INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

2025, Vol. 20(1), 5-18
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DOI: https://doi.org/10.14597/infraeco.2025.001

ASSESSMENT OF WATER REQUIREMENTS FOR ROBINIA PSEUDOACACIA L. ON RECLAIMED AREAS

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ABSTRACT

Water is a crucial natural resource, influencing plant productivity and sustaining ecosystems. Black locust, known for its drought resistance and adaptability to unfavorable conditions, is frequently used in the recovery of degraded regions. During juvenile phase, black locust requires sufficient soil moisture for proper growth. The objective of the research was to assess the water needs of black locust in the second stage of growth on reclamation plantations, specifically starting three years after planting. Water requirements were evaluated for five regions in Poland between 1 June and 31 August in 1981–2010. Water requirements, quantified as crop evapotranspiration, were determined by multiplying the plant coefficient by the reference evapotranspiration. The Blaney-Criddle equation, with the plant coefficient adapted using the Żakowicz method, was applied to estimate reference evapotranspiration. It was found that the average water requirements from June to August were 370 mm. Rainfall deficits were observed in all regions, with the highest shortfalls in central Poland. Additionally, all regions demonstrated an upward trend in water requirements for this species. The results provide valuable insights for planning and implementing irrigation strategies for black locust cultivated in reclamation plantations in Poland, supporting the sustainable management of water resources in the region.

Keywords: *Black locust, irrigation, precipitation deficit, rainfall, restoration*

INTRODUCTION

The core principle of sustainable development in our natural environment is to establish an integrated framework to progressively address pre-existing imbalances and deficiencies. This involves designing systems that minimize conflicts on spatial, functional, ecological, and social levels while enhancing the overall quality of life. It also includes safeguarding the integrity of both the natural and cultural environment, optimizing the system efficiency and the effectiveness of structural development, and promoting responsible resource management, mainly concerning water resources (Koreleski, 2007).

The black locust tree is highly valued for its contributions to honey production and its ornamental qualities. It ranks among the most widely cultivated deciduous trees worldwide (Schütt *et al*., 2006). Remarkably, this species has modest soil fertility requirements (Ellenberg and Leuschner, 2010), often thriving on abandoned or fallow lands (Başnou, 2009) and flourishing under optimal light conditions in early forest succession areas (Obidziński and Woziwoda, 2016). Its remarkability to harsh environmental conditions, such as air pollution and highly acidic soils, distinguishes the black locust (Huntley, 1990). As a result, it has been successfully used in reclamation plantings (Dilly *et al.,* 2010, Żakowicz, 2010). Recently, the cultivation of black locust for energy production has become popular, owing to its biological properties, particularly its efficient wood energy potential. The calorific value of black locust trunk wood, both in a dry and fresh state, is especially notable (Kraszkiewicz, 2016).

The black locust is an especially adaptable tree with minimal habitat requirements, often acting as a pioneer plant and displacing other woody species. Its preferred habitats typically include ruderal areas such as railway embankments, roadsides, old gravel pits, sand pits, and even rubbish dumps. The species' extensive root system is particularly remarkable, as it not only stabilizes the soil surface but also prevents erosion. In parts of Europe, particularly southern regions, the black locust's expansion has been so successful that it has begun to dominate the local tree population (Yüksek, 2012, Li *et al.,* 2018). The black locust is also widely used for establishing protective plant belts, which are vital in land reclamation efforts, providing ecological benefits and shelter for small animals (Nuța and Niculescu, 2011).

Afforestation is a fundamental approach to enhancing the function of agricultural landscapes (Pałys and Węgorek, 2005) and protecting soil and water resources (Józefaciuk *et al.,* 1995). Selecting the appropriate plant species is crucial for the success of afforestation. These species should be able to adapt easily to adverse environmental conditions, regenerate quickly after damage, exhibit low susceptibility to diseases and pests, and demonstrate rapid growth (Zajączkowski *et al.,* 2001). The ecological characteristics of the black locust closely match with these criteria (Zajączkowski *et al.,* 2001, Węgorek and Kraszkiewicz, 2005).

Black locust, known for its drought tolerance, rapid regeneration, and symbiotic relationship with nitrogen-fixing Rhizobium bacteria, has the potential to become the leading deciduous tree species in short rotation plantations on nutrient-poor soils. In the state of Brandenburg, Germany, situated in Central Europe with a continental climate and annual precipitation below 600 mm, the black locust has been successfully cultivated for over 250 years, primarily for wood production (Mantovani *et al.,* 2013). Black locust trees are effectively used in reclamation projects (Dilly *et al.,* 2010). *Robinia pseudoacacia* L. is commonly employed for the biological reclamation of post-industrial wastelands and degraded lands (Rahmonov, 2009). Notably, black locust thrives even in reclaimed post-mining areas characterized by spring-to-summer drought and poor soil water availability (Mantovani *et al.*, 2014a).

Despite its modest water needs, young black locust trees need adequate soil moisture until they establish a symbiotic relationship with Rhizobium bacteria (Rédei *et al.,* 2008). In Poland, *Robinia pseudoacacia* L. is widely used for reclaiming a significant portion of degraded lands. Its applications include forest reclamation on the slopes of external dumps from open-cast mines and nutrient-poor, loose sands. Black locust plays a crucial role in stabilizing substrates and improving soil nutrient content. Areas reclaimed with black locust are effectively protected against wind and water erosion. The leaves of the black locust provide a primary source of organic matter, fostering humus layer development and enriching the soil with essential macro- and micro-elements (Rahmonov and Parusel, 2012). Black locust forests enhance nutrient-deficient substrates with nutrients and organic colloids, significantly influencing the progress of ecosystem processes, thereby contributing to habitat diversity (Read *et al.*, 2002, Tamminen *et al.*, 2004).

The extensive use of black locust in reclamation plantings has significant potential for bioenergy production (Cafourek *et al.*, 2016). Ensuring the survival of plantings in reclaimed areas is a fundamental strategy during the initial phase of reclamation. Successful development of reclamation plantings requires two key elements: selecting the appropriate species and planting high-quality seedlings (Klimek *et al.,* 2008, 2009, 2011, 2013), as well as providing adequate soil moisture through irrigation (Żakowicz, 2010). While mature black locust trees can readily adapt to dry soil conditions, trees in the juvenile phase require optimal soil moisture levels. This can be achieved through irrigation techniques that compensate for precipitation deficits (Żakowicz, 2010, Mantovani *et al.*, 2014 a, b).

The primary aim of this study was to estimate the water requirements of black locust trees during the second stage of growth on reclamation plantations, specifically in the period beginning three years after reclamation. The research focused on the three-month period of increased water needs for black locust, occurring from June to August. This study builds upon previous research by Rolbiecki *et al.* (2019), who evaluated the water requirements of young black locust seedlings during the first phase of development on reclamation plantations, from planting until three years after planting.

MATERIAL AND METHOD

This study calculated the water requirements of black locust (*Robinia pseudoacacia* L.) over three years following planting in a reclaimed area, assuming the plant's water needs equivalent to potential crop evapotranspiration under sufficient soil moisture conditions. The water needs of young black locust trees were assessed using the crop coefficient method, which involves multiplying the crop coefficient by the reference evapotranspiration. The calculations were carried out using Equation (1):

$$\mathrm{ETp} = \mathrm{ETo} \times \mathrm{kc} \tag{1}$$

where:
ETp – represents potential crop evapotranspiration (mm)
ETo – denotes reference evapotranspiration (mm)
kc – is the crop coefficient, defined as the ratio of evapotranspiration measured under adequate soil moisture conditions to reference evapotranspiration (Łabędzki, 2006).

The Blaney-Criddla formula, adjusted to Polish conditions by Żakowicz (2010), was used to calculate the reference evapotranspiration. Equation (2) was applied for the calculations:

$$ETo = n \times [p \times (0.437 \times t + 7.6) - 1.5] \quad (2)$$

where:
ETo – represents reference evapotranspiration (mm)
n – is the number of days in the month
p – refers to evaporation coefficients by Doorenbos and Pruitt (1977) for specific months and latitude, as determined from tables, t – indicates the monthly mean air temperature (°C).

For young black locust trees growing in reclaimed areas, starting three years after reclamation, crop coefficients were applied according to the guidelines established by Żakowicz (2010).

The calculations were conducted for the period from 1 June to 31 August, which corresponds to the time when plants in Poland have the highest water requirements during the growing season. The water requirements of black locust trees were estimated based on data collected over a thirty-year span, from 1981 to 2010, from five meteorological stations located in Olsztyn, Bydgoszcz, Warsaw, Wrocław, and Kraków. These stations represent various agro-climatic regions of Poland, including the north–east region (N–E), central–north–west region (C–N–E), central–east region (C–E), south–west region (S–W), and south–east region (S–E), respectively (Figure 1).

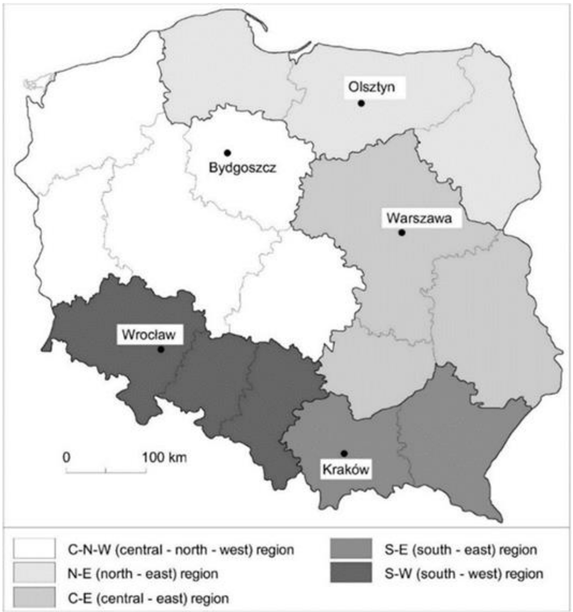

Figure 1. Geographical position of the investigated regions in Poland

The rainfall deficit for young black locust trees was calculated by subtracting the cumulative precipitation from the total potential crop evapotranspiration. To evaluate the rainfall deficit under different probabilities, including normal years ($N_{50\%}$), medium dry years ($N_{25\%}$), and very dry years ($N_{10\%}$), Ostromęcki's method was applied (Żakowicz *et al.*, 2009) using Equation (3):

$$\mathrm{Np\%} = \mathrm{Ap\%} \times \mathrm{ETp} - \mathrm{Bp\%} \times \mathrm{P} \quad (3)$$

where:
Np% – represents the precipitation deficit at the occurrence probability p% (mm per period)
Ap% and Bp% – are numerical factors that describe the variability of evapotranspiration and precipitation for a specific meteorological station
ETp – signifies the multi-year average evapotranspiration during the study period (mm per period)
P – denotes the multi-year average precipitation for the same period (mm per period).

RESULT AND DISCUSSION

The variation in water requirements of young black locust trees, as indicated by the coefficient of variation computed over the thirty-year period between 1981 and 2010 for the months of peak water demand—June, July, and August—showed relatively low values, ranging from 3.7% in the central–east region to 4.1% in the south–west region of Poland (Table 2).

Table 2. Characteristics of black locust water requirements from June to August, 1981–2010

Characteristic	Region of Poland	Water needs
Minimum (mm)	north–east	340.0
	central–north–west	358.8
	central–east	354.3
	south–west	330.9
	south–east	327.9
Maximum (mm)	north–east	393.2
	central–north–west	417.8
	central–east	415.6
	south–west	391.2
	south–east	388.2
Median (mm)	north–east	365.9
	central–north–west	385.9
	central–east	384.1
	south–west	357.7
	south–east	358.7
Standard deviation (mm)	north–east	14.3
	central–north–west	15.2
	central–east	14.2
	south–west	14.6
	south–east	13.5
Variation coefficient (%)	north–east	3.9
	central–north–west	3.9
	central–east	3.7
	south–west	4.1
	south–east	3.8

During the analyzed period from 1981 to 2010, a noticeable trend of increasing water requirements for black locust trees from 1 June 31 to August was observed across all regions across Poland (Figures 2 a–f). The trend lines depicting the variability of black locust water requirements (R^2) demonstrated a significant upward trajectory throughout the country ($R^2 = 0.2556$) (Figure 2 f). The lowest R^2 value for this trend was observed in the central–north–west region of the country (R^2 = 0.0907) (Figure 2 b). Conversely, in the north–east region (R^2 = 0.2525) (Figure 2 a), south–west region (R^2 = 0.2674) (Figure 2 d), central–east region (R^2 = 0.2734) (Figure 2 c), and south–east region (R^2 = 0.3447) (Figure 2 e) of Poland, the trend of increasing water requirements for black locust trees was notably more pronounced. The most significant increase in water requirements was observed in the south–east region of Poland, with an increase of 9.1 mm per decade (Figure 2 e). In contrast, the smallest rise in water needs occurred in the central–north–west region, with an increase of 5.3 mm per decade (Figure 2 b). On average, across Poland, from 1981 to 2010, during the period from 1 June to 31 August, the water requirements of black locust increased by an average of 8 mm per decade (Figure 7).

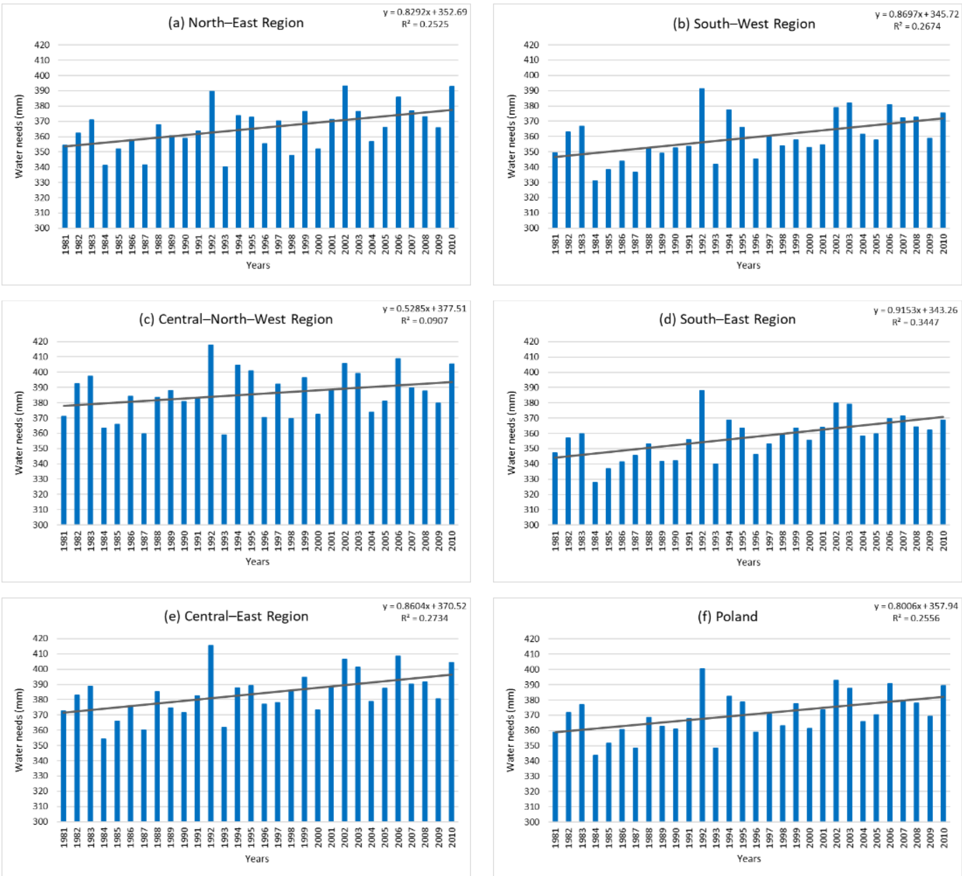

Figure 2. The time trend analysis of black locust water requirements in the particular regions of Poland. The solid line corresponds to the trend line

The most substantial water needs for black locust trees, as considered in the current study, were observed in the central regions of Poland. During the three-decade period from June to August, the highest water needs were recorded in the central–north–west (386 mm) and central–east (384 mm) regions of the country (Figure 3). In contrast, the lowest water needs were calculated in the south–west (359 mm) and south–east (357 mm) regions of Poland. Several studies affirm the suitability of central Poland for agricultural (Stachowski and Markiewicz 2011, Żarski *et al.*, 2013), horticultural (Żarski *et al.*, 2013, Rolbiecki *et al.*, 2002 a, b), and forestry crops (Rolbiecki *et al.*, 2018), despite these areas experiencing the highest rainfall deficits and having soil with low water retention. These studies concurrently emphasize the necessity of irrigation for productive land use in these regions.

According to Żakowicz *et al.* (2009), precipitation deficit calculations were made based on the probability of occurrence for normal years ($N_{50\%}$, i.e., once every two years), medium dry years ($N_{25\%}$, i.e., once every four years), and very dry years ($N_{10\%}$, i.e., once every ten years). In these three categories of years, the plants' water demand is met by 50%, 75%, and 90%, respectively. In the current study, from 1 June to 31 August, the largest rainfall deficit for normal years ($N_{50\%}$) was observed in the central–north–west region of Poland (197 mm) and the central–east region (173 mm), while the lowest was recorded in the south–east region (105 mm) of the country (Table 3). On the other hand, the rainfall deficit in medium dry years ($N_{25\%}$) and very dry years ($N_{10\%}$) was significantly greater in the north–east (277 mm and 364 mm, respectively), central–north–west (287 mm and 356 mm, respectively) and central–east regions (281 mm and 402 mm, respectively), compared to the south–west (213 mm and 301 mm, respectively) and south–west regions (191 mm and 242 mm, respectively) of the country.

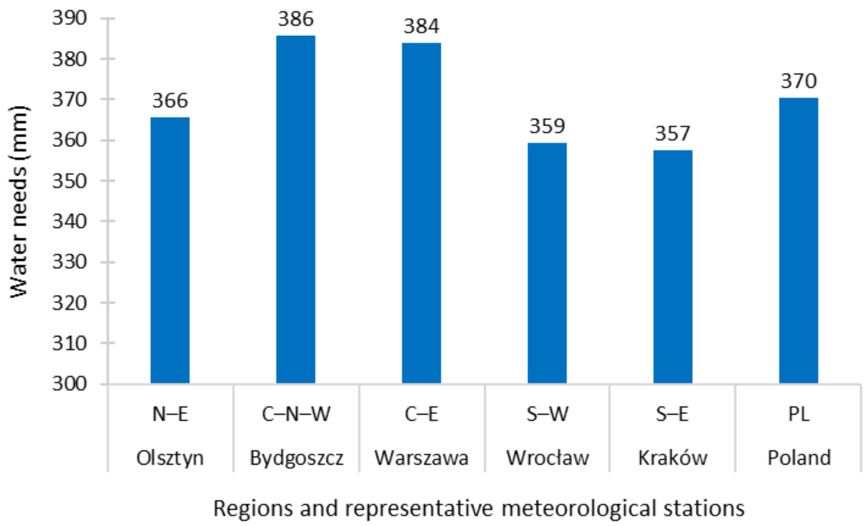

Figure 3. Black locust water needs for the June–August period in various regions of Poland: N–E, north–east; C–N–E, central–north–west; C–E, central–east; S–W, south–west and S–E, south–east region, PL, Poland

Table 3. Rainfall deficit (mm) calculated for black locust trees in various regions of Poland

Probability of rainfall deficit occurrence	Region of Poland				
	North–East	Central–North–West	Central–East	South–West	South–East
Normal years	150	197	173	141	105
Medium dry years	277	287	281	213	191
Very dry years	364	356	402	301	242

On average, the calculated water needs for black locust trees in Poland from 1 June to 31 August were 370 mm, as depicted in Figure 3. The natural habitat of black locust trees originally spans a humid to sub-humid climatic region in North America, characterized by an annual precipitation ranging from 1020 mm to 1830 mm. Remarkably, black locust trees exhibit a high degree of drought tolerance and can thrive across a wide range of climatic and soil conditions (Mantovani *et al.*, 2013, 2015).

Globally, this tree species plays a significant role in enhancing soil fertility and positively influencing the chemical properties of the soil (*Bolat et al*., 2016), contributing significantly to the reclamation of degraded soils (Mantovani *et al.,* 2015, Quinkenstein *et al.*, 2011, Nicolescu *et al.*, 2018). In central Europe, which has a continental climate, particularly in marginal areas like post-mining lands with limited water resources and challenging soil conditions, black locust cultivation for biomass production has been successful (Mantovani *et al.*, 2013) It's noteworthy that in these post-mining regions, where pre-dawn water potential as low as –0.5 MPa was observed during summer droughts, stem growth was severely limited. Nevertheless, black locust plants managed to survive these adverse weather and soil conditions (Mantovani *et al.,* 2015).

The results presented in this study indicate a growing trend in the water needs of black locust trees from 1 June to 31 August across Poland. Rapid climate changes, including rising temperature, may further increase the water needs of these plants in the near future. In light of this, plants developed in reclamation areas will be particularly vulnerable to adverse climate changes. Consequently, adaptation measures, including irrigation, become crucial and are among the most significant agro-technical practices that support plant development when rainfall is insufficient (Rolbiecki *et al.,* 2018, Kuchar and Iwański, 2013, Kuchar *et al.*, 2015, 2017). According to Ptach *et al.* (2018), irrigation is widely recognized as a critical melioration technique that facilitates the growth of trees and shrubs in various planting settings, including forests and tree nurseries. Numerous experiments conducted in central Poland have demonstrated the positive impact of irrigation on the seedling development of various tree species, including Scots pine (Klimek *et al.*, 2008), white birch (Klimek *et al.*, 2009), European larch (Klimek *et al.*, 2011), little leaf linden (Klimek *et al.*, 2013), and paulownia (Ptach *et al.*, 2018).

Earlier studies conducted by Żakowicz (2010) and Żakowicz and Hewelke (2012) have already established the effectiveness of micro-sprinkler irrigation for black locust grown in reclaimed areas in central Poland. These studies observed that irrigation using water from sewage treatment plants or rainwater positively influenced the height, trunk area, and crown area of black locust plants. Additionally, Mantovani *et al.* (2013, 2014 a, b) repeatedly noted the positive effects of drip irrigation on the growth and development of two-year-old black locust trees.

CONCLUSION

The study presented here indicates that, in the reclaimed areas in Poland, the average water requirements for young black locust trees during the three summer months (June, July, August) starting three years after planting, amounted to 370 mm. Rainfall deficits were calculated across Poland, with the most significant deficits observed in the central–north–west and central–east regions. Furthermore, an upward trend in water needs is evident. Black locust trees, known for their drought tolerance, are commonly used in the ecological restoration of degraded areas. However, during the early stages of growth, these trees require optimal soil moisture levels to ensure proper development, which is a crucial consideration for reclamation projects on degraded lands. The water requirement values obtained from this study can be valuable in developing a program for supplementary irrigation treatments in the reclamation plantings of young black locust trees, aimed at optimizing their growth in Poland. This strategy will facilitate the efficient management of water resources in the studied area. Future research should focus on evaluating the impact of irrigation on black locust trees during periods of water deficit.

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Received: 02.12.2025
Revised: 02.02.2025
Accepted: 05.02.2025