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Impact of the projected climate change on soybean water needs in the Kuyavia region in Poland

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Abstract: According to the SRES A1B climate change scenario, by the end of the 21st century temperature in Poland will increase by 2–4°C, no increase in precipitation totals is predicted. This will rise crop irrigation needs and necessity to develop irrigation systems. Due to increase in temperature and needs of sustainable agriculture development some changes in crop growing structure will occur. An increase interest in high protein crops cultivation has been noted last years and further extension of these acreage is foreseen. Identifying the future water needs of these plants is crucial for planning and implementing sustainable agricultural production. In the study, the impact of projected air temperature changes on soybean water needs, one of the most valuable high-protein crops, in 2021–2050 in the Kuyavia region in Poland was analysed. The calculations based on meteorological data collected in 1981–2010 were considered as the reference period. Potential evapotranspiration was adopted as a measure of crop water requirements. The potential evapotranspiration was estimated using the Penman–Monteith method and crop coefficient. Based on these estimations, it was found that in the forecast years the soybean water needs will increase by 5% in the growing period (from 21 April to 10 September), and by 8% in June–August. The highest monthly soybean water needs increase (by 15%) may occur in August. The predicted climate changes and the increase in the arable crops water requirements, may contribute to an increase in the irrigated area in the Kuyavia region and necessity of rational management of water resources.

Keywords: climate change scenario, crop water needs, evapotranspiration, *Glycine max* (L.) Merr., irrigation, precipitation, protein crops

INTRODUCTION

In the light of the climate change scenario considered to be the most probable (A2), it is predicted that at the end of the 21st century the increase in global temperature will amount to about 4°C [ALCAMO *et al.* 2007; IPCC 2007; ŁABĘDZKI *et al.* 2013; RANDALL *et al.* 2007]. In Poland, an increase in temperature can be expected in the range of 2–4°C [ŁABĘDZKI *et al.* 2013]. On the basis of over 80 years of observations carried out in Bydgoszcz, situated in Kuyavian-Pomeranian Province, it has been noticed a significant increasing trend in the mean annual air temperature in this region, raising by 0.19°C per 10 years and consequently by about 2.0°C per 100 years [KASPERSKA-WOŁOWICZ, BOLEWSKI 2015]. In this region also unfavorable distribution of precipitation, with frequent and long-lasting dry periods is recorded. Such periods, lasting even longer than 21 days, are also recorded in wet years [KASPERSKA-WOŁOWICZ *et al.* 2003]. It is important that, most of the scenarios for Poland do not predict an increase in total annual precipitation. However, one can expect an increase in winter precipitation and a decrease in summer precipitation [ALCAMO *et al.* 2007; EEA 2008; IPCC 2007; KUNDZEWICZ 2003; 2007; PARRY 2000; RANDALL *et al.* 2007]. Similar climate change scenarios also apply to the Bydgoszcz region, both in terms of temperature [BĄK, ŁABĘDZKI 2014b] and precipitation [BĄK, ŁABĘDZKI 2014a].

Kuyavian-Pomeranian Province is an important area of agricultural crop production in Poland. Especially, its central and southern part, called Kuyavia (*pl Kujawy*), faces a serious challenge of increasing risk of production caused by aforementioned climatic changes, manifested among others by changes in temperature and precipitation distribution [ŁABĘDZKI 2009a; 2009b]. In Kuyavian-Pomeranian Province, similarly to Greater Poland and Mazovian provinces, there is the greatest natural need for the development of irrigation in Poland. This region, especially Kuyavia, is also characterized by very high irrigation water needs due to climate conditions (large rainfall deficits resulting from negative values of the climatic water balance, that is the difference between precipitation and reference evapotranspiration) [KACA 2017; KACA, REK-KACA 2019; ŁABĘDZKI 2017].

The global warming being observed for years may, due to the high climatic requirements of soybeans [ŚLIWA *et al.* 2015], contribute to increasing both the area and efficiency of soybean production in Poland. Soybean (*Glycine max* (L.) Merr.) is one of the most valuable species among legumes. Soybean, which contains 40–45% protein, 18–24% fat and 26% carbohydrate, is important for both animal and human nutrition [KARACA *et al.* 2018]. Due to the fact that it comes from the continental climate, it is genetically adapted to periodical water deficits. Soybean tolerates drought quite well, what is favored on the one hand by strongly developed pile root system, and on the other hand by hair on the stems, leaves and pods reducing transpiration. However, in the conditions of prolonged drought, soybean reacts very strongly to the lack of water: it grows poorly, has fewer pods and seeds in the pods, has small seeds and matures unevenly. Prematurely dried seeds from the upper parts of the stem do not develop viable embryos. Under such conditions, the germination capacity of soybean can drop even to 40% [BASF 2017; JANECZKO *et al.* 2011]. In the research by ECK *et al.* [1987], water stress throughout the last three weeks of the soybean growing period reduced yields in the two consecutive years of the study by 21% and 65%, respectively. Water stress imposed at the beginning seed formation and extending to the end of the growing period (5 weeks) reduced yields by 45% and 88%, respectively, in two consecutive years of the study.

The area of soybean cultivation in Poland is not large, in the years 2014–2019 ranged between 12000 and 24000 ha and has been increasing [Polska… 2021]. The low cultivation area of soybean is mainly due to the high climatic requirements of this species, i.e. sowing in soil at temperature at least of 12°C and the average air temperature during crop growth not lower than 15°C [FLOREK *et al.* 2012; JERZAK *et al.* 2012]. According to the most recent source, the optimal date for sowing soybean in Poland is from the last decade of April till the first decade of May, when the top layer of the soil reaches temperature of 10°C [COBORU 2021; DORSZEWSKI *et al.* 2019; Polska… 2021]. The reason for the increase in the acreage of soybean cultivation in Poland is primarily the growing number of cultivars adapted to cultivation in the climatic conditions of Poland, as well as compared to other high-protein crops, higher content of nutrients and lower soil requirements [GAWĘDA *et al.* 2014].

Nowadays, the cultivation of soybean in Poland is subsidized due to the fact that it is a high-protein plant. As a result, the profitability of soybean cultivation is higher than that of cereals (including maize) and similar to the profitability of rapeseed. In addition, this plant cultivation is beneficial for soil biodiversity [DORSZEWSKI *et al.* 2019; Polska… 2021].

The costs of establishing a soybean plantation can be balanced by crop yield amount of about 2 $Mg \cdot ha^{-1}$. In Poland the yield of soybean varies from about 1.5 to 2.5 $Mg \cdot ha^{-1}$ but even more than 3 $Mg \cdot ha^{-1}$ have been already achieved. In addition to the profit resulting directly from grain production, the profitability of soybean cultivation is also influenced by additional economic benefits, as nitrogen bound by nodular bacteria, improved soil structure and an increase in yield of succeeding crops. The value of these additional benefits can be estimated at approximately PLN800$\cdot ha^{-1}$ [Polska… 2021].

Summing up, among the economic and environmental/agronomy opportunities of growing soybean in climate conditions of Poland are: growing demand for soybean in food industry, fodder and biofuel; increasing number of soybean purchase points in the country; currently subsidies for high-protein crops; non-genetically modified varieties; crop rotation enriched with soybean makes production more sustainable and diversified; due to symbiosis with nodule bacteria less doses of nitrogen fertilizers are required for soybeans and crops grown after; increasing tendency in air temperature. Among the risks are: lack of agricultural subsidies; reduction in crop yield and production due to unfavorable weather and not maintained irrigation and drainage systems.

In this context, the question arises as to how the expected climate change will affect the water needs in crop production in Poland. This study is an attempt to analyze this impact in relation to soybean cultivation in 2021–2050 based on the climate change scenario for Poland SRES: A1B. The A1 scenarios presents three alternative directions in terms of technological changes in the energy system, which differ in technological emphasis: A1FI – fossil intensive, A1T – non-fossil energy sources, and A1B – a balance between all sources, where "balanced" is not relying too heavily on one particular energy source [IPCC 2007].

The aim of our study was to estimate the water needs of soybeans during the growing season in the period 2021–2050 in the Kuyavia region. The calculations based on the current climate conditions and expected changes in air temperatures. The Kuyavia region is located in central Poland, the zone with the greatest needs for supplementary irrigation during the growing season [Jagosz *et al.* 2021; Kaca, Rek-Kaca 2019; Łabędzki 2017; Markiewicz 2011; Stachowski, Rolbiecki *et al.* 2021].

STUDY MATERIALS AND METHODS

The study is based on the projected in the years 2021–2050 values of average monthly air temperatures for the agricultural area, called Kuyavia, situated in the southern part of Kuyavian-Pomeranian Province, in central Poland (Fig. 1). The predicted values were used according to the climate change scenario for Poland SRES (Special Report on Emissions Scenarios): A1B [Bąk, Łabędzki 2014b; IPCC 2007]. As the reference, thirty years period of 1981–2010 was adopted, using the average monthly air temperatures at Bydgoszcz measured at the agro-meteorological station located in the experimental field of the Institute of Technology and Life Sciences. The station, due to the long history of measurements, can be considered as representative for the Kujavia agro-climatic conditions. The calculations were made for the growing season of soybeans, that is from 21 April to 10 September.

The water needs of soybeans (*Glycine max* (L.) Merr.) were calculated using the crop coefficient method based on the reference evapotranspiration according to Penman–Monteith formula [Łabędzki *et al.* 1996]. In this method, water needs are identified with crop evapotranspiration of a given plant species. The crop evapotranspiration of soybeans was calculated from the Equation (1):

$$ETp = ETo \cdot kc \tag{1}$$

where: ETp = crop potential evapotranspiration (mm); ETo = reference evapotranspiration (mm); kc = crop coefficient calculated as the relation of evapotranspiration measured in conditions of sufficient soil moisture to the reference evapotranspiration [Łabędzki 2006].

The values of the crop coefficient for the individual months of the soybean growing season are presented in Table 1.

Table 1. Crop coefficient for the Penman–Monteith equation for soybean in the Kuyavia region

Month	Decade	Crop coefficient
April	3	0.13
May	1	0.67
	2	
	3	
June	1	1.00
	2	
	3	
July	1	1.10
	2	
	3	
August	1	0.90
	2	
	3	
September	1	0.17

Source: own elaboration on the basis of Allen *et al.* [1998], Doorenbos and Pruitt [1977], Doorenbos and Kassam [1979].

In the reference period (1981–2010) the reference evapotranspiration was determined according to the Penman–Monteith Equation (2) [Allen *et al.* 1998; Doorenbos, Kassam 1979; Doorenbos, Pruitt 1977; Łabędzki *et al.* 2011]:

$$ETo = n\frac{0.408\Delta R_n + \gamma\frac{900}{T+273}u(e_s - e_a)}{\Delta + \gamma(1 + 0.34u)} \tag{2}$$

where: ETo = reference evapotranspiration (mm·d^{-1}); n = number of days; Δ = slope vapour pressure curve (kPa·°C^{-1}); Rn = net solar radiation at the crop surface (MJ·m^{-2}·d^{-1}); γ = psychrometric constant (kPa·°C^{-1}); T = air temperature at 2 m height (°C); u = wind speed at 2 m height (m·s^{-1}); es = saturation vapour pressure (kPa); ea = actual vapour pressure (kPa).

In the years 2021–2050 the reference evapotranspiration was calculated using simple linear regression between the Penman–Monteith reference evapotranspiration and air temperature. These equations were determined using the data of the reference period (2021–2050). The same methodological assumption was previously adopted by Łabędzki *et al.* [2013] estimating reference evapotranspiration according to the Penman–Monteith to determine water needs of late potato crop evapotranspiration in the long term period of 2021–2050 and 2071–2100.

The results were statistically processed by determining the following values: mean, normal (median), maximum and minimum, as well as standard deviation and coefficient of variation. An attempt was also made to specify the possible tendencies of changes in the analyzed indicator of soybean water needs in two compared periods with the use of linear regression analysis and identifying correlation and determination coefficients. The significance of the correlation coefficients, with the sample size n = 30, was determined for p = 0.05. The value of the correlation coefficient, according to the confidence interval, was significant for $r_p \geq 0.362$.

RESULTS

The highest differences in monthly sums of soybean water needs in the reference period (1981–2010), expressed as standard deviation, were calculated in the months from May to August and ranged from 8.0 to 18.7 mm (Tab. 2). The highest monthly standard deviation values, 13.4 and 18.7 mm, occurred in June and July, respectively. The strongest diversification of monthly sums of soybean water needs in the forecast years (2021–2050) also was noted in the period from May to August and varied from 9.9 to 16.8 mm. Also in June and July, the highest monthly standard deviation values, amounting to 16.8 and 14.9 mm, respectively, were predicted. Relative differentiation of soybean water needs during the period from April to September, expressed by the coefficient of variation, amounted to 8.3 and 9.3% for the reference and forecast period, respectively. The highest values of coefficient of variation were found in September (15.0%) in the reference period and May (17.5%) in the forecast one.

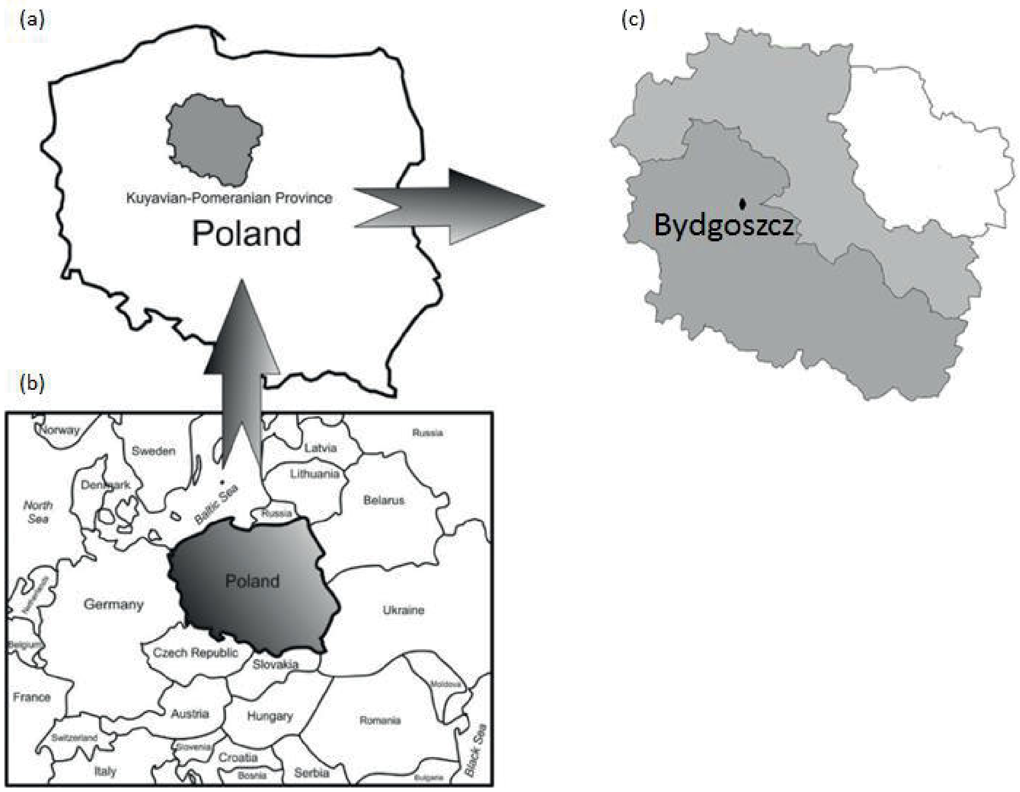

Fig. 1. Location of Kuyavian-Pomeranian Province in Poland (a) and Europe (b), location of the agro-climatic station in Bydgoszcz and the potential irrigation needs in Kuyavian-Pomeranian Province [Łabędzki 2017]: dark grey – high, grey – moderate, white – low (c). The highest needs concern south and south-western part of the province, in which a large part is the Kuyavia region; source: own elaboration and literature

Table 2. Statistical characteristics of soybean water needs during the growing season (from 21 April to 10 September) in the reference (1981–2010) and forecast (2021–2050) years

Characteristic	Months						
	21–30 Apr	1–31 May	1–30 Jun	1–31 Jul	1–31 Aug	1–10 Sept	Apr-Sep
1981–2010							
Mean (mm)	2.8	66.0	106.9	127.4	84.6	2.8	390.5
Minimum (mm)	2.3	46.3	80.4	93.9	66.5	2.1	311.8
Maximum (mm)	3.9	81.6	139.4	167.2	105.3	3.7	465.5
Median (mm)	2.7	67.5	106.0	120.1	83.9	2.7	384.2
Standard deviation (mm)	0.4	8.0	13.4	18.7	9.9	0.4	32.6
Coefficient of variation (%)	13.0	12.5	12.5	14.7	11.7	15.0	8.3
2021–2050							
Mean (mm)	2.6	61.3	109.2	137.9	97.9	3.5	412.4
Minimum (mm)	2.0	43.1	78.2	104.2	74.8	2.8	332.5
Maximum (mm)	3.5	85.6	140.9	164.6	118.3	4.0	483.3
Median (mm)	2.6	60.3	109.1	137.8	97.9	3.4	414.8
Standard deviation (mm)	0.3	10.7	16.8	14.9	9.9	0.3	38.4
Coefficient of variation (%)	12.1	17.5	15.4	10.8	10.1	9.5	9.3

Source: own study.

Table 3 presents the linear trend equations of the temporal variability of soybean water needs, which were determined for its growing periods (from 21 April to 10 September) in two periods 1981–2010 and 2021–2050. The results show that in the forecast period (2021–2050), with the exception of the first decade of September, the monthly water needs of soybean presented an upward tendency.

In each decade (ten years) of the forecast thirty years (2021–2050), the seasonal water needs of soybean (in the period from the 3rd decade of April to the 1st decade of September) increased by 11 mm. Among the analysed months, soybean water needs increased the most in June and August, by 4.0 mm and 4.4 mm, respectively, but the significant trend was found only in August (Fig. 2, Tab. 3).

Table 3. Trend equations of the sums of soybean water needs (mm) during the growing season (from 21 April to 10 September) in the reference (1981–2010) and forecast (2021–2050) years

Period	Trend equation	Coefficient of determination R^2	Tendency of water needs (mm·decade^{-1})
1981–2010			
21–30 April	y = 0.0095x + 2.6231	0.0535	0.1
1–31 May	y = −0.1297x + 68.028	0.0205	−1.3
1–30 June	y = 0.2764x + 102.66	0.0331	2.8
1–31 July	y = −0.0704x + 128.5	0.0011	−0.7
1–31 August	y = −0.1297x + 86.58	0.0133	−1.3
1–10 September	y = 0.0007x + 2.8024	0.0002	0.0
June–August	y = 0.0762x + 317.74	0.0005	0.8
April–September	y = −0.0434x + 391.2	0.0001	−0.4
2021–2050			
21–30 April	y = 0.0081x + 2.4897	0.0505	0.1
1–31 May	y = 0.1836x + 58.459	0.0228	1.8
1–30 June	y = 0.395x + 103.05	0.0429	4.0
1–31 July	y = 0.0797x + 136.7	0.0022	0.8
1–31 August	y = 0.4393x + 91.115*	0.1540	4.4
1–10 September	y = −0.0038x + 3.5238	0.0101	0.0
June–August	y = 0.914x + 330.86	0.0678	9.1
April–September	y = 1.1019x + 395.34	0.0639	11.0

* Significant at p = 0.05.
Source: own study.

The average daily water needs of soybean varied from month to month, the highest amount was found in July (4.4 mm in the forecast period and 4.1 mm in the reference period) (Fig. 3). In June, both in the forecast period and in the reference period, the average daily water needs of soybean was 3.6 mm. In May, daily water needs were estimated by 2.0 mm and 2.1 mm in the forecast and reference periods respectively, and in August by 3.2 mm and 2.7 mm in the forecast and reference periods respectively. Soybean needed the least amount of water (about

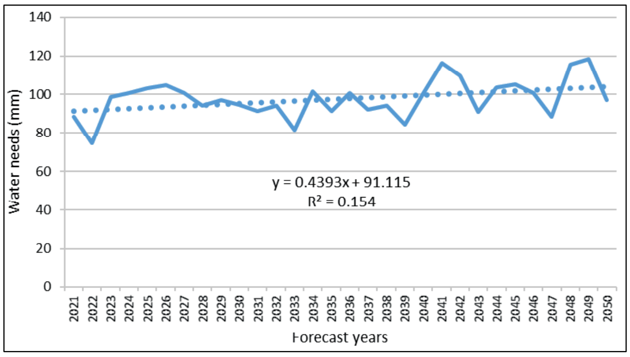

Fig. 2. Predicted amount of soybean water needs in August in the forecast years (2021–2050); source: own study

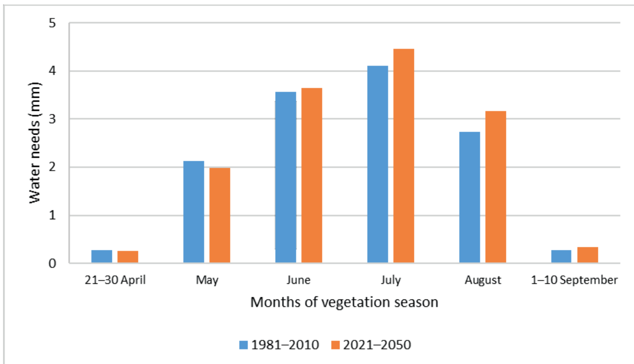

Fig. 3. Average daily water needs of soybean during the growing season in the reference (1981–2010) and forecast (2021–2050) years; source: own study

0.3 mm per day) in the beginning and the end of development stages, i.e. third decade of April and the first decade of September.

The calculations carried out for the thermal conditions forecast in the Kuyavia region in the thirty-year period 2021–2050 show that the water needs for soybean cultivation, expressed by the values of potential evapotranspiration, will increase (Fig. 4, Tab. 4). In the growing season of soybean (from the 3rd decade of April to the 1st decade of September) an increase in water needs by 5% (21 mm) can be expected. In the period June–August, the value of water needs will increase by 26 mm (8%) in view of the expected temperature change. The highest monthly water needs increase for soybean (by 13 mm, i.e. 15%) may occur in August.

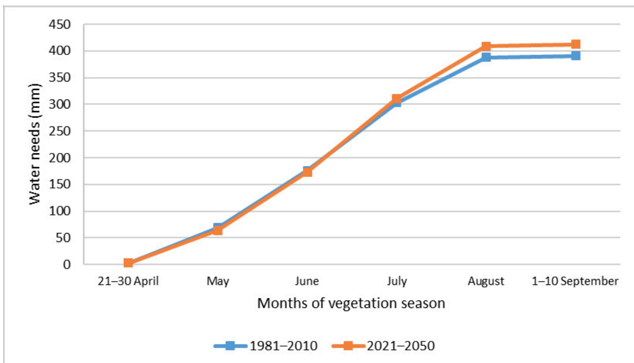

Fig. 4. Cumulative sums of soybean water needs from the third decade of April till the first decade of September in the reference (1981–2010) and forecast (2021–2050) years; source: own study

Table 4. The soybean water needs (mm) during the growing season (from 21 April to 10 September) in the reference (1981–2010) and forecast (2021–2050) years

Years	Period							
	21–20 Apr	1–31 May	1–30Jun	1–31 Jul	1–31 Aug	1–10 Sep	Jun– Aug	Apr– Sep
1981–2010 (A)	3	66	107	127	85	3	319	391
2021–2050 (B)	3	61	109	138	98	3	345	412
Difference (mm) A–B (%)	0	–5	2	11	13	0	26	21
	0	8	2	9	15	0	8	5

Source: own study.

DISCUSSION

Taking into account the importance of soybean cultivation and problem of decreasing water resources due to climate change, the discussion is focused on main topic of the study the soybean water needs.

When deciding to grow a given plant species, it is important to estimate the size of the yield that allows achieving a level of direct surplus competitive with other crops. The profitability of crop cultivation can be measured by the value of the gross margin per 1 ha, that is (in absolute term) calculated as the difference between the production value (revenue) and direct costs. Currently there is large differentiation of the soybean production value in Poland, influenced mainly by agronomy practices/ cultivation technology and weather. The variation in direct costs is small, the dominant share in these there is that of the seed material. The analysis of growing non-genetically modified soybean in Kuyavian-Pomeranian Province in Poland show, to be relatively profitable, the soybean yield should be at least 2.50 $Mg \cdot ha^{-1}$. Currently at this yield the revenues are well above expenses (acc. to authors of current study, the gross margin rate is above 50%). Achieving at least this yield ensures a competitive gross margin with other crops [Dorszewski *et al.* 2019].

The water needs of soybean in the Kuyavia region (central Poland), calculated using the crop coefficient method and expressed as potential evapotranspiration, amounted to 391 mm in the reference period (1981–2010) and 412 mm in the forecast period (2021–2050). For comparison, under the climate conditions of eastern Nebraska (quite similar to these in central Poland but more humid climate), the water needs of soybean (expressed as evapotranspiration) on average in the first five years of cultivation were 452 mm under irrigation and 431 mm without irrigation (rainfed soybean) [Suyker, Verma 2009]. In the study by Specht *et al.* [2001] high temperatures and no rainfall in 1995 led to such severe drought that the 100% of soybean evapotranspiration (equalled 410 mm) had to be supplemented by irrigation treatments. In turn, in the field experiment carried out in the climatic conditions of Vojvodina region (Novi Sad, Serbia) in 1993–2004 evapotranspiration rate in irrigation conditions ranged from 432 to 501 mm, and in rainfed conditions in the interval from 170 to 450 mm [Pejić *et al.* 2011].

This study is a pioneering one dealing with the impact of the projected climate change on the water needs of soybean in the years 2021–2050 in the Kuyavia region. The results obtained in this study, indicating a systematic increase in the water needs of plants, are consistent with many previous reports on the water needs of other plant species [Costa *et al.* 2007; Fraga *et al.* 2018; Kenny, Harrison 1992; Kuchar *et al.* 2015; 2017; Kuchar, Iwański 2011; 2013; Łabędzki *et al.* 2013; Serra *et al.* 2014]. The reports from such Institutions as the European Environment Agency [EFA 2008] or the Intergovernmental Panel on Climate Change [IPCC 2007] also predict an increase in water needs of arable crops in central Europe in the 21st century.

However, it should be clearly emphasized that in the present study, the increase in water needs estimated for soybean grown in the Kuyavia region is the effect only of an increase in air temperature, which results mainly from the adopted methodological assumptions [Bąk, Łabędzki 2014b; Łabędzki *et al.* 2013]. In the current research, the forecast changes in other meteorological elements (solar radiation, air humidity, wind speed), which have undoubtedly big impact on evapotranspiration, were not taken into account. It was also assumed that the nature of the relationship between air temperature and reference evapotranspiration will not change. The relationships derived for individual months of the growing season in the 1981–2010 period were extrapolated and used for calculations of the reference evapotranspiration in the forecast thirty-year period 2021–2050. Similar methodological assumptions were apply in the study by Łabędzki *et al.* [2013], who extrapolated the relationships derived for the 1970–2004 period and then used them to calculate the reference evapotranspiration in two predicted long term periods (2021–2050 and 2071–2100). In the present study, it was also assumed that the crop coefficient would not change. However, it should be clearly emphasized that in the light of the current knowledge, there are no credible premises and no research indicating that these relationships and parameters, under the conditions of future climate change, will be the same [Łabędzki 2006; Łabędzki *et al.* 1996; 2013].

It seems very likely that the predicted climate change and the associated increase in plants water needs, as well as decrease in available water resources in soils, should result in an increase in irrigated area and an rise in irrigation water requirements. Such scenarios are considered in the other European countries, as well in other parts of the World [Abedinpour *et al.* 2014; Dewedar 2021]. For example, net irrigation water needs is expected to increase by 40% in northern Germany, and by as much as 70% in south-eastern England [Döll 2002]. A similar increase can also be expected in Poland [Łabędzki 2009a; 2009b; Łabędzki *et al.* 2013]. Climate change also forces the need to modify the technology of water use and management of water resources in the field (improving the irrigation systems used) towards saving water and increasing the efficiency of water use [Altobelli *et al.* 2021; Barker *et al.* 2019; Bellaloui, Mengistu 2008; Falloon, Betts 2010; Łabędzki 2009a; 2009b; Olesen, Bindi 2002; Schlegel *et al.* 2016].

Due to limited water resources, one of the strategies for optimum utilization of water resources in agriculture is deficit irrigation. This irrigation strategy has been investigated as a valuable and sustainable approach to production in dry areas [ABDELRAOUF *et al.* 2021] and it is appreciated in temperate climate as well. Based on the study of the effects of different irrigation regimes on soybean yield, water use efficiency, harvest index, oil and protein, it was found that any increase in the irrigation water amount resulted in the rise of the dry matter and seed yield of different soybean cultivars. Increasing the amount of irrigation water also had a significant influence on the percentage of protein and oil in seed [SHAMS *et al.* 2014]. In the study carried out by CRABTREE *et al.* [1985] soybean were irrigated using furrow systems. It was found that although the yield of alternate-furrow-irrigated soybean was significantly lower, an acceptable yield was still achieved with the use of 40–50% less irrigation water; i.e. the water savings in the alternate-furrow irrigation and the resulting lower yields are an acceptable compromise. To demonstrate the usefulness of supplemental irrigation as an alternative to full-season and non-irrigation to achieve high yield and seed quality of soybean, in the mid-south USA studies were conducted, which concluded that supplemental irrigation at the reproductive stage may be a possible alternative for full season irrigation of this species [BELLALOUI, MENGISTU 2008]. Also, ECK *et al.* [1987] found that in soybean cultivation in the stressful climate of the Southern High Plains of the USA, limited irrigation is appropriate, however, the susceptibility of plants to drought stress during seed development may cause some limitations in the use of this irrigation method. In this study, soybean has been found to be a plant for which limited irrigation is more suitable than maize, but less than cotton, grain sorghum, or wheat. Also in the study of MARKOVIĆ *et al.* [2016] deficit irrigation of soybean was applied. The experiment was carried out in three different years in terms of meteorological conditions in sub-humid area. Averaged across the years at full irrigated plots, grain yield of soybean was reduced in comparison to deficit irrigated plots. These studies confirm that the management of deficit irrigation is an effective means of protecting water resources and increase soybean yields.

CONCLUSIONS

Based on calculations estimating the impact of climate change on soybean water needs, it was found that in the projected thirty-year season of 2021–2050, the water needs of soybean during its growing period (from the 3rd decade of April to the 1st decade of September) will increase and the expected growth will be 5% (21 mm). In the period from 1 June to 31 August, the water needs of soybean, in view of the expected temperature increase, will rise by 26 mm (8%). The highest monthly increase in soybean water needs, by 13 mm (i.e. 15%), may occur in August.

Growing soybean as a valuable nutrient and rotation crop can be a part of sustainable and profitable crop production in the near future. It will be possible in fields with an efficiently operating and maintained irrigation and drainage system.

The expected climate changes, and consequently the forecast increase in the arable crops water demands, may contribute to an increase in the irrigated area in the Kuyavia region and necessity of rational management of water resource.

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