WATER REQUIREMENTS OF SELECTED ENERGY PLANT (*HELIANTHUS TUBEROSUS* L.) IN CENTRAL POLAND

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Abstract: The basic task of a modern sustainable agricultural economy is the rational management of natural resources. This study aims to estimate the water requirements of Jerusalem artichoke in Central Poland in the vegetation period of 20 years. This plant is used as an important energy plant and has a significant potential for biomass production. The water requirements were identified with the potential evapotranspiration and considered using the method of plant coefficients based on reference evapotranspiration. The calculations concerned the vegetation period of Jerusalem artichoke, which, according to the assumptions, begins on 21 May and ends on 31 October. The method of crop coefficients is based on reference evapotranspiration (ETo). The result showed that the average water requirements of Jerusalem artichoke during the growing season ranged from 304 to 317 mm, with the highest monthly water requirements occurring in June and July. A significant upward trend in the water requirements was observed throughout Central Poland, increasing by 4.6 to 8.7 mm in each subsequent decade. The greatest rainfall deficit occurred in the period from June to August and amounted to 41, 106, and 150 mm in normal, medium dry, and very dry years, respectively. The results will allow for precise and economical management of natural water resources during supplementary irrigation of Jerusalem artichoke and will contribute to increasing the cultivation area of this species in Central Poland. In addition, an important aspect of this type of cultivation is the growing demand for green energy, as well as economic aspects.

Keywords: crop productivity, Jerusalem artichoke, natural resources, sustainability, water needs.

Introduction

Jerusalem artichoke (*Helianthus tuberosus* L.) is a versatile plant with medicinal, edible, fodder, ornamental, and industrial applications. It is widely cultivated as an energy crop due to its high biomass production potential, efficient photosynthesis, and rapid dry matter accumulation. Its biomass is utilized for bioethanol production, direct combustion, and conversion into briquettes, pellets, or biogas [1; 2]. The plant's increasing popularity is largely attributed to its low habitat requirements [1]. It thrives in a wide range of soil and climatic conditions, demonstrating resistance to frost and drought [2]. However, optimal growth occurs in warm, humid environments with nutrient-rich, well-aerated soils, whereas clayey, waterlogged, or acidic soils negatively affect yields [3].

Jerusalem artichoke is cultivated worldwide and demonstrates tolerance to various abiotic stresses, including drought, which has become an increasing concern due to climate warming [4]. Despite its drought tolerance, water stress can significantly reduce this species' growth, physiological parameters, and yield [5-7]. Studies have shown that irrigation enhances underground biomass and tuber yield compared to non-irrigated conditions [8-12]. Irrigation needs of Jerusalem artichoke vary depending on the climate. In the Mediterranean, drip irrigation is applied from June to September [13], while in Spain, irrigation is used once or twice per week in June and September, increasing to three times per week during July and August [14]. Besides irrigation, selecting cultivars suited to local conditions is also an effective strategy for cultivating Jerusalem artichoke, particularly in sandy and dry soils [15].

In Central Poland, with sandy soils and low rainfall [16], Jerusalem artichoke offers potential benefits such as preventing land degradation, stimulating economic growth, and enhancing renewable energy production [2]. However, its irrigation needs remain insufficiently studied. Previous estimates were based on potato water demand [11], while Żyromski et al. [3] established crop coefficients for Jerusalem artichoke using lysimetric methods in western Poland. These coefficients facilitate the estimation of Jerusalem artichoke's evapotranspiration in other Polish regions.

This study aimed to determine the water requirements of Jerusalem artichoke in Central Poland from 1981 to 2020, assess rainfall deficits, and identify trends in water requirements. The findings will contribute to more efficient water resource management for irrigation and may encourage the expansion of Jerusalem artichoke cultivation in a region with particularly high irrigation needs [17].

DOI: 10.22616/ERDev.2025.24.TF130

Materials and methods

The water requirements of Jerusalem artichoke (*Helianthus tuberosus* L.) from 1981 to 2020 were determined for the growing season (May 21-October 31) using the FAO-56 crop coefficients method [18]. This approach is based on reference evapotranspiration (ETo) [19], with water needs estimated through potential evapotranspiration (ETp). The Kc values were derived as the ratio of field water consumption by Jerusalem artichoke to ETo, using the Blaney-Criddle equation modified by Żakowicz [20]. Field water consumption (ETp of Jerusalem artichoke) was calculated for 1971-2010 based on ETo from the FAO-56 Penman-Monteith method [18] and Kc values obtained in a three-year lysimetric study by Żyromski et al. [3]. The monthly Kc values were: 0.44 (May 21-31), 0.72 (June), 0.66 (July), 0.57 (August), 0.50 (September), and 0.49 (October) [3; 18]. ETp was calculated using equation 1 [17]:

$$ETp = Kc \times ETo, \tag{1}$$

where Kc – crop coefficient [3; 18; 20];
ETo – reference evapotranspiration (mm).

ETo was calculated using the Blaney-Criddle reference evapotranspiration modified by Żakowicz [20] according to equation 2:

$$ETo = n \times [p \times (0.437 \times t + 7.6) - 1.5], \tag{2}$$

where n – number of days in a month;
p – evaporation coefficient for each month and latitude [21];
t – average monthly air temperature (°C).

The rainfall deficit (Np%), with a probability of occurrence equal to p% (mm per period), was determined for normal ($N_{50\%}$), medium-dry ($N_{25\%}$), and very dry ($N_{10\%}$) years using the Ostromęcki method according to equation 3 [22]:

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

where $Ap\%$ and $Bp\%$ – numerical coefficients characterizing the variability of evapotranspiration and rainfall for a given weather station;
ETp – multi-year average evapotranspiration for the analysed period (mm per period);
P – multi-year average rainfall for the analysed period (mm per period).

Meteorological data (temperature and rainfall) for the period 1981-2020 were obtained from four weather stations: Bydgoszcz (53°08'N, 18°01'E), Warszawa (52°09'N, 20°59'E), Poznan (52°25'N, 16°50'E), Lodz (51°44'N, 19°24'E) representing Kuyavian-Pomeranian (K-P), Masovian (M), Greater Poland (GP), and Lodz (L) Provinces, respectively.

Statistical analyses included mean, standard deviation, and the coefficient of variation. Trends in water requirements were examined using linear regression, with correlation significance tested at $p = 0.1$, 0.05, and 0.01 (sample size: $n = 40$).

Results

The highest variability coefficient for the entire growing season (4.6%) was observed in GP, while October exhibited the greatest variability (over 12.6%) across all provinces (Tab. 1). The highest monthly variability coefficient (14.2%) occurred in K-P, whereas the lowest values (5.1-6.8%) were recorded in June-August. The highest potential evapotranspiration was observed in M (317 mm), while the lowest was recorded in L (304 mm). The highest monthly water requirements were noted in K-P and M, peaking at 91 mm in June and 89 mm in July.

Table 1

Statistical characteristics of Jerusalem artichoke water requirements in Central Poland; K-P–Kuyavian-Pomeranian, M–Masovian, GP–Greater Poland, and L–Lodz Provinces

Statistical Characteristics	Province	May 21-31	June	July	Aug.	Sept.	Oct.	May-Oct.
Mean, mm	K-P	15	91	89	66	35	19	316
Standard deviation, mm		1.13	5.47	5.33	3.55	2.62	2.62	11.11
Variability coefficient, %		7.4	6.0	6.0	5.4	7.4	14.2	3.5

Table 1 (continued)

Statistical Characteristics	Province	May 21-31	June	July	Aug.	Sept.	Oct.	May-Oct.
Mean, mm	GP	15	89	87	65	36	20	311
Standard deviation, mm		1.11	6.00	5.76	3.92	3.69	2.59	14.18
Variability coefficient, %		7.4	6.8	6.7	6.0	10.3	13.1	4.6
Mean, mm	M	15	91	89	67	36	20	317
Standard deviation, mm		1.00	5.38	4.94	3.42	2.60	2.48	11.39
Variability coefficient, %		6.5	5.9	5.6	5.1	7.3	12.6	3.6
Mean, mm	L	15	87	85	64	34	19	304
Standard deviation, mm		1.02	5.35	5.37	3.44	2.70	2.56	11.02
Variability coefficient, %		7.0	6.2	6.3	5.3	7.8	13.5	3.6

Linear regression analysis indicated a significant upward trend in water requirements during the growing season (Tab. 2, Fig. 1). The strongest correlation was observed in June and August across all provinces. No significant trends were found in May and October, nor in July (K-P) and September (K-P and L). Water requirements increased by 4.6-8.7 mm per decade, with the most pronounced rise occurring in June (3.1 mm per decade in GP, 2.0 mm per decade in K-P).

Table 2

Correlation coefficient and trend of Jerusalem Artichoke water requirements in 1981–2020

Months of gowing season	Provinces of Central Poland							
	Kuyavian–Pomeranian		Masovian		Greater Poland		Lodz	
	LCC	TWN	LCC	TWN	LCC	TWN	LCC	TWN
May 21-31	ns	0.0	ns	0.0	ns	0.1	ns	0.0
June	0.434***	2.0	0.509***	2.4	0.597***	3.1	0.563***	2.6
July	ns	0.8	0.357**	1.5	0.389**	1.9	0.335**	1.6
August	0.313**	1.0	0.496***	1.5	0.544***	1.8	0.408***	1.2
September	ns	0.6	0.345**	0.8	0.403***	1.3	ns	0.6
October	ns	0.2	ns	0.3	ns	0.4	ns	0.1
May-October	0.479***	4.6	0.653***	6.4	0.706***	8.7	0.636***	6.1

LCC–linear correlation coefficient; TWN–tendency of water requirements (mm per decade);
ns–not significant, **–significant at $p = 0.05$, ***–significant at $p = 0.01$

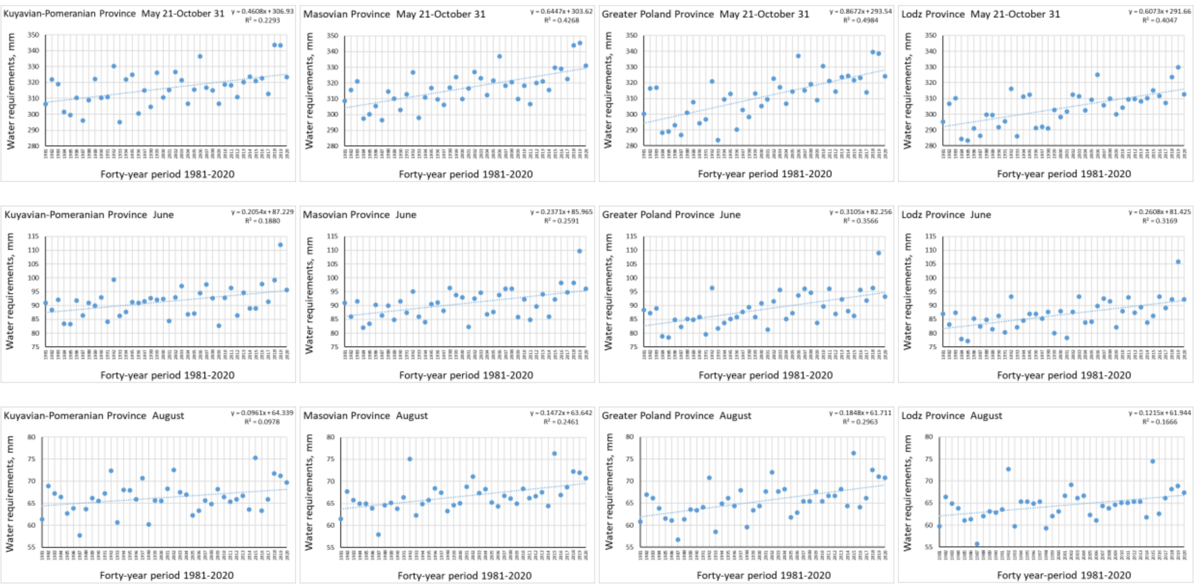

Fig. 1. **Time trend of Jerusalem artichoke water requirements;** dashed line shows the trend

In normal years, no rainfall deficit was recorded in April, September, or October (Tab. 3). In medium-dry years, no deficit was observed in October, and in GP and L, also in September. In dry years, rainfall deficits were minimal, with only M experiencing a minor 1.1 mm deficit in October.

Table 3

Rainfall deficit (mm) in cultivation of Jerusalem artichoke in Central Poland

Provinces of Central Poland	Years	Months of growing season					
		May 21-31	June	July	Aug.	Sept.	Oct.
Kuyavian-Pomeranian	Normal	–	34.4	11.0	9.2	–	–
Masovian		–	30.2	5.2	9.6	–	–
Greater Poland		–	19.2	8.4	2.5	–	–
Lodz		–	23.6	5.1	6.8	–	–
Mean		–	26.8	7.4	7.0	–	–
Kuyavian-Pomeranian	Dry	3.6	54.9	35.5	27.3	3.9	–
Masovian		3.4	50.7	30.2	27.4	7.1	–
Greater Poland		0.8	42.6	33.3	22.0	–	–
Lodz		0.8	44.9	29.6	24.8	–	–
Mean		2.2	48.3	32.1	25.3	–	–
Kuyavian-Pomeranian	Very dry	6.8	69.8	52.3	39.6	11.8	–
Masovian		6.6	65.4	47.0	39.5	14.8	1.1
Greater Poland		4.3	58.8	50.2	35.1	6.0	–
Lodz		4.2	59.9	46.0	37.0	5.8	–
Mean		5.5	63.5	48.9	37.8	9.6	–

During the growing season, the highest rainfall deficits were observed in K-P (55, 125, and 180 mm in normal, medium-dry, and very dry years, respectively), while the lowest was recorded in L (36, 100, and 153 mm) and M (30, 99, and 154 mm) (Fig. 2a). The greatest rainfall deficits occurred from June to August, peaking in K-P (55, 118, and 162 mm) and remaining lowest in L (36, 99, and 143 mm) and M (30, 98, and 144 mm) (Fig. 2b). On average, rainfall deficits throughout the growing season were 41 mm in normal years, 108 mm in medium-dry years, and 165 mm in very dry years (Fig. 2c). During peak water demand (June-August), rainfall deficits reached 41 mm, 106 mm, and 150 mm, respectively.

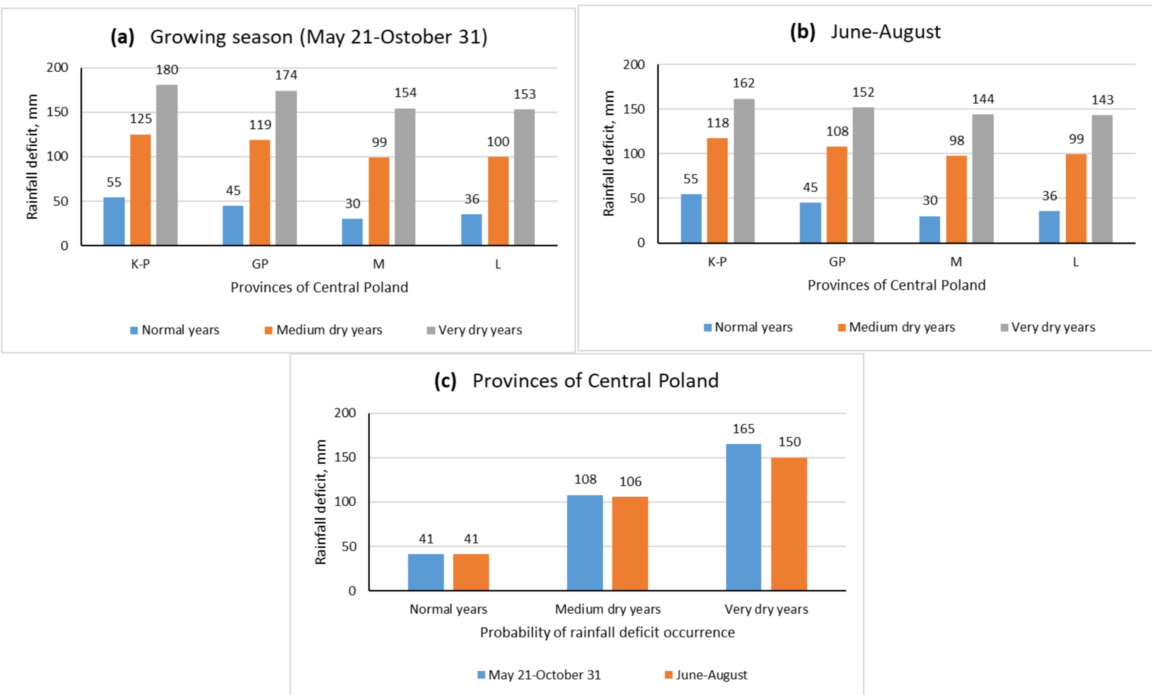

Fig. 2. **Rainfall deficit in Jerusalem artichoke cultivation:** (a) growing season, (b) June-August, (c) Central Poland, K-P – Kuyavian-Pomeranian, M – Masovian, GP – Greater Poland, and L – Lodz Provinces

Discussion

This study estimates the water requirements of Jerusalem artichoke in Central Poland during the 1981-2020 growing seasons and analyses trends in water needs and rainfall deficits. Jerusalem artichoke thrives in regions with annual rainfall of at least 500 mm [23]. Central Poland, has the lowest average rainfall (500-550 mm), but some areas receive as little as 300 mm. This region experiences high ETo and a high risk of meteorological drought [24]. A negative climatic water balance confirms the need for supplementary irrigation [16]. Although climate change prognoses do not predict less annual rainfall in Central Europe, rising temperature is expected to increase ETo and exacerbate the water deficit [25-27].

This study, along with previous research on climate change effects in Kuyavia [28], is among the few investigations in Jerusalem artichoke water requirements in Central Poland. Table 4 compares these results with previous Polish studies, which vary in methodology, location, and study period. Bogucka et al. [11; 12] conducted a one-year field experiment (2018) in northeaster Poland, where they estimated the water requirements of Jerusalem artichoke using reference values for late potato cultivars. Żyromski et al. [3] performed lysimetric studies (2011-2013) in southwester Poland, applying the crop coefficient method with the Penman-Monteith and modified Blaney-Criddle methods. In these studies, the Kc values ranged from 0.457 (late May) to 0.412 (late October), peaking at 0.945 (late June).

Table 4

Comparison of Jerusalem artichoke water requirements (mm) in Poland

Reference	Part of Poland	Year of study	Months of growing season					
			May	June	July	Aug.	Sept.	Oct.
[11; 12][1]	North-East	2008	62	74	97	79	50	–
[3][2]	South-West	2011-2013	44	83	85	66	30	21
[28]	Kuyavia Region	1981-2010	15[3]	89	89	65	34	–
	Kuyavia Region	2020-2050[4]	14[3]	91	96	75	42	–
Current study	Central Poland	1981-2020	15[3]	89	89	65	35	20

[1] Adopted according to the water needs of late potato [11; 12], [2]Own calculations based on Kc given by [3]; [3]Between 21 and 31 May; [4]Forecast period [according to 26; 27]

Water availability is a key factor in Jerusalem artichoke cultivation [29; 30]. In Poland, irrigation increased biomass yield by over 40% and tuber yield by 60%, despite adequate total rainfall, highlighting the significance of rainfall distribution [15]. Similar yield increases were observed in Italy [31] and China [32]. Drought during flowering and tuber formation can reduce yield by up to 20% [29], with early cultivars being more drought-sensitive than late ones [29; 30]. Biomass has significant potential for meeting growing energy demands. It provides 75% of the EU's renewable thermal energy and accounts for 80-86% of renewable energy in Poland [33-35].

Water use efficiency (WUE) is particularly relevant when comparing *H. tuberosus* to other bioenergy crops. WUE of these species varies depending on environmental conditions and cultivation practices. *H. tuberosus* exhibits moderate WUE and adapts well to diverse growing conditions [5; 7; 15]; however, its biomass productivity is lower than that of C4 species such as *Miscanthus × giganteus* [35] and *Sorghum bicolor* [37]. The superior WUE of *M. × giganteus* and *S. bicolor* is attributed to their C4 photosynthetic pathway, which enhances efficiency under limited moisture availability. In contrast, *Salix* spp. [38] and *Sida hermaphrodita* [39] display greater plasticity in response to water availability, but their productivity depends heavily on soil moisture levels. *Silphium perfoliatum* [39; 40] exhibits relatively high WUE and may serve as a viable alternative to C4 crops in temperate climates and suboptimal soils, but it remains less efficient than *M. × giganteus* and *S. bicolor*.

This study identified a significant upward trend in Jerusalem artichoke water needs in Central Poland between 1981 and 2020, particularly from June to August. Water needs increased by 4.6-8.7 mm per decade, likely due to rising temperatures [25]. Projections for 2021-2050 indicate a further increase in Jerusalem artichoke water demand during the intensive growth period (May-September), from 292 to 318 mm in Kuyavia (+9%) [28]. These trends suggest that future climate change will further elevate crop water needs [26; 27; 36; 41]. Given these findings, expanding the irrigation infrastructure is crucial, particularly in Central Poland [42; 43]. Identification of the most effective crop management method can increase the energy production efficiency. However, the extent of future irrigation development and water consumption will depend on climate factors, agricultural policies, and economic conditions.

Conclusions

The water requirements of Jerusalem artichoke in Central Poland (1981-2020) during the growing season were 304-317 mm, peaking in June and July in K-P and M. A significant upward trend was observed, with an increase of 4.6-8.7 mm per decade. The highest rainfall deficits occurred in K-P, particularly from June to August. Given Central Poland's high irrigation demand, these findings support efficient irrigation planning and sustainable water management. Estimating water requirements may also encourage expanded Jerusalem artichoke cultivation, contributing to its economic revival.

Author contributions

Conceptualization, S.R.; methodology, S.R. and R.R.; software, A.K.-B.; validation, S.R. and R.R.; formal analysis, S.R. and R.K.-T.; investigation, S.R., R.R. and R.K.-T.; data curation, S.R. and B.J.; writing – original draft preparation, S.R., B.J. and R.K.-T.; writing – review and editing, S.R., A.K.-B. and R.K.-T.; visualization, S.R. and B.J.; project administration, A.K.-B.; funding acquisition, R.R. All authors have read and agreed to the published version of the manuscript.

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