands, valleys
5.	Rainfall (mm)	< 500 annually on average (over 600 and, in some parts, near 400)	About 600 and 750 in some parts of the region
6.	Average temperature (°C)	8.0°C	7.5°C-8.0°C
7.	Growing season length (days)	210-220	208-220
8.	Main industries – products	Agro-food processing products: mills, flour, groats, pasta, sugar, oil, fruit and vegetables. Other major products: spirits, tobacco, buildings, chemicals, machinery, wood and paper and furniture	Agro-food processing products: mills, flour, groats, pasta sugar, cold storage, fruit and vegetables, tobacco, brewery items, herb and beekeeping plants. Meads, Stomach Bitter vodka, herbal teas and syrups, buildings, chemical and mining industry region
9.	Total employees in 2012 (thousands of people)	791.0	947.0
10.	Farmland area (thousand hectares)	1,011.9	1,409.2
11.	Soil quality (percentage of high quality soil / share in total area)	76.60 including 36.70 of specially-protected soil	76.30 including 31.30 of specially-protected soil
12.	Quality indicator of agricultural production space (scores)	71.0	74.1
13.	Production potential of individual farms (scores)	139.0	85.0

Source: Authors' investigation.

Description of Agroclimatic survey

To verify the formulated hypothesis, it was necessary to make an analysis based on the integrated assessments based on the UTP and the Institute of Agrophysics in Lublin surveys and large-scale economic model outputs. Therefore, the agroclimatic surveys made in the analysed regions were described.

Kujawsko-Pomorskie Region

For determining the dependencies between the yields of selected crops and climate change parameters to predict their yields in long-term perspectives (2030, 2050), the UTP agroclimatic data and statistical approach were used.

The most important environmental factor directly affecting the quantity and quality of agricultural production in certain soil conditions is the weather pattern which is characterised by a very high variability in various time scales. In the temperate climate that is transitional between maritime and continental – typical for the central part of Poland, including the Kujawsko-Pomorskie Region – this variability results in large fluctuations in efficiency indicators of agricultural production in different growing seasons (Żarski *et al.* 2013, Kuśmierek-Tomaszewska *et al.* 2013). These variations increase along with a decrease in the capabilities of retention of precipitation by the soil. In the Kujawsko-Pomorskie Region, sandy soils constitute a significant part of the 869,000 hectares of arable land, with a low water capacity and retention of deep groundwater, limiting the ability of water absorption. Therefore, it was assumed that the main weather factor in the region affecting crop yields is the amount and distribution of rainfall in the growing season with duration of an average of 219 days - between March and November (Żarski *et al.* 2009).

The calculation algorithm called the 'statistical-empirical type of weather-yield model' was applied in the study. With the use of statistical tools, the model allowed one to determine the impact of the amount and distribution of rainfall on the quantity of the yield of selected crops. The study included also the use of a model of statistical and empirical dependency regression (linear regression model weather-yield) between the amount of rainfall in different periods (independent variable X) and the level of yield of various crops according to GUS data (dependent variable Y). This provides a basis on which to identify the consequences of potential climate change in regional agricultural production, as well as to assess the ability to respond to these changes (Dragańska 2010, Rozbicki 2013).

This research made use of the results of the standard measurements of rainfall carried out at the Research Station of the University of Technology and Life Sciences in Bydgoszcz, located in the poorly urbanised and industrialised area of the Mochle village (φ = 53°13' N, λ = 17°51'E, h = 98,5 m a.s.l.), approximately 20

km from the city centre. This measuring point, operating continuously since 1949, is therefore free from the influence of anthropogenic factors of an urban area and is representative of the Kujawsko-Pomorskie Region (Bojar *et al.* 2012). Data regarding the acreage and yields of selected crops under production conditions in the Kujawsko-Pomorskie Region were taken from databases of the Central Statistical Office placed on the websites (BDL GUS). The yields data taken into account covered the period of 1999-2011 and pertained to groups of crops which are dominant in the regional structure of sowings: cereals in total, wheat with the predominance of winter wheat, barley with the predominance of spring barley, and potatoes.

Lublin Region

Modelling data were used to define the dependencies between the yields of selected crop (wheat) and climate change parameters to predict their yield in long-term perspectives (2030, 2050).

The survey was conducted based on the data characterised below (Henric 1996). During the years 1992-1995, the Institute of Agrophysics in Lublin (IAL PAS) participated in the ACCESS project – Agroclimatic Change and European Soil Suitability. The goal of the project was to evaluate the impact of climatic change on agricultural production on the European scale, against the hypothesis of global warming due to the greenhouse effect. In the framework of this project, a computer model simulating crop growth and water balance under real or modified climatic conditions was constructed. The calibration of the model was conducted at the experimental site at Grabow, belonging to the Institute of Soil Sciences and Plant Cultivation in Pulawy. The site is representative of large areas of soil (sand, loamy sand and 'light' loam) derived from coarser-textured glacial sediments in Central and Eastern Europe, and farmed under a 'continental' climate (dry warm summers, cold winters with severe frosts, but frequently without prolonged or deep total snow cover). The climate, soil and other data were gathered from that site in the framework of the aforementioned project. The soil water content, temperature and electrical conductivity were measured with the use of a TDR device. The measurements were conducted in 1993 and 1994 during the vegetation period, at seven soil depths (0 – surface, 10, 20, 30, 50, 80 and 130 cm.). In laboratory conditions, the soil bulk density and retention curves of the investigated soils were also determined.

Empirical data on wheat yield and precipitation ($\varphi = 51^{o}31' N$, $\lambda = 22^{o}73' E$, h = 207 m a.s.l.) obtained from the Institute of Agrophysics in Lublin during the years 1982-1993 for the region of Lublin were evaluated with reference to the yield-weather dependence with the use of the methodology described in the previous paragraph.

Description of integrated assessments of yield-precipitation relations and agricultural output methods

In regional case study analysis, data from CAPRI (large-scale) models were used based on the following assumptions.

For the survey data regional resolution, NUTS2 was considered. Kujawsko-Pomorskie belongs to the PL6 Northern Region (NUTS 1), PL61 voivodeship (NUTS 2). Lubelskie belongs to the PL3 Eastern Region (NUTS 1), PL31 voivodeship (NUTS 2).

The SSP2 socio-economic adaptation and mitigation challenges (fossil and recourse intensity) are at a medium level and the present climate within AgMIP S1 is assumed. SSP2 is called "Continuation" and includes a slowly decreasing fossil fuel dependency, reductions to resources and energy intensity, uneven development of low-income countries, few weak global institutions, slow continuation of globalisation with some barriers remaining, well-regulated information flow, medium economic growth, slow convergence, high intra-regional disparities, medium population growth related to medium educational investments and a delay in achievement of MDGs (Köchy and Zimmermann 2013). Land-use change regulation, land productivity growth and the environmental impact of food consumption are at a medium level while international trade is regionalised. The GCM (Global Climate Models) and crop model is at zero.

To characterise the outputs of some important crops within the Kujawsko-Pomorskie and Lubelskie regions, some calculations based on CAPRI databases and the agroclimatic findings from the UTP and the IAL PAS were made.
In a regional case study analysis, the data from the CAPRI model (CAPRI 2012) were used, based on the assumptions of the S1 AgMIP scenario created with SSP2 and RCP – present climate and a specific bioenergy model, and they concerned farmland areas, yields and input prices from 2010, 2030 and 2050 for modelling crops.

The total volume of output of the selected crop of the region expressed in physical units is calculated according to formula 1:

$$TRO = L \cdot Y \tag{1}$$

where: TRO – total regional output of a given crop (number of thousand tonnes)
L – land area of a given crop (number of hectares), Y – yield of a given crop (number of tonnes per 1 hectare) (from the CAPRI database or from the UTP findings)

Next, the values of production of particular crops within the region were calculated to compare the findings based on the CAPRI model and the findings

based at linked CAPRI and the agroclimatic models of the University of Technology and Life Sciences according formula 2 :

$$TOV = L \cdot Y \cdot P \quad (2)$$

where: TOV – total regional value of output of a given crop (thousand euro), L – land area of a given crop (number of hectares), Y – yield of a given crop (number of tonnes per 1 hectare) (from the CAPRI database or from the UTP findings), P – producer prices (euro/t)/

All parameters in these formulas were set up using methods described within the CAPRI database.

RESULTS

The findings on forecasted yields of cereals, wheat, barley, potato for the Kujawsko-Pomorskie Region

This chapter presents the test results obtained with the use of methods described in Material and Methods Section for Kujawsko-Pomorskie. The obtained findings show that extreme lengths of periods without precipitation occur for series of 7 and 8 decades with a high probability in 2030 and 2050, which determines a high risk of occurrence of such extreme natural events.

Remarks on dependencies between yields and precipitation

The fundamental tool used in this study was the Pearson correlation coefficient. The relationship between the selected crop yield and the amount of rainfall was investigated, taking into account the total rainfall in various time steps (a single month or a period of a few months) representing a segment of or the entire growing and development period of the tested plants: April - s1, April and May - s2, from April to June – s3, from April to July – s4, May – s5, May and June – s6, from May to July – s7, from May to August - s8. The paper presents values of correlation coefficients for crop yields (potato, barley, wheat and cereals in total) and the rainfall in the investigated periods s1, s2, s3, s4, s5, s6, s7 and s8 in order to find the strongest relationships between rainfall totals over a specified period of the tested plant development and its yield.

For the sum s1, only the coefficient of correlation with potato crops is significant and negative. The sum s2 does not correlate significantly with any of the crops. In the case of the sum s3, significant and positive coefficients were obtained for barley and wheat in total. The same plants show a significant and positive correlation for the sum s4. The sum s5 does not show any significant correla-

tion with any of the studied crops. Thus, it can be concluded that precipitation from the period of one month does not have a significant impact on the yield.

The sum s6 shows a positive and significant correlation with barley, wheat and cereals in general. It is worth noting that for barley the correlation coefficient is $r = 0.83$ and is at the significance level of $\alpha = 0.00025$. For the sum s7, the same crops are important. For the sum s8, potatoes are statistically significant in addition to the cereals listed above. Precipitation in August has a significant impact on the yield of potatoes. The abovementioned findings can be helpful for economic models in defining parameters describing the forecasted yields (cereals, soft wheat, barley, potatoes).

Application of the dependencies for forecasting undesirable phenomena

The analysis of statistical data on yields shows that low cereal yields are associated with long periods without precipitation. This fact will be the basis for building a simple regression model enabling one to predict the occurrence of adverse events in the cultivation of selected plants. Taking into account that the highest correlation coefficient was obtained in the case of yields of barley and the amount of precipitation - s6, barley crops were chosen for further detailed analysis. Below, the occurrence of a significant dependence of the yield of barley on the length of successive ten days without precipitation is shown. On the basis of data on the yields of barley and length of the series of ten days without rain, a regression line describing the dependence of the yield of barley on the number of ten days without rain was determined. The regression line takes the form of yield = length of series * (– 544) + 34.90. The correlation coefficient $R = 0.595$: the square of the correlation coefficient is called the coefficient of determination and defines the percentage of variation explained by the equation, $R^2 = 0.354$. Testing of the significance of the regression equation was performed using the F test, the calculated value of the F-statistics = 6.58, and the significance level corresponding to this value p – value = 0.025. On this basis, it was concluded that the proposed regression equation is statistically significant.

The distribution of the series of ten days without precipitation is the basis for determining the probability of occurrence of a series of a predetermined length. Based on $n = 14$ data on the length of series in the years 1999 to 2012, it was hypothesised that the tested distribution is consistent with the Poisson distribution. The Poisson distribution parameter λ is estimated on the basis of the statistical sample and is equal to $\lambda = 2.71$. The goodness of fit test of the empirical distribution with the Poisson distribution allowed to calculate the value of statistics $\chi^2 = 1.4$.

The significance level of the test p – value = 0.93 shows that there is no reason to reject the hypothesis of a Poisson distribution. Based on the probability

distribution of a random variable with a Poisson distribution, the risk of the occurrence of a period without precipitation for a period interval of specified length can be estimated. Let X denote the length of the longest series without rain per year, we assume that the random variable X has a Poisson distribution with the parameter $\lambda = 2.71$.

X_n denotes the length of the longest series of ten days without rain in n years. The occurrence of a series without rain of the length of at least k ten days in n years can be marked as $X_n \geq k$. The likelihood of this happening was calculated according to the following formula 3 :

$$P\{ X_n \geq k\} = 1 - P\{ X_n < k\} = 1 - P\{ X < k \}^n \quad (3)$$

For the assessment of occurrence of a long series of ten days without rain until 2030 we assume n = 17, and by 2050 it is n = 27. Table 2 shows the values of probability $P\{X_n \geq k\}$ for the years 2030 and 2050, series length k = 7, 8, 9, 10.

Table 2. Probability of occurrence of a series of ten days without precipitation until 2030 and 2050

Year	Series length	Probability
2030	7	0.302
	8	0.109
	9	0.032
	10	0.009
2050	7	0.543
	8	0.222
	9	0.070
	10	0.019

The calculation results presented in Table 2 show that for the length of series of ten days without rain equal to k = 7, 8 the calculated probability is relatively high. This means that the probability of the occurrence of extreme weather events in the considered time span is high.

The findings on forecasted yields of wheat for the Lubelskie Region

This chapter presents the test results obtained with the use of methods described in the Section about description of the agroclimatic survey for the region of Lublin.

For the figures from the region of Lublin, the correlation coefficients of the values of sums s1, s2, ..., s8 including the size of the wheat crop were tested. All correlation coefficients are not statistically significant.

A lack of significant precipitation-yield dependencies of wheat in Lubelskie can lead to the conclusion that it is difficult to forecast the impact of the precipitation distribution and/or level on wheat yields in 2030 and 2050 in Lubelskie due to the fact that some natural factors such as precipitation, soil, vegetation period and some other factors are different for the analysed regions, points, unlike in the Kujawsko-Pomorskie Region. However, specific conditions of the region in question should not be omitted.

Integrated assessments of outputs of agriculture in Kujawsko-Pomorskie and Lubelskie regions

Regarding the methods described in this article, an evaluation of the forecasted volume and value of the output of cereals, wheat, barley and potatoes in Kujawsko-Pomorskie and Lubelskie in 2010, 2030 and 2050 was made.

Forecasted changes in areas, yields and prices for local conditions were set up on the basis of wide area models and the appropriate data, while the yield changes under local circumstances were verified and presented in the paper methodology.

First, measures according to presented assumptions were calculated. The data presented in Table 3 were applied for calculating regional agricultural outputs with the CAPRI regional models.

Table 3. The regional data set-up on a wide area model

Items	Input prices			Land (1000 ha)			Average Yields (t ha^{-1})		
	2010	2030	2050	2010	2030	2050	2010	2030	2050
Cereals	94.0	157.0	213.6	620.0	486.2	494.3	3.5	7.0	9.4
Soft wheat	104.0	165.7	178.1	182.9	145.9	94.5	4.6	5.4	5.3
Barley	93.0	128.9	166.2	111.4	89.2	91.3	3.4	3.9	4.3
Potatoes	55.5	73.7	100.2	20.9	7.8	10.1	18.7	23.0	24.9

Source: Authors' investigation based on CAPRI data and model.

Next, yields were calculated with the described methodology (Tab. 4). Series of data concerning input prices, land areas and average yields of analysed crop activities (Tab. 3) in Figures 2 and 3 named "CAPRI-Kujawsko-Pomorskie, CAPRI Lublin" were calculated exclusively with the use of regional data from the CAPRI database. For the series of data called "CAPRI-UTP", input prices and land areas of the analysed crop activities were calculated with the use of regional

data from the CAPRI database, while variants of the expected minimum and maximum yields were calculated with the findings calculated using agroclimatic dependencies in the Kujawsko-Pomorskie Region that are presented in Table 4. The findings are shown in Figure 2, highlighting the calculated outputs according to linked integrated assessments based on the CAPRI and Agro climatic UTP findings as follows (Formula 1).

Table 4. Forecasted yields (t ha^{-1}) (range of forecasted values) met with agroclimatic findings

Crops	Minimum value	Maximum value
Cereals	2.51	3.67
Soft wheat	3.10	4.10
Barley	1.63	3.33
Potatoes	15.30	21.00

Source: Authors` investigation

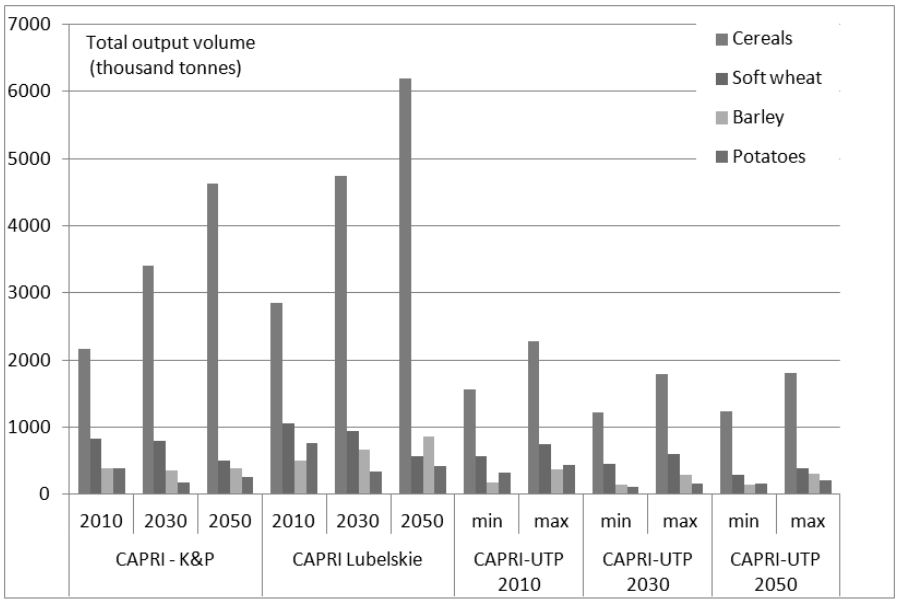

Fig. 2. Comparison between CAPRI-Kujawsko-Pomorskie, CAPRI Lubelskie and CAPRI-UTP model volume outputs (for average yields - converted to tonnes).
Source: own study based on CAPRI and AGROCLIMATIC UTP data and models. Explanation: min, max – limit values of range of forecasted values of yields (Tab. 4)

The facts expressed in Figure 3 allow one to compare the Kujawsko-Pomorskie and Lubelskie forecasted volume outputs where Lubelskie, because of

the greater area of sown land, reaches a higher volume of output of surveyed crops than the Kujawsko-Pomorskie Region. One can also see that the forecasted extreme weather conditions strongly affect total volume outputs in the Kujawsko-Pomorskie Region which are essentially different from the agricultural outputs set up on modelling assumptions (for average yields). Hence, specific detailed analysis shows undesired drops in the frequency of precipitation, irrespective of selected crop activities' agricultural outputs calculated on the assumed average yields in the region in the future, which increases the probability of occurrence in the region, as well as the period of forecasting is longer.

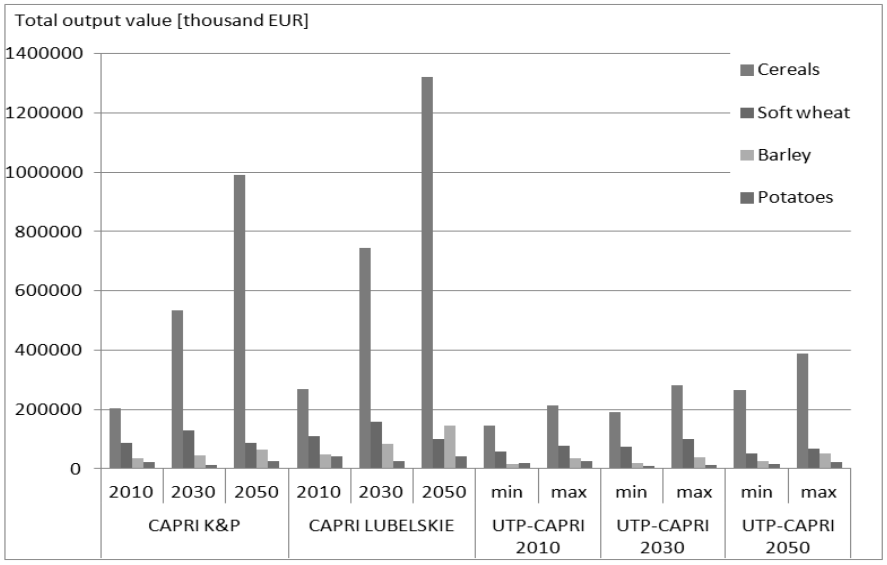

Fig. 3. Comparison between CAPRI Kujawsko-Pomorskie CAPRI LUBELSKIE and CAPRI-UTP model value outputs (for average yields – converted to EURO).
Source: own study based on CAPRI and Agro Climatic UTP data and models. Explanation: min, max – limit values of range of forecasted values of yields (Tab. 4).

According to the research by Kuchar and Iwański (2013), the simulated total rainfall in the growing season in central Poland for the period 2050-2060 will remain at the current level (GISS scenario) or decrease by approximately 30% (HadCM3 and GFDL scenario R14), depending on the scenario of climate change. All of the climate change scenarios indicate an increase in the variance of rainfall, up to 20%. This implies an increased risk of water shortages for plants and the rising need to irrigate crops during periods of atmospheric and soil droughts occurring more frequently than at present.

The probability of occurrence of extreme climatic phenomena (a number of ten days without precipitation) increases as the period of forecasting in modelling is prolonged. Hence, the risk of the decrease in yields and the relevant total value of output of cereals, wheat, barley and potatoes in the region will also increase.

DISCUSSION AND SUMMARY

A comprehensive exploration of the integrated scenarios of mitigation, adaptation and residual climate impacts will require significant contributions from climate modelling, integrated assessment modelling and impact / adaptation / vulnerability research. Nowadays, the problem is too complex to reach such a comprehensive integration within individual crosscutting studies, however, such studies will be of great importance to obtain a better-integrated view on mitigation and adaptation (Kriegler 2012). The analysis of climate change impact, adaptation and vulnerabilities depends, to great extent, on the assumptions concerning the underlying socio-economic developments, but employed socio-economic scenarios to a lesser degree. This is caused by the multitude of contexts and scales of such analysis (Kriegler 2012). Differences in wide area models, such as those presented in the paper modelling approach assumptions, regarding socio-economic scenarios and specific situations of the analysed regions may concern the unemployment level, the tax system structure and its imperfections, the share of informal economy, the barriers to capital flow and trade imbalances, biased saving behaviours, the presence or absence of social safety nets, and can change the assessment of modelled scenarios in the future (Babiker and Eckaus 2007, Guivarch *et al.* 2011). The regional case study approach presented here can develop shared socio-economic pathways as one of the many contributions and collaborative work between integrated assessment and the impact / adaptation / vulnerability researchers (Kriegler *et al.* 2012).

The calculation of the future agricultural output volume and value in Kujawsko-Pomorskie affected by the changes in yields of cereals, wheat, barley and potatoes, expected changes to their yields because of precipitation and its distribution, extreme changes in 2030 and 2050, and large-scale spatial model assumptions described briefly in the Materials and Methods Section, allow one to create some forecasts with a defined probability of occurrence of extreme output changes compared to average ones.

CONCLUSIONS

1. The elaborated method of forecasting long series without precipitation was positively verified. Projections of producer prices from the selected model baseline scenarios (GAMP) were also possible after the comparison of models based on regional empirical data. This allows one to forecast the levels of outputs

of selected crops in agriculture in the surveyed regions in 2030 and 2050, calculated according to differentiated simulated assumptions. It can help with conducting a more appropriate agricultural and trade food policy to ensure food safety in different spatial scales of Europe and balance the food supply and demand in the perspective of the next 40-50 years.

2. The survey conducted in the Lubelskie Region does not confirm essential and statistically verified dependencies between precipitation levels, distribution, and their impact on the yield of wheat. This can be, to some extent, explained with a smaller deficit of water in Lubelskie, as compared to this deficit in Kujawsko-Pomorskie. This allows one to conclude that the impact of specific regional climatic conditions in Poland for the production of some crops, e.g. wheat, cannot be excluded, although in quantitative hold it is not always possible to verify it statistically. Hence, the impact of specific conditions of different regions on the dependency yield–precipitation is different.

3. This allows one to verify the formulated hypothesis positively, meaning that extreme precipitation events can strongly influence the agricultural output of important crops within the analysed regions in a view of average trends forecasted on the basis of large-scale spatial models and data.

4. Further research towards more extended regional studies, including more specific conditions of regions selected in this paper, will be continued and based on the integrated assessments of the economical and crop models studied.

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WPŁYW EKSTREMALNYCH ZMIAN KLIMATU NA PROGNOZOWANĄ PRODUKCJĘ ROLNICZĄ

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S t r e s z c z e n i e . W pracy przedstawiono ogólną charakterystykę zasobów rolnych w województwach kujawsko-pomorskim i lubelskim, oszacowanych na podstawie baz danych statystycznych i przeglądu literatury. Niektóre specyficzne cechy regionów, ze szczególnym uwzględnieniem przewidywanych ekstremalnych zmian klimatu, zostały również uwzględnione. Na tej podstawie oszacowano kilka istotnych statystycznie zależności pomiędzy parametrami klimatycznymi i rentownością wybranych najważniejszych upraw w wyżej wymienionych regionach. Zależności te zostały opracowane na podstawie badań empirycznych przeprowadzonych w Uniwersytecie Technologiczno-Przyrodniczym w Bydgoszczy oraz w Instytucie Agrofizyki PAN w Lublinie. Aby określić żądane zależności konieczne było użycie metody prognozowania długich serii dekad bez opadów. Zostały podjęte prace, aby zintegrowane oceny prognozowania wpływu zmian klimatu na zasoby rolne i rentowność gospodarstw opierały się na zależności plon – opad oraz o dane pochodzące z modeli regionalnych, takich jak ceny obszarów rolnych i plonów.

S ł o w a k l u c z o w e : ekonomia rolnicza, rolnictwo, zmiany klimatu, produkcja roślinna, ocena integracji