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Climate change effects on water requirements of *Cucurbita pepo* L. under bare and mulched soil conditions

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ABSTRACT

This study evaluates the impact of projected climate change on the water requirements of summer squash (*Cucurbita pepo* L.) cultivated under bare and mulched soil conditions in the Kuyavia region (central Poland). The study is based on long-term meteorological observations and climate projections, combined with the FAO Penman–Monteith method and crop coefficient (Kc) approach. Water requirements were estimated based on reference evapotranspiration (ETo) calculated using the FAO Penman–Monteith method for the reference period (1981–2010) and the forecast period (2021–2050). Rainfall deficits were determined using the Ostromęcki method. The results indicate an increase in water requirements during the forecast period for both cultivation systems, amounting to 27.4 mm (8.2%) for bare soil and 23.8 mm (8.7%) for mulched soil over the growing season. The highest increase is expected in August (approximately 16%), identifying this month as the most critical for irrigation. Mulching significantly reduced water requirements by approximately 18–19% compared to bare soil. Rainfall deficits are projected to increase substantially, particularly in July, and may reach up to 310 mm during very dry years for bare soil conditions. The findings highlight the growing importance of irrigation in Central Poland under changing climatic conditions and demonstrate the effectiveness of mulching as a water-saving practice. The results may support irrigation planning and the design of water storage systems for sustainable crop production.

Keywords: evapotranspiration, crop coefficient, irrigation requirement, rainfall deficit, soil management, summer squash.

INTRODUCTION

Summer squash (*Cucurbita pepo* L.) originates from Central America and the southern United States, but is currently cultivated worldwide under both temperate and tropical climatic conditions [Narke et al., 2015; Martínez-Valdivieso et al., 2017]. It is an important vegetable crop, valued for its edible fruits, flowers, and leaves, as well as for its nutritional and medicinal properties [Mohammed et al., 2011; Salehi et al., 2019]. The fruits of summer squash are rich in bioactive compounds, including amino acids, carbohydrates, flavonoids, minerals (particularly potassium), phenolic compounds, and vitamins (α-tocopherol, vitamin A, β-carotene, vitamin B2, vitamin C, and vitamin E). These constituents contribute to various health benefits, including protection against oxidative stress, cardiovascular diseases, diabetes, and certain types of cancer. Additionally, summer squash is characterized by low caloric value and high dietary fiber content [Greifenberg et al., 1996; Díaz et al., 2020].

In Poland, summer squash is predominantly cultivated under open-field conditions [Kaniszewski and Treder, 2021]. Its productivity largely depends on precipitation patterns and thermal conditions during the growing season [Kaniszewski, 2006; Maughan et al., 2015]. Despite relatively high water requirements, the crop can partially tolerate short-term water deficits due to its well-developed root system [Kaniszewski and Treder, 2021]. However, vegetable production, both in Poland and globally, is increasingly exposed to climate-related risks. These include uneven precipitation distribution, increased air temperature variability, and a higher frequency of extreme weather events. Earlier climate projections based on the SRES A2 scenario indicated a potential global temperature increase of approximately 4 °C by the end of the 21st century [Alcamo et al., 2007; IPCC, 2007; Randall et al., 2007]. More recent projections (e.g., RCP and SSP scenarios) confirm a consistent warming trend, with expected temperature increases in Poland ranging from approximately 2 to 4 °C, depending on the emission pathway. It is also projected that, except for coastal areas, mean summer air temperatures (July–August) may exceed 25 °C [Łabędzki, 2009a; 2009b]. While all climate models consistently predict rising temperatures, projections of precipitation remain more uncertain. Most models for Poland do not indicate a significant increase in annual precipitation totals, and some even suggest a decline, particularly during the growing season [Łabędzki, 2009a; 2009b; Bąk and Łabędzki, 2014a].

Maintaining optimal soil moisture throughout the growing period is essential for achieving high yields and ensuring good fruit quality. Consequently, irrigation plays a crucial role in summer squash cultivation [Maughan et al., 2015]. Numerous studies have demonstrated that appropriate irrigation management significantly influences plant growth, yield, and water use efficiency [Ahmet et al., 2004; Al-Omran et al., 2005]. Water deficits can result in poor and uneven emergence, reduced yield, malformed fruits, and increased susceptibility to physiological disorders and diseases [Maughan et al., 2015]. Proper irrigation scheduling not only enhances water use efficiency but also improves plant nutritional status [Ibrahim and Selim, 2007; 2010; El-Gindy et al., 2009]. Furthermore, irrigation methods and frequency significantly affect fruit quality and overall productivity [Amer, 2011; Okasha et al., 2020; Santosh and Maitra, 2021]. Various irrigation systems are used in summer squash cultivation, including furrow, sprinkler, and drip irrigation [Maughan et al., 2015; Okasha et al., 2020; Santosh and Maitra, 2021]. Among these, drip irrigation is considered the most efficient, as it delivers water directly to the root zone, minimizes losses, and improves both yield and quality [Al-Omran et al., 2005; El-Gindy et al., 2009; Santosh and Maitra, 2021]. When combined with fertigation, drip irrigation allows for precise application of water and nutrients, leading to increased resource use efficiency and improved crop performance [Maughan et al., 2015; Ibrahim and Selim, 2007; El-Gindy et al., 2009].

Increasing agricultural productivity while conserving natural resources, particularly water, is a key objective of sustainable horticulture [Feng et al., 2023; Ju et al., 2023]. Under ongoing climate change, irrigation is becoming indispensable, especially in regions prone to water scarcity [Hussain et al., 2023; Nhamo et al., 2016]. Therefore, the implementation of water-saving irrigation technologies and efficient irrigation management strategies is essential to ensure sustainable use of increasingly limited water resources [Zhou et al., 2021; Lakhiar et al., 2024].

The aim of this study was threefold: (1) to estimate the water requirements and their temporal trends for summer squash (*Cucurbita pepo* L.) during the reference period (1981–2010) and the forecast period (2021–2050); (2) to assess the variability of water requirements depending on the cultivation method and the month of the vegetation period; and (3) to quantify rainfall deficits for summer squash cultivation.

Given the ongoing intensification of climate warming, supplementary irrigation is expected to become increasingly necessary for summer squash cultivation across Poland, particularly in central regions. Detailed knowledge of crop water requirements and rainfall deficits is essential for effective irrigation planning and management. The results of this study provide new insights into the water needs of summer squash under changing climatic conditions and can support the design and optimization of irrigation systems, contributing to more efficient and sustainable water resource management.

MATERIALS AND METHODS

This study assessed the water requirements, their temporal trends, and rainfall deficits for summer squash (*Cucurbita pepo* L.) cultivated in the Kuyavia region (central Poland). Two cultivation systems were considered: cultivation on bare soil and cultivation on soil mulched with plastic film. Calculations were performed for both a reference period (1981–2010) and a forecast period (2021–2050). The entire vegetation period of summer squash in the study region, from 11 May to 10 September, was analyzed, with particular emphasis on the main irrigation period from 1 June to 31 August.

Meteorological data for the reference period (monthly mean air temperature and total precipitation) were obtained from long-term observations conducted at the Institute of Technology and Life Sciences. The meteorological station located near Bydgoszcz, with more than 30 years of continuous measurements, was considered representative of the climatic conditions of the Kuyavia region, situated in the southern part of the Kuyavian–Pomeranian Province (Figure 1). Kuyavia is one of the key agricultural regions in Poland and is characterized by high irrigation requirements during the growing season [Nyc and Pokładek, 2009]. Previous studies have highlighted the importance of irrigation for crop production under the climatic conditions of central Poland [Rolbiecki et al., 2002a; 2002b]. The region is characterized by a considerable precipitation deficit relative to reference evapotranspiration. The long-term average climatic water balance (April–September), defined as the difference between precipitation and reference evapotranspiration calculated using the Penman–Monteith method, is approximately −200 mm, indicating substantial irrigation needs [Łabędzki et al., 2011; Łabędzki, 2014].

Projected monthly air temperature and precipitation totals for the period 2021–2050 were derived from climate projections based on the SRES A1B emission scenario [IPCC, 2007; Randall et al., 2007; Bąk and Łabędzki, 2014b]. Although newer climate scenarios (RCP/SSP) are currently available, the A1B scenario remains widely used in regional agrometeorological studies, allowing for comparability with earlier research.

The water requirements of summer squash were expressed as crop evapotranspiration under optimal water conditions (*ETp;* mm), calculated using the crop coefficient (*Kc*) approach (Equation 1):

$$ETp = Kc \times ETo, \quad (1)$$

where: *Kc* is the crop coefficient (dimensionless), and *ETo* is the reference evapotranspiration (mm).

Reference evapotranspiration (*ETo*) for the reference period was calculated using the FAO Penman–Monteith method [Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979] (Equation 2):

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

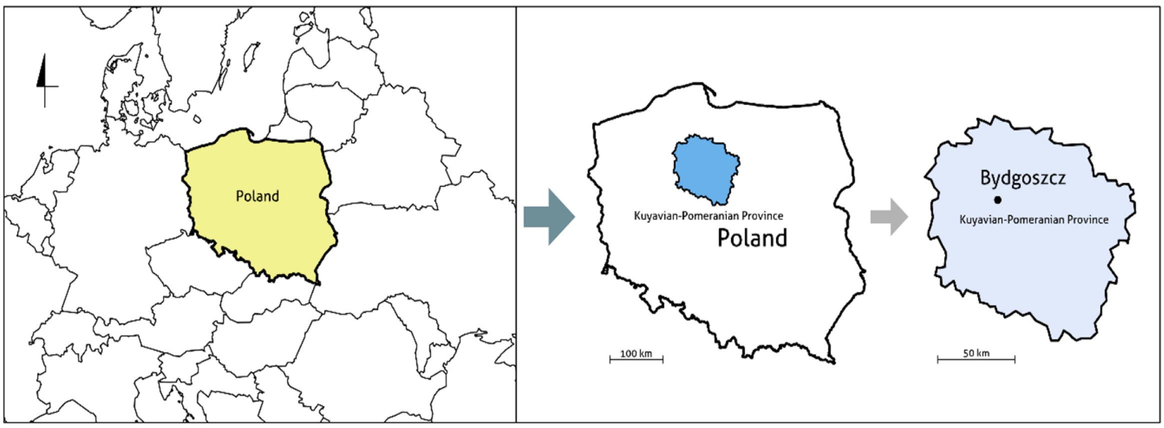

Figure 1. Location of the study area: Poland, Kuyavian–Pomeranian Province, and the meteorological station near Bydgoszcz

where: n is the number of days in the decade, Δ is the slope of the saturation vapor pressure curve (kPa °C^{-1}), R_n is net radiation (MJ m^{-2} d^{-1}), γ is the psychrometric constant (kPa °C^{-1}), T is mean air temperature (°C), u is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), and e_a is actual vapor pressure (kPa).

For the forecast period (2021–2050), ETo was estimated using linear regression relationships between ETo (calculated with the Penman–Monteith method [Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979]) and air temperature, developed based on data from the reference period. A similar methodological approach has been applied in previous studies for estimating crop water requirements under climate change conditions for crops such as late potato [Łabędzki et al., 2013], Miscanthus [Rolbiecki et al., 2021a], and Jerusalem artichoke [Rolbiecki et al., 2023a].

Crop coefficient (*Kc*) values were adapted to the FAO Penman–Monteith method [Żakowicz et al., 2009; Simonne et al., 2010]. Separate Kc values were applied for cultivation on bare soil and for soil mulched with plastic film. The coefficients for bare soil were adopted from Żakowicz et al. [2009], whereas those for mulched soil were based on Simonne et al. [2010]. Monthly Kc values for the vegetation period of summer squash in the Kuyavia region are presented in Figure 2.

Rainfall deficit (*Np%*) for summer squash was calculated using the Ostromęcki method (Equation 3):

$$Np\% = Ap\% \times ETp - Bp\% \times P, \tag{3}$$

where: $Np\%$ is the rainfall deficit with a probability of occurrence p (%) (mm·period^{-1}), $Ap\%$ and $Bp\%$ are empirical coefficients describing the variability of evapotranspiration and precipitation for the given station, ETp is the crop evapotranspiration under optimal water conditions (mm), and P is the long-term average precipitation total for the analyzed period (mm·period^{-1}) [Żakowicz and Hewelke, 2002; Żakowicz et al., 2009].

Statistical analyses of the calculated water requirements included determination of mean, median, minimum, and maximum values, as well as standard deviation (SD) and coefficient of variation (CV). Trends in water requirements for both the reference and forecast periods were evaluated using linear regression analysis, including calculation of correlation (r) and determination (R^2) coefficients. The significance of correlation coefficients ($n = 30$) was assessed at the significance level of $p = 0.05$. The critical value of the correlation coefficient was assumed as $r \geq 0.362$ [Platt, 1978].

RESULTS

The results indicate that the water requirements of summer squash during the forecast period (2021–2050) will be higher than those observed in the reference period (1981–2010), both for cultivation on bare soil and on mulched soil

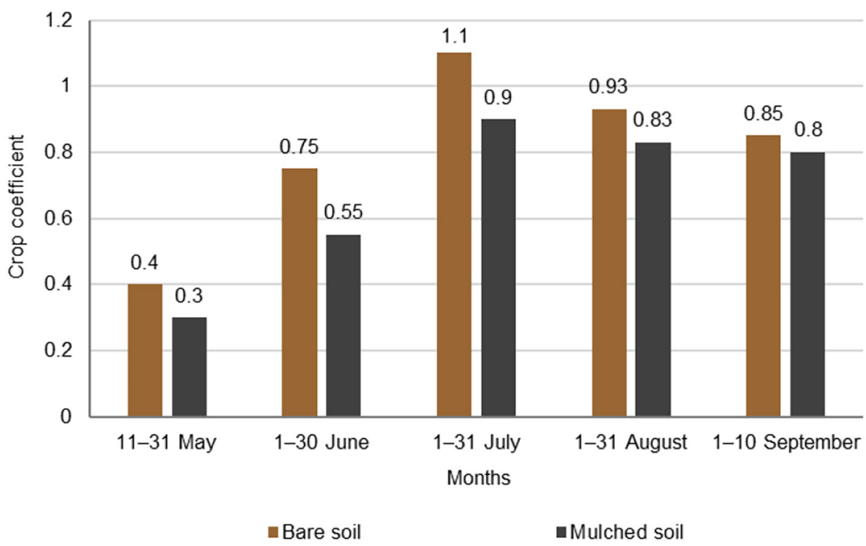

Figure 2. Crop coefficient (Kc) values for summer squash grown on bare and mulched soil during the vegetation period

Table 1. Water requirements (mm) of summer squash cultivated on bare and mulched soil in the reference and forecast periods

Statistical characteristics	Reference period (1981–2010)		Forecast period (2021–2050)	
	Bare soil	Mulched soil	Bare soil	Mulched soil
Vegetation period (11 May–10 September)				
Mean	335.9	274.5	363.3	298.3
Median	333.9	273.3	367.4	300.8
Minimum	271.4	222.3	300.4	248.5
Maximum	404.4	331.3	423.4	348.5
SD	29.8	24.4	31.7	25.7
Irrigation period (1 June–31 August)				
Mean	295.0	241.1	321.0	263.2
Median	291.3	238.3	325.0	265.8
Minimum	236.6	193.6	264.3	216.7
Maximum	362.2	297.1	375.2	308.5
SD	28.8	23.5	28.2	22.9

Note: SD means standard deviation.

(Table 1). The variability of water requirements was assessed using the standard deviation (SD). SD values for summer squash water requirements, both for the entire vegetation period (11 May–10 September) and the irrigation period (1 June–31 August), are higher in the forecast period than in the reference period. Lower SD values were consistently found for mulched soil compared to bare soil in both analyzed periods, indicating reduced variability under mulching conditions.

The results are presented graphically using box-and-whisker plots, which provide a clear and comprehensive visualization of variability and distribution patterns in water requirements. Figures 3a and 3b show the mean values together with ± SD and ± 2SD, thereby illustrating both the typical range of variability and the extent of more extreme observations. In contrast, Figures 3c and 3d present the median, interquartile range (25th–75th percentiles), and minimum and maximum values, offering a robust and complementary description of the data distribution that is less sensitive to outliers and skewed values. The analysis indicates that summer squash cultivated on mulched soil exhibited consistently lower water requirements compared to plants grown on bare soil, both for the entire vegetation period and for the peak water demand period. Under average conditions, this difference exceeded 30 mm, highlighting the effectiveness of mulching in reducing crop water use. In the projection period, an overall increase in water requirements is expected for both cultivation systems; however, the magnitude of change is greater for bare soil. This pattern further confirms that mulching contributes to reduced crop water demand and may play an important role in mitigating the effects of increasing evapotranspiration under changing climatic conditions.

The relative variability of water requirements, expressed as the coefficient of variation (CV), is presented in Figure 4. The CV values were generally higher in the reference period than in the forecast period. Additionally, higher variability was observed during the irrigation period compared to the entire vegetation period. In most cases, slightly lower CV values were recorded for mulched soil compared to bare soil. An exception was observed for the reference period, where CV values for the entire vegetation period were similar for both cultivation methods.

Analysis of daily and monthly water requirements (Figure 5) indicates that, from June to September, both daily and monthly ETp values will be higher in the forecast period than in the reference period. A decrease is expected only at the beginning of the vegetation period (11–31 May). The highest water requirements are projected for July, with mean daily values reaching approximately 4.5 mm, corresponding to a monthly total of about 138 mm. In both analyzed periods, higher water requirements were consistently observed for bare soil compared to mulched soil.

Trend analysis revealed a statistically significant increase in water requirements in August during the forecast period (Table 2), for both

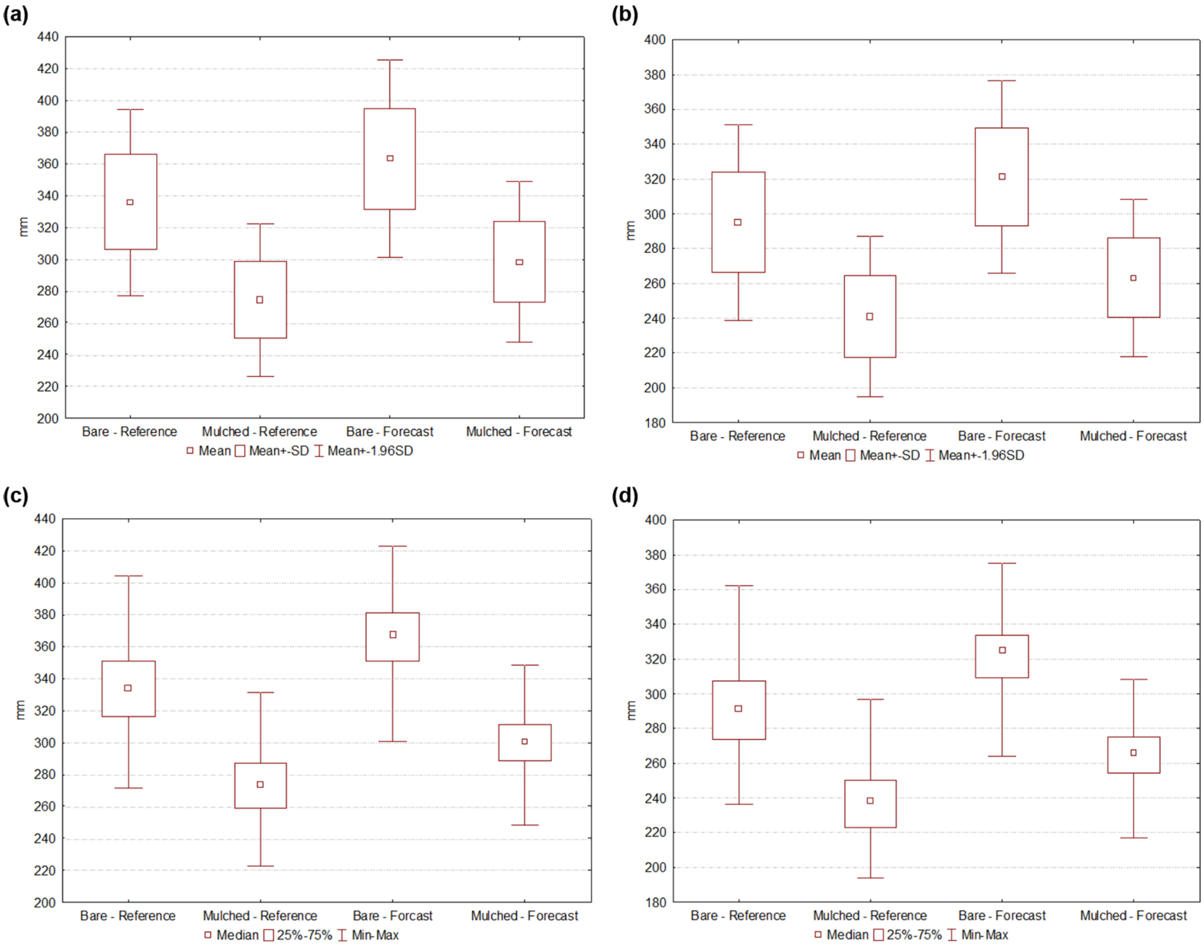

Figure 3. Statistical characteristics of water requirements of summer squash cultivated on bare and mulched soil in the reference (1981–2010) and forecast (2021–2050) periods: mean ± SD, and ± 1.96 SD for the vegetation period (a) and irrigation period (b); median, interquartile range, and extreme values for the vegetation period (c) and the irrigation period (d)

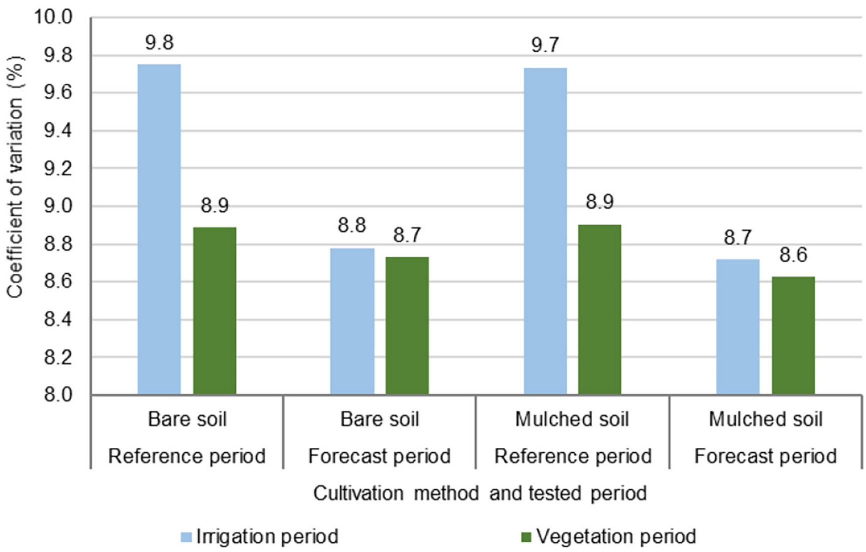

Figure 4. Coefficient of variation (%) of water requirements of summer squash cultivated on bare and mulched soil in the reference and forecast periods

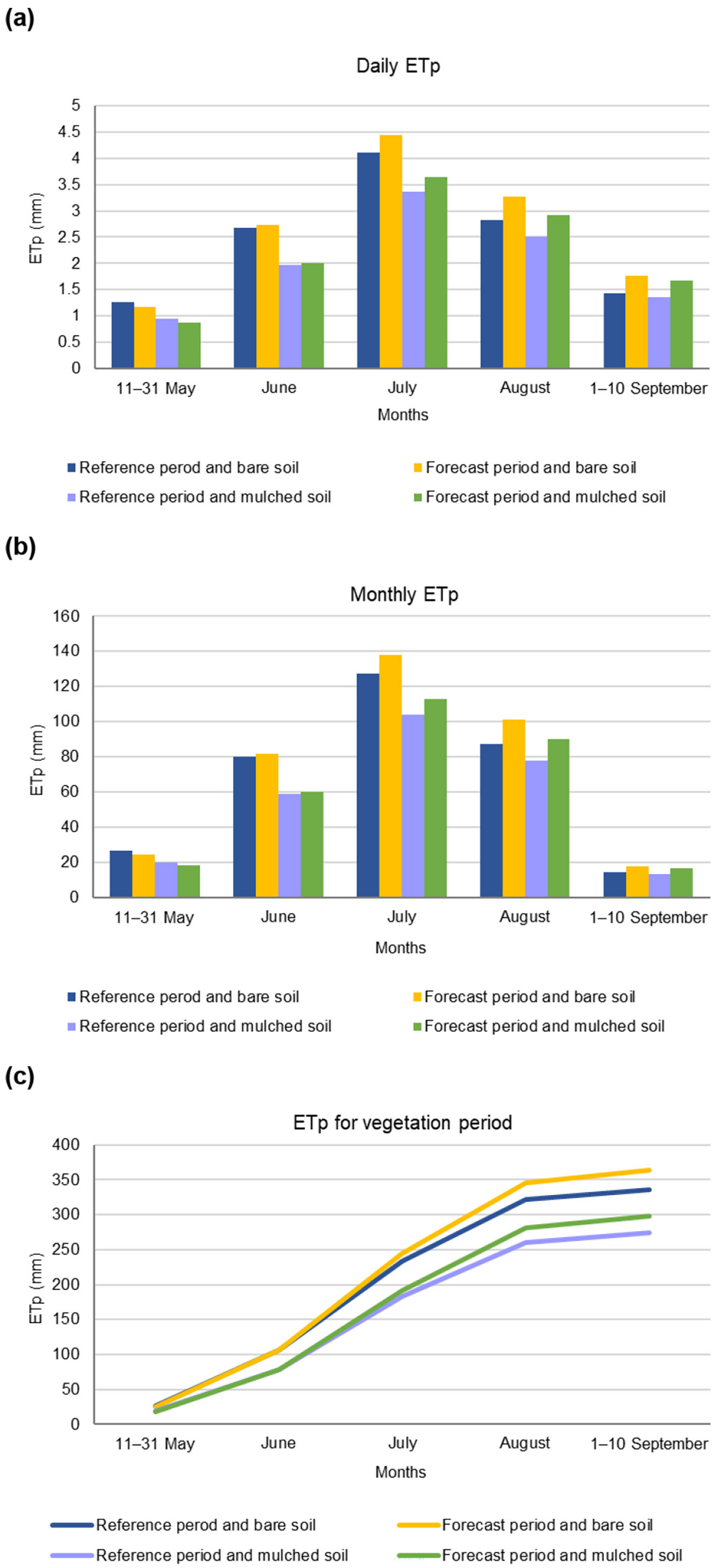

Figure 5. Water requirements (ETp) of summer squash during the vegetation period: daily ETp (a), monthly ETp (b), and cumulative ETp (c) for the reference and forecast periods

cultivation systems. No significant trends were detected for the reference period.

The equations describing significant temporal trends in August water requirements during the forecast period are presented in Table 3. Based on these equations, water requirements are expected to increase by approximately 4.1 mm per decade for bare soil and 4.5 mm per decade for mulched soil.

Rainfall deficits for summer squash cultivated on bare soil in the Kuyavia region are shown in Figure 6. The highest monthly deficits occurred in July. During the reference period, these amounted to 49 mm, 77 mm, and 98 mm in normal, medium-dry, and very dry years, respectively (Figure 6a). In the forecast period, these values are expected to increase substantially, reaching 95 mm, 118 mm, and 136 mm, respectively (Figure 6b). Total rainfall deficits for the entire vegetation period are also projected to increase, from 106 mm, 180 mm, and 237 mm (reference period) to 201 mm, 263 mm, and 310 mm (forecast period) for normal, medium-dry, and very dry years, respectively (Figures 6c and 6d).

Rainfall deficits for mulched soil (Figure 7) were consistently lower than those for bare soil. The highest deficits also occurred in July, amounting to 26 mm, 52 mm, and 70 mm in normal, medium-dry, and very dry years, respectively, during the reference period. These values are projected to increase to 70 mm, 90 mm, and 106 mm in the forecast period (Figures 7a and 7b). Similarly, total seasonal deficits for mulched soil are expected to increase from 52 mm, 117 mm, and 164 mm to 145 mm, 198 mm, and 240 mm, respectively (Figures 7c and 7d).

Table 2. Significance of trends in water requirements of summer squash cultivated on bare and mulched soil in the reference (1981–2010) and forecast (2021–2050) periods

Studied periods	Reference period		Forecast period	
	Bare soil	Mulched soil	Bare soil	Mulched soil
11–31 May	ns	ns	ns	ns
1–30 June	ns	ns	ns	ns
1–31 July	ns	ns	ns	ns
1–31 August	ns	ns	*	*
1–10 September	ns	ns	ns	ns
1 June-31 July	ns	ns	ns	ns
1 July–31 August	ns	ns	ns	ns
1 June–31 August[1]	ns	ns	ns	ns
11 May–10 September[2]	ns	ns	ns	ns

Note: [1]irrigation period; [2]vegetation period; ns means not significant at $p < 0.05$; * means significant at $p < 0.05$.

Table 3. Significant temporal trend equations for the water requirements (mm) of summer squash cultivated on bare and mulched soil in August during the forecast period

Cultivation method	Time trend equation	Determination coefficient (R^2)	Tendency of water requirements (mm per decade^{-1})
Bare soil	y = 0.4051x + 84.028	0.154	4.1
Mulched soil	y = 0.4539x + 94.152	0.154	4.5

Table 4. Comparison of water requirements (mm) of summer squash between the reference (1981–2010) and forecast (2021–2050) periods

Period	Cultivation method	Reference period (A)	Forecast period (B)	Difference B–A	
				mm	%
Vegetation period 11 May–10 September	Bare soil	335.9	363.3	27.4	8.2
	Mulched soil	274.5	298.3	23.8	8.7
Irrigation period 1 June–31 August	Bare soil	295.0	321.0	26.0	8.8
	Mulched soil	241.1	263.2	22.1	9.2
1–30 June	Bare soil	80.2	81.9	1.7	2.1
	Mulched soil	58.8	60.0	1.2	2.0
1–31 July	Bare soil	127.4	137.9	10.5	8.2
	Mulched soil	104.2	112.9	8.7	8.3
1–31 August	Bare soil	87.4	101.2	13.8	15.8
	Mulched soil	78.0	90.3	12.3	15.8

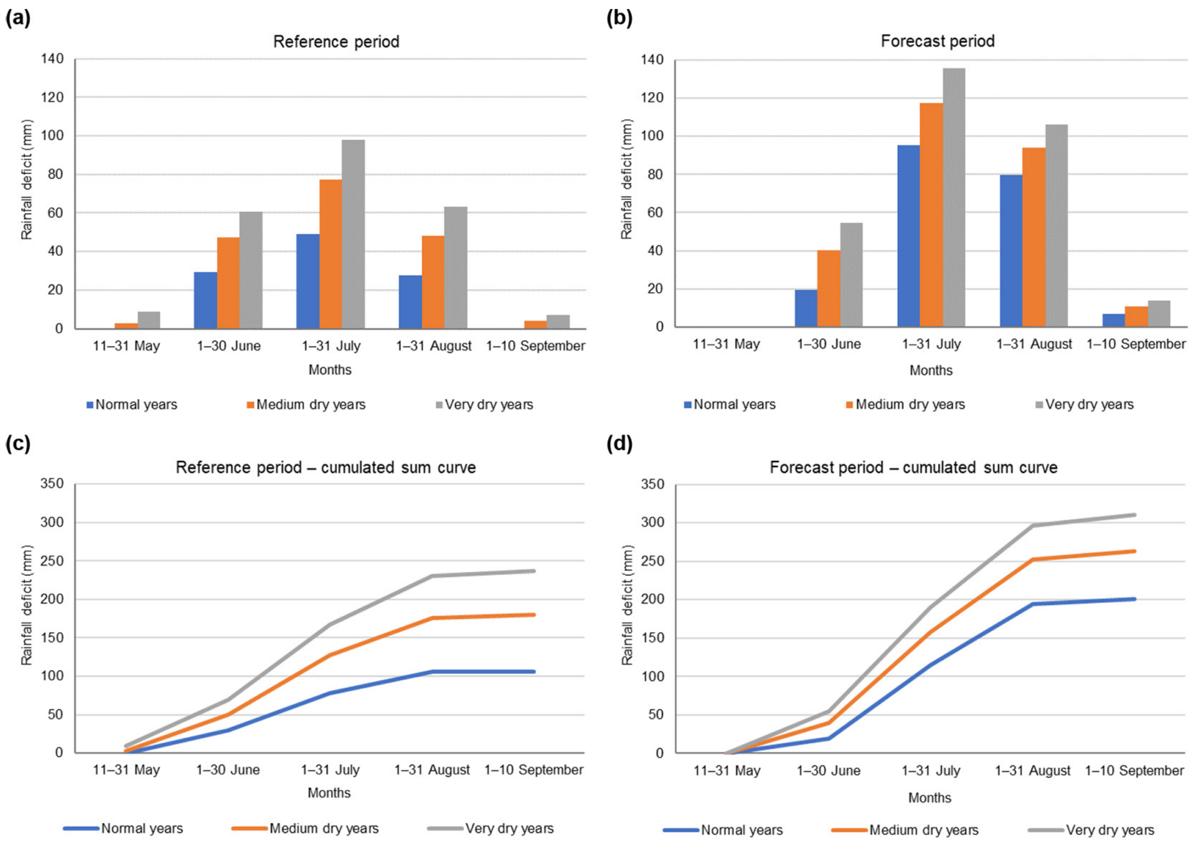

Figure 6. Rainfall deficits (a, b) and cumulative deficit curves (c, d) for summer squash cultivated on bare soil in the reference (a, c) and forecast (b, d) periods

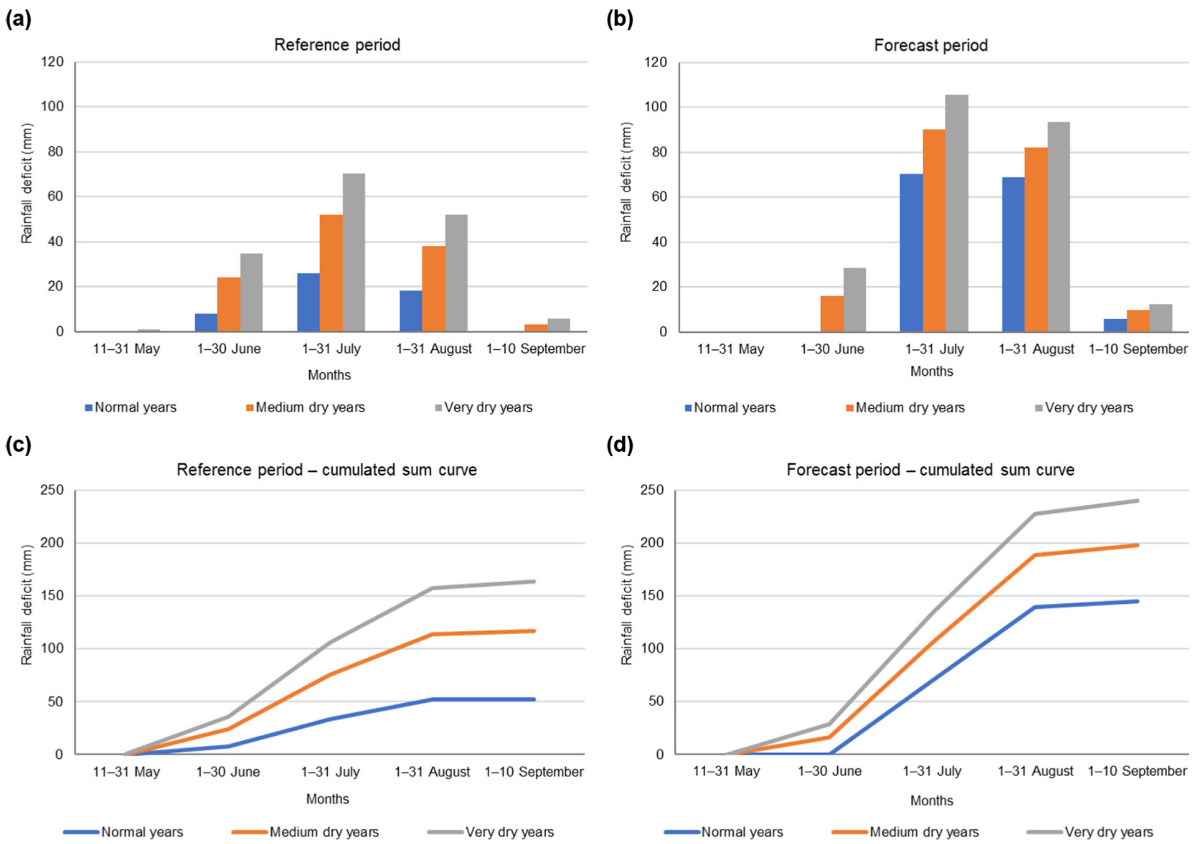

Figure 7. Rainfall deficits (a, b) and cumulative deficit curves (c, d) for summer squash cultivated on mulched soil in the reference (a, c) and forecast (b, d) periods

Overall, the results confirm that water requirements of summer squash, expressed as potential evapotranspiration (ETp), will increase under forecast climate conditions (Table 4). For the entire vegetation period, the increase ranges from 23.8 mm to 27.4 mm, corresponding to an 8–9% rise depending on the cultivation method. The most pronounced increase is expected in August, ranging from 12.3 mm to 13.8 mm (approximately 16%), highlighting this month as the most critical period in terms of future water demand.

DISCUSSION

The water requirements of summer squash during the growing season under Polish climatic conditions are estimated at approximately 400 mm [Kaniszewski, 2006; Kaniszewski and Treder, 2021]. In the present study, lower values were obtained for the Kuyavia region during the reference period, amounting to 336 mm for cultivation on bare soil and 275 mm for mulched soil. These discrepancies may result from differences in climatic conditions between the analyzed period (1981–2010) and those considered in earlier studies, as well as from methodological differences in estimating crop water requirements. In this study, water requirements were calculated using the crop coefficient (Kc) approach based on reference evapotranspiration (ETo), which is widely regarded as a reliable method for estimating crop water needs under optimal soil moisture conditions [Łabędzki et al., 1996]. The Penman–Monteith method, recommended by FAO [Allen et al., 1998], was applied to calculate ETo. In contrast, earlier studies [Kaniszewski, 2006; Kaniszewski and Treder, 2021] do not explicitly specify the methodology used, which may further contribute to the observed differences.

The findings clearly indicate that mulching significantly reduces crop water requirements. In the present study, evapotranspiration of summer squash cultivated on mulched soil was approximately 18–19% lower compared to bare soil. These findings are consistent with previous studies reporting reductions in water use ranging from 10% to 30% under mulched conditions [Simonne et al., 2010; Zotarelli et al., 2008, 2018; Dukes et al., 2012]. The reduction in water demand is primarily associated with decreased soil evaporation and improved soil moisture retention under mulch.

Although summer squash exhibits relatively high water requirements, it demonstrates a certain tolerance to short-term water deficits due to its well-developed root system [Kaniszewski and Treder, 2021]. The root system is extensively branched, with the majority of roots located in the upper soil layers. While the taproot can reach depths of up to 2 m, most lateral roots are concentrated within the top 30 cm of soil, forming a dense network within a radius of 4–6 m. Additionally, adventitious roots emerging from stem nodes contribute to enhanced water uptake [Dzieżyc, 1988]. This root architecture enables efficient utilization of soil water; however, it also makes the crop sensitive to moisture deficits in the upper soil layers.

Maintaining appropriate soil moisture levels throughout the growing season is therefore essential. It has been recommended that soil moisture in the root zone should not fall below 60% of field capacity in May and September, 70% in June and July, and 80% in August [Dzieżyc, 1988]. Under Polish conditions, seasonal irrigation requirements for summer squash cultivated using sprinkler systems typically range from 100 to 150 mm, with individual irrigation doses of 30–40 mm applied two to three times during the growing season [Kaniszewski, 2006]. Other studies suggest that total irrigation requirements may reach approximately 120 mm in dry years and 80 mm in medium dry years [Dzieżyc, 1988].

The present study addresses a gap in knowledge regarding the combined effects of climate change and soil management practices (mulching versus bare soil) on the water requirements of summer squash under Central European conditions. Previous studies have typically examined irrigation or mulching separately, whereas this study provides an integrated assessment under projected climatic conditions.

Ongoing climate change, particularly the projected increase in air temperature, is expected to significantly increase water requirements for a wide range of crops, including vegetables [Rolbiecki et al., 2024; Rolbiecki et al., 2025], fruit crops [Jagosz et al., 2021; Rolbiecki et al., 2023b], and other field crops [Kasperska-Wołowicz et al., 2021; Figas et al., 2024]. The results of this study confirm this trend for summer squash in the Kuyavia region. During the forecast period (2021–2050), water requirements are expected to increase by approximately 27 mm (8%) for bare soil and 24 mm (9%) for mulched soil. These findings highlight the growing importance of irrigation as a key adaptation measure under changing climatic conditions. Central Poland, including the Kuyavia region, is already characterized by the highest precipitation deficits in the country [Kuchar et al., 2015; 2017], making irrigation essential for maintaining stable crop production [Rolbiecki et al., 2021b; 2021c].

The results highlight the importance of integrating mulching and efficient irrigation strategies as climate adaptation measures. The demonstrated reduction in water demand under mulched conditions may significantly decrease irrigation costs and improve water use efficiency, which is particularly important in regions with limited water resources.

The estimation of rainfall deficits is crucial for determining irrigation requirements and for designing water storage systems [Żakowicz et al., 2009]. The methodology applied assumes that rainfall deficits in normal, medium-dry, and very dry years correspond to 50%, 75%, and 90% of crop water requirements, respectively [Żakowicz and Hewelke, 2002; Żakowicz et al., 2009]. Based on the results obtained in this study, the required net storage capacity of an irrigation reservoir was calculated for a 40 ha summer squash plantation. The calculations were performed using the relationship: rainfall deficit × cultivated area × 10 m^3, assuming that 1 mm of water corresponds to 10 m^3 per hectare. The results (Table 5) indicate that the required reservoir capacity varies depending on the cultivation system and hydrological conditions. For bare soil, the required capacity ranges from 80,400 m^3 in normal years to 124,000 m^3 in very dry years, whereas for mulched soil it ranges from 58,000 m^3 to 96,000 m^3. These findings demonstrate that mulching not only reduces water requirements but also significantly lowers the required capacity of irrigation infrastructure, which may contribute to improved water resource management and reduced investment costs.

Table 5. Net irrigation water storage capacity for a 40 ha summer squash plantation cultivated on bare and mulched soil

Years	Net capacity of the reservoir for irrigation water (m^3)	
	Bare soil	Mulched soil
Normal years	80 400	58 000
Medium-dry years	105 200	79 200
Very dry years	124 000	96 000

In summary, the results of this study demonstrate that climate change is likely to increase the water requirements of summer squash in Central Poland, particularly during peak demand periods. At the same time, the application of mulching significantly reduces crop water use and mitigates the effects of increasing evapotranspiration. These findings highlight the importance of combining efficient irrigation strategies with soil management practices to ensure sustainable water use and maintain stable crop production under future climatic conditions.

CONCLUSIONS

Climate change is expected to increase the water requirements of summer squash in Central Poland, with projected increases of approximately 8–9% during the growing season. The most pronounced rise in water demand is anticipated in August, where increases of up to 16% highlight this month as the most critical period for irrigation management. At the same time, the application of mulching significantly reduces crop water requirements by approximately 18–19% compared to bare soil, confirming its effectiveness as a water-saving practice. In addition to increasing crop water demand, climate change is also projected to intensify rainfall deficits, particularly in July and during dry years, further emphasizing the necessity of supplementary irrigation. The results demonstrate that mulching not only reduces water consumption but also decreases the required capacity of irrigation reservoirs, contributing to more efficient water resource management and lower infrastructure requirements. Overall, the findings underline the importance of integrating efficient irrigation strategies with soil management practices as key adaptation measures to ensure sustainable horticultural production under future climatic conditions.

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