

Effect of different irrigation regimes on the early development of pot-grown black locust saplings

Attila OMBÓDI¹ – Andrea CSORBAINÉ GÓGÁN¹ – Kálmán POGRÁNYI¹ – Katalin POSTA¹

1: Hungarian University of Agriculture and Life Sciences, Páter Károly utca 1. 2100 Gödöllő, Hungary
e-mail: ombodi.attila@uni-mate.hu

Abstract: Black locust currently is considered to be the most important tree species of short-rotation forests in Hungary with the purpose of either woody biomass or industrial wood. Despite the general supposition on the drought tolerance of the species, water availability seems to be a more limiting factor to exploit the growing potential of highly productive new varieties than nutrient amendments. Preliminary measurements of the current study were made on the connection between the depth of the water-retaining soil layer and the growth of saplings on black locust plantations. A significant negative correlation was found between the depth of the water-retaining layer, the stem diameter and the height of the saplings. To investigate the phenomenon, a model experiment was launched with loamy sand soil in the pots. During six weeks, pots were watered every morning up to the weight referring to the 30, 40, 60 and 80% of field capacity (FC). Our results showed that 30% FC was only sufficient for the survival of the saplings, growth was only noticeable at plants with 40% FC or more. During the first 4 weeks, differences in growth and cumulative evapotranspiration between the 60% and 80% FC treatment were not considerable. However, in the last two weeks, saplings with the highest FC produced substantially higher biomass, resulting in a one-third higher final weight than those of 60% FC. Even with the limited soil capacity of the pots, water use of these saplings of 1 m height and 1 cm stem diameter exceeded 1.5 L per day. Our results confirmed that black locust is a water-intensive species with a high water use potential, which emphasizes the importance of irrigation on nurseries and the first years of plantations.

Keywords: Turbo Obelisk clone, plant development, relative chlorophyll content, plant mass, water use efficiency

Received 6 January 2022, Revised 7 June 2022, Accepted 7 June 2022

 This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

Introduction

Black locust (*Robinia pseudoacacia* L.), belonging to the Fabaceae family, is considered to be one of the most commonly cultivated broad-leaved tree species in the World (Schwärzel et al., 2018). Due to its high adaptability, the species is one of the three most widespread non-native tree species in Europe (Lambdon et al., 2008). Black locust is a widely cultivated tree especially on the Chinese loess Plateau (Jiao et al., 2018), or on the Great Plain in Hungary (Rédei et al., 2008). Currently, the black locust is the most important tree species in Hungary with a to-

tal surface of 445 000 hectares, representing 24% of the Hungarian forest area (KSH, n.d.).

Black locust is diversely utilized for building, firewood or as an exceptional honey plant for bees (Kurtz & Hansen, 2017), even successfully applied in the reclamation of lignite opencast areas in Germany (Grünwald et al., 2009). The tree is commonly used in short rotation coppice forests in Hungary and Germany (Grünwald et al., 2009; Rédei & Veperdi, 2009).

A suitable environment, selected varieties and intensive cultivation technology can help to exploit its intensive growing potential and

high-quality timber (Keresztesi, 1988; Rédei & Veperdi, 2009). The yield on a biomass energy plantation was mainly affected by soil water availability (Megyes, 2013). Our first observations made on young, fertilized plantations established with high-potential clones seem to confirm the above findings (unpublished observations).

Black locust originates from the humid and sub-humid regions of the Appalachia mountains and the Ozark Plateau with annual rainfall between 800–1800 mm (Gaffin & Hotz, 2000; Kurtz & Hansen, 2017). Therefore, the species is considered to be a water-demanding and drought-sensitive plant (Wu, Huang, & Warrington, 2015; Yan, Yamanaka, Yamamoto, & Du, 2009). Still, black locust is proved to be a highly adaptable species to drought compared to other broad-leaved species by numerous studies (Han & Kakubari, 1995; Li et al., 2018; Rolbiecki et al., 2019; Veste & Kriebitzsch, 2010). The plasticity of the species makes the tree suitable for biomass plantations throughout the arid regions of Central and Eastern Europe (Mantovani et al., 2014b). Black locust either can reduce leaf size and transpiration (Mantovani et al., 2014a) or enhance its nitrogen fixation (Mantovani et al., 2015b) under long-term drought stress, however, the growth rate and biomass production of the trees decline considerably (Mantovani et al., 2013, 2014b; Veste et al., 2013).

Under well-watered conditions, transpiration of the tree increases without an improvement in photosynthetic activity, for this reason, black locust cannot be treated as a water-saving tree species (Mantovani et al., 2011, 2014a). The water use efficiency (WUE) value of the black locust ranges on a wide scale from 0.03 kg m⁻³ in humid to 0.74 kg m⁻³ in semi-arid areas (Hu et al., 2001). Yet, Mantovani et al. (2014b, 2014a, 2015) measured remarkably higher values of 2.3–2.8 kg m⁻³ with three-year-old saplings under arid conditions. Nevertheless, those WUE values

of black locust were still markedly lower than the 4–6 kg m⁻³ values of willow and poplar trees, both widely used as biomass producers. Contrary to poplar, precipitation can affect the growth of black locust not only in the storage (Nov–Apr) and the main growth (May–June) period but also in the late growth period (Aug–Nov) (Manninger, 2008). Black locust can exploit the whole water resource of the soil even under humid circumstances (Veste & Kriebitzsch, 2010), resulting in the drying out of plantation soil (Jiao et al., 2019; Y.-L. Wang et al., 2010; Wu et al., 2015).

Saplings are sensitive to spring/summer drought after the establishment of a plantation, so suitable water management is necessary in dry areas (Rolbiecki et al., 2019; Veste & Kriebitzsch, 2010). A former study proved that irrigation in the first year can improve growth by 80%, while biomass increase dropped to 50% by the third year. Addition of 200–500 mm water, representing the half of the in-season precipitation enhanced biomass production by 75%. In the same experiment, the growth-stimulating effect of irrigation and nitrogen fertilization accumulated (Bongarten et al., 1992). Yet, irrigation under humid environment of the Appalachian did not affect plant survival in a two-year-experiment (Brinks et al., 2011). Note that in lower, water-affected spots, 100% plant mortality was registered (Bongarten et al., 1992). Airy environment around the roots is necessary with a soil water level not higher than 150 cm (Megyes, 2013).

Kurtz and Hansen (2017) estimated black locust yearly water demand between 400 and 1650 mm. Daily evapotranspiration (ET) of the species is calculated 3–4 mm for the summer season (L. Wang et al., 2011), confirmed by a Polish value of 3.5 mm. However, due to global climate change, yearly ET increased by 9 mm in a decade during a period of 1980–2010 (Rolbiecki et al., 2019). Above

the potential evapotranspiration value (PET) of 3.2–4.0 mm, depending on soil type, ET of the black locust would not grow higher (Wu et al., 2015). In Hungary, black locust is generally planted on looser soils. Under optimal water circumstances, ET of black locust was higher and more dependent on weather in sandy soils than on loamy, clayey ones (Wu et al., 2015).

High survival rate and fast early growth of young black locust saplings is essential in intensive short rotation woody plantations. Literature findings and the authors' own observations both confirm that water availability can even have higher impact on biomass production than variety or nutrient content of the soil. Our objective was to run a simple experiment to investigate the connection between soil hydrology parameters and the initial sapling growth in a newly established black locust plantation. Effect of soil water content on early (first 3 months) growth of black locust saplings 'Turbo Obelisk' variety was also investigated in a pot experiment.

Materials and Methods

Examination on the plantation

The investigated plantation of 1.3 ha was planted on the outskirts of Tápiószele (N 47.306484, E 19.885437) on 7 April 2018, for nutrient supplementation experiment and variety comparison. After planting, the seedlings were cut back to trunk. The clones of the fast growing cultivar 'Turbo Obelisk' OBE-01, OBE-34, OBE-53, OBE-69 were planted in 2m x 2m spacing. The area is characterised by an altitude of 95 m above sea level, an average annual air temperature of 10.0–10.3°C and an annual rainfall of 530–550 mm. The area is dry and poorly drained, with groundwater depths of between 2 and 4 m. Soil analysis carried out during the pre-planting survey shows that the soil is sandy, alkaline, high in lime (5–10%)

and low in organic matter (less than 1%).

In some parts of the plantation, there were serious differences in size between adjacent seedlings of the same clone and fertilization treatment, which could not be explained by plant health reasons. In mid-April 2020, in five such areas, we made 6 m long and 2 m deep narrow trenches next to 3–3 trees, in which we measured the depth of the aquifer layer under the trunks of the trees to an accuracy of 5 cm. In addition, we measured the stem diameter of the trees above ground with a caliper to the nearest millimetre and the height of the trees with a tape measure to the nearest 10 cm. The 15 trees measured were clones OBE-01 (3), OBE-34 (3) and OBE-53 (9). Correlation analyses between aquifer layer depth and plant characteristics were performed to find correlations, without separating data from different clones during this data analysis.

Container experiment

The containerized water supply experiment was conducted at the Department of Horticulture, Szent István University, Gödöllő-Szárítópuszta, in an unheated, plastic covered multi span greenhouse equipped with automatic roof ventilation. The temperature was recorded every half hour with a thermometer (TR 71-S, T & D Corporation, Japan) placed between the containers. The data showed that the average air temperature during the experiment was 26.4°C, which is about the same as the temperature on a hot summer day in the Hungarian Great Plain, a typical area of black locust plantations. Irradiance data were obtained from the Private type climate computer of a glasshouse, located 20 m from the experiment site. The daily average solar irradiance was 269 W m⁻².

For the experiment, micropropagated clone of the very intensive growing cultivar Turbo Obelisk, OBE-01 was used. The small plants, initially grown in 25 × 25 × 40 mm rock-wool starter plugs, were transplanted into 12

cm diameter polypropylene pots on 8 June 2020. The pots were filled with the same soil - fertilizer mixture that was later used in the container phase. We used 370 g of dry soil per pot. The seedlings were grown in the pots until 30 June, after which 40 seedlings of average height were selected and transplanted into pots for the experiment. The soil used for the experiment was collected from a loamy sand top soil layer of one of the farm's fields. The laboratory analysis showed that the soil was slightly alkaline ($\text{pH}_{\text{KCl}} = 7.4$), with low humus (0.83%), salt (<0.02%) and lime (<0.2%) content. Although the soil contained moderate amounts of nutrients, to ensure that nutrient levels, especially nitrogen, did not limit seedling growth, a controlled release Osmocote fertilizer (8–9 months 12:11:17 + microelements) was mixed into the soil. The dose applied was 2.5 kg m^{-3} , which is the same rate used for black locust seedlings in the nurseries. The field capacity of the soil was measured as 33.2 % gravimetric water content.

The soil to be used for the experiment was air-dried, crushed to pass through a 2-mm sieve, mixed with the fertilizer, and then poured into 12 L polypropylene containers. The amount of soil loaded in one container corresponded to 11.28 kg of soil with 0% water capacity, dried at 105 °C to constant weight. We planted a seedling in the centre of each container, then watered each with 0.5 litres of water to ensure safe rooting.

Treatment started 3 days after the transplant. Four water availability levels were applied, maximum 30, 40, 60 and 80% of the field capacity (FC), corresponding to successively 10.0, 13.3, 20.0 and 26.6 wt% water content. 10–10 containers of each treatment were set up. Based on our preliminary studies, using a baseline water capacity level below 30% would no longer have ensured the safe survival of the seedlings. We achieved the specified water capacity levels in the experiment by measuring the weight of each container

on a digital balance to the nearest 10 gram from 8:00 to 9:00 every morning from July 3 until the end of the experiment, and then watering to the weight required to achieve the specified water capacity level. The required amount of water was slowly poured onto the surface of the soil, allowing time for infiltration without the water staying on the surface. The soil surface was regularly loosened to avoid soil compaction. The daily ET rate was calculated based on the weight measurements, then daily values were summed up. Due to the continuous weight gain of the growing black locust seedlings, a weight correction was applied to the measurements at increasing rates throughout the experiment. At the very end of the experiment, the rates of correction in the 30, 40, 60 and 80% water capacity treatments were 10, 50, 150 and 200 g, respectively.

From planting to the end of the experiment, the stem diameter, height and relative chlorophyll content of the leaves of each seedling were measured approximately every two weeks (0, 16, 30, 43 days after planting on 30 June, 16 July, 30 July and 13 August 2020). Stem diameters were measured with a digital caliper, to the nearest tenth of a millimetre, perpendicular to the stem axis, 3–4 cm above the soil surface. Plant height was measured from the soil surface to the growing tip using a measuring rod, with an accuracy of centimetres. The relative chlorophyll content of the leaves was measured to the nearest tenth of a SPAD value using a Minolta SPAD 502. The measurement was performed on the middle leaflets of the youngest mature leaves, 4 leaves per plant.

At the end of the experiment (14 August 2020), the fresh and dry weight and dry matter content of the above-ground parts of the plants were also determined. The fresh plant mass was obtained by cutting the stems at ground level two hours after morning watering and immediately measuring their mass on a digital precision balance, to the nearest

hundredth of a gram. The cut stem sections were then dried in a drying oven at 70°C until constant weight was reached. The dry mass was also measured to the nearest hundredth of a gram. The dry matter content was calculated as the ratio of fresh to dry weight, expressed as a percentage.

Statistical evaluation of the data was carried out using a one-way analysis of variance to examine the effect of water supply level on each of the characteristics examined. For mean separation of the treatment averages statistically, the Fisher's least significant difference test was used as a post-hoc test with a 5% level of significance (LSD5%).

Results and discussion

Results of the plantation survey

The results of the survey confirmed the exceptional growth vigour of the 'Turbo Obelisk' clones, as they were able to reach trunk diameters of over 40 mm and heights of up to 5 m two years after pruning back to trunk. While the least developed specimens were around 2.5 m tall and 10–15 mm stem diameter. The depth of aquifer layer in the trenches varied between 40 and 130 cm (Figure 1).

Despite the fact that data from individuals of the three different clones included in the study were analysed together, a significant negative correlation between aquifer depth and tree size was found. The correlation was slightly stronger for plant height than for trunk diameter (Figure 1). Thus, during the first two years, the depth of the aquifer layer beneath a given plant was a major determinant of its development. Differences of up to 100% in stem thickness and height could occur between neighbouring individuals. Where the plantation had a loamy aquifer in the sandy soil at a depth shallower than 80 cm, a markedly better growth was observed due to better water supply. This result is con-

sistent with literature claims that black locust is a water-demanding tree species (Kurtz & Hansen, 2017; Wu et al., 2015; Yan et al., 2009).

Results of the container experiment

Trends in water consumption

The daily weight loss of the containers consisted of two factors, evaporation of the soil surface and transpiration of the seedlings. In the treatments with higher FC, evaporative water loss was higher due to a more wet soil surface. This is evidenced by the results of the first days, when there was no significant difference in plant size and thus presumably transpiration between treatments, yet the daily water consumption of the 60 and 80% treatments (0.35–0.50 L per container) was much higher than that of the 30 and 40% treatments (0.08–0.25 L per container).

In the 30% maximum FC treatment, the daily ET was very low throughout the experiment, between 0.08 and 0.30 L, and did not increase much with the progress of the experiment. Accordingly, the cumulative ET of this treatment showed a linear trend (Figure 2). The tendency was similar for the 40% treatment, except that the average daily ET value over the whole period was 50% higher (0.25 L) than for the 30% treatment (0.16 L). Daily ET values in the 40% treatment had a wider range, with values between 0.12 and 0.39 L. By the end of the experimental period, the cumulative ET per container for the 30% treatment was 6.61 L and for the 40% treatment 10.41 L. This difference between the two treatments increased steadily throughout the experimental period (Figure 2).

During the first four weeks of the experiment, the daily ET per container of the 60% and 80% treatments varied between 0.34 and 0.44 L and did not show a large increase during this period. The cumulative water consumption of the two treatments was then still completely the same (Figure 2). We attribute this to the fact that, based on the results of

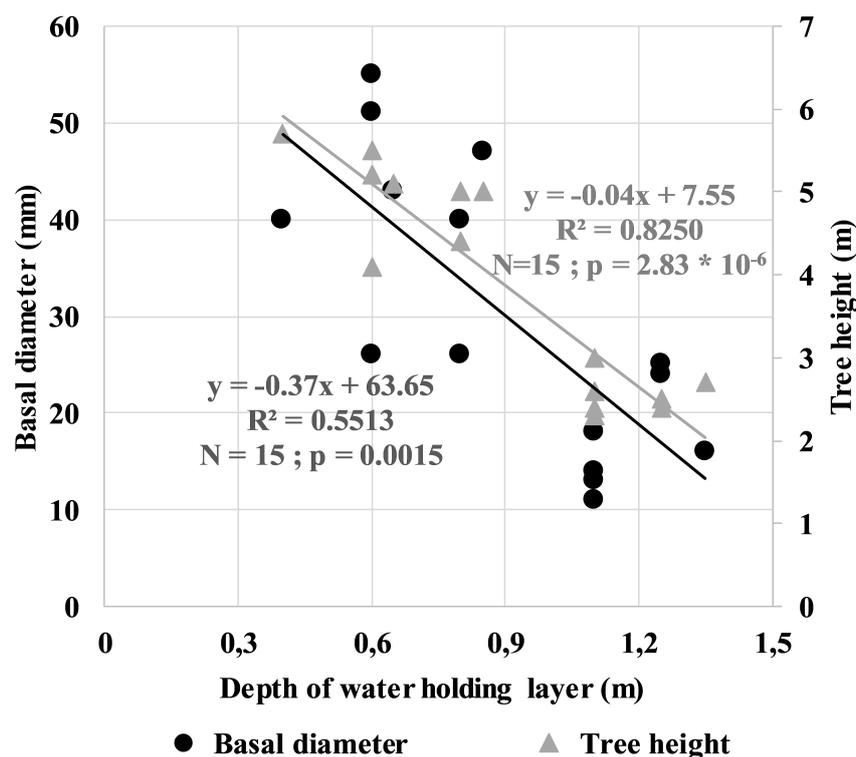


Figure 1. Correlation between aquifer level depth and trunk diameter and height of 'Turbo Obelisk' black locust trees next to the sample trenches in a plantation, two years after planting (Tápiószele, 2020)

Wu et al. (2015), transpiration of black locust seedlings in sandy soils above 60% water capacity is no longer limited by soil water content. It is a well-known phenomenon that transpiration of plants only starts to decline below a critical soil water capacity level (Sadras & Milroy, 1996). In the first month of the study, there was not yet a difference in seedling size and thus canopy area between 60 and 80% treatments that would have created a significant difference in ET. During this period, the cumulative ET of these two treatments also followed a linear trend (Figure 2).

However, during the last two weeks of the experiment, in the 60 and 80% treatments, seedling growth accelerated greatly, with increasing canopy area and a large increase in transpiration water loss. The daily ET values increased dramatically, always being above 0.7 L, and in the 80% treatment they even

exceeded 1.5 L per day on several occasions at the end of the experiment. This also meant that the 80% field water capacity value achieved in these containers at morning irrigation had dropped to around 30–40% after 24 h. This justified ending the experiment just six weeks after it started. During these final two weeks, a significant difference in ET between the 60 and 80% treatments had already developed. A similar trend was observed by Mantovani et al. (2011). In their lizymetric experiment, the cumulative water consumption of the low water supply (35% FC) black locust seedlings was already at the very beginning largely below that of the medium and high water supply treatments, but only after a month did a difference start to emerge between the latter two. In our study, by the end of the experimental period, the cumulative ET was 23.88 L, or 16% less in the 60% FC treatment than that of the 28.44 L of

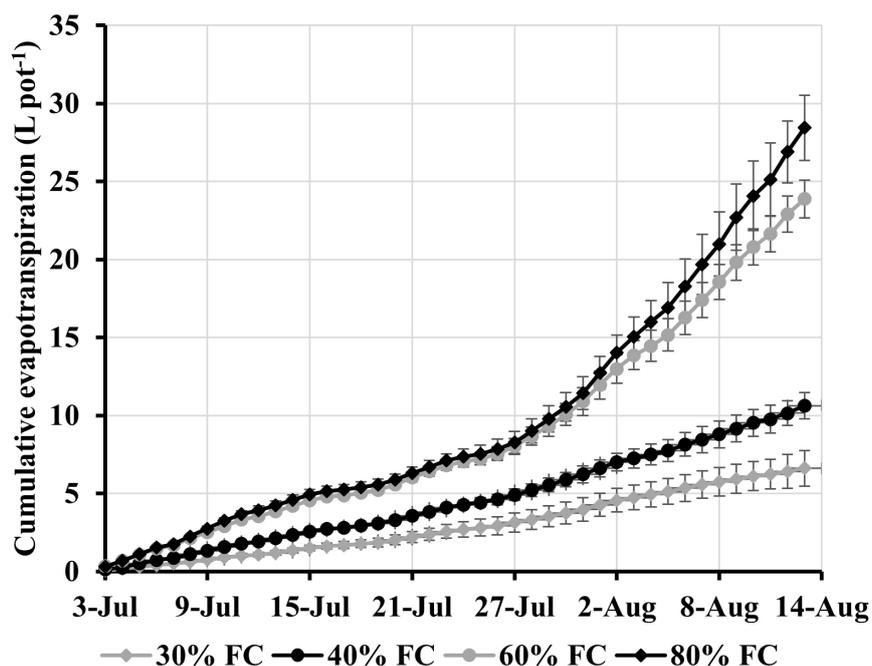


Figure 2. Evolution of the summed evapotranspiration values of containerized 'Turbo Obelisk' black locust seedlings under different maximum water capacity rate treatments (FC = Field Capacity)

the 80 % FC treatment. The water consumption of the 40% treatment (10.41 L) was 63% lower than that of the 80% treatment, almost identical to the 61% difference between transpiration of well and scarcely watered black locust seedlings recorded in the experiment of Mantovani et al. (2013).

Plant height and stem diameter

At the end of the potted growing period, at the first measurement after transplanting, there was no significant difference in the mean height of the seedlings. After almost two weeks, at the 2nd measurement (16 July 2018), the effect of improved water supply was already evident, despite the slow initial development. The plants in the 60% FC and 80% FC treatments were significantly taller than the seedlings in the two lower FC treatments (Table 1). By the time of the third measurement, one month after the start of the treatment, there was also a significant difference in plant height between the

30 and 40% FC treatments. Plants in the 30% FC treatment grew significantly slower and overall grew only 7 cm taller during the study. In contrast to the 30% FC treatment, the 40% water capacity was already a high enough water supply level for the seedlings to not only survive but also grow significantly. From mid-July onwards, their height growth accelerated and by the end of the experiment they had reached an average height of nearly 60 cm. There was no significant difference in height between plants in the two higher water treatments in any of the measurements (Table 1). In these two treatments, seedlings that were initially 12 cm tall grew to an average height of 1 m during the month and a half of the experiment.

Based on measurements taken immediately after planting, there were statistically significant differences in stem diameter between treatment averages, but these were small and did not affect the final results of

Table 1. Effect of soil water content on certain growth characteristics of 'Turbo Obelisk' black locust seedlings (mean \pm SD)

Plant height (cm)	30.06.	16.07.	30.07.	13.08.
30% FC	14 \pm 1	16 \pm 2 ^{b1}	19 \pm 3 ^c	21 \pm 6 ^c
40% FC	12 \pm 2	17 \pm 4 ^b	34 \pm 5 ^b	58 \pm 5 ^b
60% FC	12 \pm 3	24 \pm 4 ^a	60 \pm 7 ^a	100 \pm 5 ^a
80% FC	12 \pm 2	26 \pm 6 ^a	61 \pm 7 ^a	105 \pm 5 ^a
P-value	0.0687	1.28 \times 10 ⁻⁵	7.79 \times 10 ⁻¹³	5.34 \times 10 ⁻²⁴
LSD5%	N.S.	4.2	7.4	5.3
Basal diameter (mm)	30.06.	16.07.	30.07.	13.08.
30% FC	2.2 \pm 0.4 ^a	2.4 \pm 0.2 ^c	2.8 \pm 0.3 ^c	3.4 \pm 0.5 ^d
40% FC	2.0 \pm 0.1 ^{ab}	2.9 \pm 0.4 ^b	3.9 \pm 0.5 ^b	5.9 \pm 0.5 ^c
60% FC	2.1 \pm 0.2 ^a	3.3 \pm 0.3 ^b	6.0 \pm 0.6 ^a	9.7 \pm 0.9 ^b
80% FC	1.8 \pm 0.0 ^b	3.7 \pm 0.4 ^a	6.6 \pm 0.8 ^a	11.0 \pm 0.9 ^a
P-value	0.0334	1.52 \times 10 ⁻⁵	1.07 \times 10 ⁻¹⁰	1.11 \times 10 ⁻¹⁸
LSD5%	0.2	0.4	0.8	0.7
Relative chlorophyll content (SPAD value)	30.06.	16.07.	30.07.	13.08.
30% FC	33.3 \pm 2.7	36.8 \pm 3.8	34.8 \pm 2.8	39.0 \pm 2.0 ^b
40% FC	31.4 \pm 3.7	39.1 \pm 4.3	37.3 \pm 3.4	41.6 \pm 2.1 ^a
60% FC	34.5 \pm 2.0	38.8 \pm 4.9	33.8 \pm 1.6	40.1 \pm 1.3 ^{ab}
80% FC	31.5 \pm 3.6	37.3 \pm 4.7	34.4 \pm 3.2	38.2 \pm 3.3 ^b
P-value	0.1579	0.6750	0.0876	0.0316
LSD5%	N.S.	N.S.	N.S.	2.3

¹ Average values of the same parameter, date and letter mean no significant differences at 95% probability based on Fischer's least significant difference test

the experiment. As in the height measurement, the effect of different watering levels was already evident in the second measurement two weeks later. Significantly the largest stem diameter was obtained in the 80% FC treatment and the smallest in the 30% FC treatment, while no significant difference in stem diameter was observed between the 40% FC and 60% FC treatment seedlings (Table 1). Thus, the developmental difference between the 30% FC and 40% FC seedlings based on stem diameter was already apparent at this time, earlier than based on height. At the third measurement, the difference between the mean stem diameter of 80% FC and 60% FC increased further in numerical terms, but due to the larger

deviations, this difference did not prove to be significant at this time. Similar to the trend in the height data, the development of the 30% FC and 40% FC seedlings was increasingly lagging behind the two treatments with higher water availability and the difference between the two was also increasing in favour of the 40% FC. At the end of the experiment, the four treatments became statistically completely distinct, with each treatment having a significantly different stem diameter from the other ones. The average stem diameter of the 80% FC seedlings exceeded 1 cm, and the average of the 60% FC was close to this value (Table 1). In the 40% FC treatment, the average stem diameter was 6 mm, which was the same level reached by

plants in the two better water supply levels two weeks earlier. In the 30% FC treatment, stem diameter increased to only one and a half times during the month and a half of the study, but for this parameter a greater improvement was observed in this treatment than for height.

Relative chlorophyll content

The relative chlorophyll content results did not show as clear a trend as for plant height and stem diameter. The order of treatments differed between measurement times and significant differences were only found for the last measurement time (Table 1). Even then, there was only a verifiable difference between the highest SPAD mean of 40% FC and the mean values of 30% FC and 80% FC (Table 1). All containers were supplied with the same amount of nutrients, including nitrogen. Relative chlorophyll content is positively correlated with nitrogen supply (Li et al., 2018) and negatively correlated with foliage volume at the same nitrogen dose. Improved water supply can promote more efficient nitrogen uptake and stimulate better vegetative growth and canopy development. In turn, more intensive growth requires more nitrogen and consequently reduces the amount of nitrogen available for uptake in the soil. As a result of these relationships, the relative chlorophyll content was highest in the 40% FC treatment and lowest in the 80% FC treatment.

Plant mass

During the experiment, we were able to monitor the development of the black locust seedlings by measuring height and stem diameter, but the most reliable way to characterise the degree of development of the vegetative parts is by the production of plant mass. In our experiment, different water availability levels had a strong influence on plant mass production. There was a complete statistical separation between the treatment averages for both fresh and dry mass,

with the average value of each treatment being significantly different from all others (Table 2). The results showed a clear trend, the higher the water availability rate, the higher the plant mass. Plant weight showed a strong positive correlation with the amount of water used in the experiment (Figure 3), in agreement with the results of Mantovani and co-workers (2013, 2015a). The water demand of black locust is clearly shown by the fact that the fresh and dry plant mass was one third higher in the 80% FC treatment than in the 60% FC treatment. The difference between the plants in the two treatments was not in height but in stem diameter (Table 1) and lateral shoot development. Seedlings in the 80% FC treatment increased their fresh above-ground plant weight from 1-2 grams to 190 grams over a period of one and a half months. However, in terms of mass production in grams, the largest jump was observed between the 40% FC and 60% FC treatments, and in terms of proportions between the 30% FC and 40% FC treatments, where plant mass increased more than six-fold with only a 10% increase in water capacity (Table 2). The above ground dry matter content of young, leafy seedlings ranged between 27 and 33%. As expected, the results were significantly higher in the low water treatments with 30 and 40% FC than in the 60 and 80% FC treatments.

WUE was calculated based on the above mentioned plant mass and the cumulative ET data. On fresh weight basis WUE was 0.81, 3.11, 6.14 and 6.93, while on dry weight basis it was 0.26, 0.93, 1.70 and 1.87 kg m⁻³ for the 30, 40, 60 and 80% FC treatments, respectively. With the exception of the 30% FC treatment these values can be considered high. This is probably mainly due to the very young age of the saplings and the protected conditions.

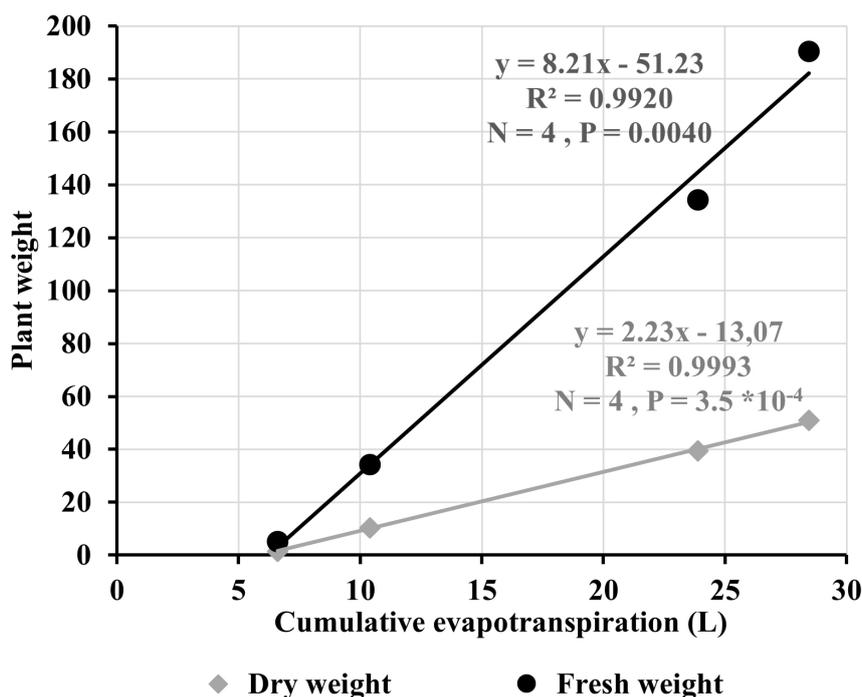


Figure 3. Correlation between evapotranspiration and the above-ground plant mass of the containerized 'Turbo Obelisk' black locust seedlings summed over the duration of the experiment

Table 2. Effect of soil water content on weight of 'Turbo Obelisk' black locust seedlings (mean \pm SD)

	fresh weight (g)	dry weight (g)	dry matter content (%)
30% FC	5.2 \pm 3.3 ^{d1}	1.6 \pm 1.0 ^d	33.0 \pm 2.3 ^a
40% FC	34.2 \pm 4.5 ^c	10.4 \pm 1.6 ^c	30.5 \pm 1.3 ^b
60% FC	143.4 \pm 19.3 ^b	39.3 \pm 6.9 ^b	27.2 \pm 1.4 ^c
80% FC	190.4 \pm 19.4 ^a	50.9 \pm 7.5 ^a	26.6 \pm 1.4 ^c
P-value	1.01 $\times 10^{-21}$	7.84 $\times 10^{-18}$	6.88 $\times 10^{-6}$
LSD5%	14.3	5.3	2.2

¹Average values of the same parameter, date and letter mean no significant differences at 95% probability based on Fischer's least significant difference test

Conclusions

Both our plantation survey and our container experiment showed that soil water availability has a strong influence on the initial growth of black locust seedlings and saplings. It is therefore advisable to pay close attention to the hydrological conditions and

the water holding capacity of the soil when selecting the area for planting. In areas with less favourable conditions, irrigation may be considered after economic calculations. It would be advisable to carry out irrigation experiments in plantations to find out the level of water supply which will still result in a

satisfactory growth rate without adversely affecting the wind and winter hardiness of the seedlings and the quality of the wood product.

In nursery production, irrigation is essential during drier summers. Our results show that in loamy sandy soils, a soil water capacity level of 30% was only sufficient for the survival of the trees, not for the initiation of growth. For this, a water capacity level of at least 40% is required. During the first month, it is enough to maintain a soil water content of 60% to ensure a sufficient growth rate. After that, however, it is advisable to maintain an even higher water capacity level of

80% to better exploit the growth potential of fast-growing varieties. At the end of our study, the daily water consumption of the 1 m tall and 1 cm stem diameter black locust seedlings reached one and a half litres even with the limited soil volume of the containers. It can be assumed that in a nursery or plantation the daily water consumption of plants of similar size would exceed even this level.

Acknowledgements

The current research was funded by 2017-1.3.1-VKE-2017-00022 project.

References

- Bongarten, B. C., Huber, D. A., & Apsley, D. K. (1992). Environmental and genetic influences on short-rotation biomass production of black locust (*Robinia pseudoacacia* L.) in the Georgia Piedmont. *Forest Ecology and Management* **55**(1), 315–331. doi: [https://doi.org/10.1016/0378-1127\(92\)90108-L](https://doi.org/10.1016/0378-1127(92)90108-L)
- Brinks, J. S., Lhotka, J. M., Barton, C. D., Warner, R. C., & Agouridis, C. T. (2011). Effects of fertilization and irrigation on American sycamore and black locust planted on a reclaimed surface mine in Appalachia. *Forest Ecology and Management* **261**(3), 640–648. doi: <https://doi.org/10.1016/j.foreco.2010.11.018>
- Gaffin, D. M., & Hotz, D. G. (2000). A precipitation and flood climatology with synoptic features of heavy rainfall across the southern Appalachian Mountains. *National Weather Digest* **24**(3), 3–16.
- Grünewald, H., Böhm, C., Quinkenstein, A., Grundmann, P., Eberts, J., & von Wühlisch, G. (2009). *Robinia pseudoacacia* L.: A Lesser Known Tree Species for Biomass Production. *BioEnergy Research* **2**(3), 123–133. doi: <https://doi.org/10.1007/s12155-009-9038-x>
- Han, Q., & Kakubari, Y. (1995). Diurnal and Seasonal Courses of Photosynthesis, Transpiration and Water Use Efficiency of Apple and Black Locust Seedlings in Different Soil Water Conditions. *Journal of the Japanese Society of Revegetation Technology* **21**(2), 114–123. doi: <https://doi.org/10.7211/jjsrt.21.114>
- Hu, Z., Wang, Z., Gao, H., & Wang, L. (2001). Research on water changes and water use efficiency in Loess gully region in Western Shanxi Province. *Journal of Shanxi Agricultural University* **21**(3), 248–251.
- Jiao, L., Lu, N., Fang, W., Li, Z., Wang, J., & Jin, Z. (2019). Determining the independent impact of soil water on forest transpiration: A case study of a black locust plantation in the Loess Plateau, China. *Journal of Hydrology* **572**(1), 671–681. doi: <https://doi.org/10.1016/j.jhydrol.2019.03.045>
- Jiao, L., Lu, N., Fu, B., Wang, J., Li, Z., Fang, W., Liu, J., Wang, C., & Zhang, L. (2018). Evapotranspiration partitioning and its implications for plant water use strategy: Evidence from a black locust plantation in the semi-arid Loess Plateau, China. *Forest Ecology and Management* **424**(1), 428–438. doi: <https://doi.org/10.1016/j.foreco.2018.05.011>

- Keresztesi, B. (1988). The black locust. Budapest: Akadémiai Kiadó.
- KSH. (n.d.). A faállománnyal borított erdőterület és az élőfakészlet megoszlása fafajcsoportok és korosztályok szerint, december 31. (2000–). Retrieved 2022, from http://www.ksh.hu/docs/hun/xstadat/xstadat_eves/i_ome002b.html
- Kurtz, C. M., & Hansen, M. H. (2017). An assessment of black locust in northern U.S. forests (Tech. Rep.). doi: <https://doi.org/10.2737/nrs-rn-248>
- Lambdon, P., Pyšek, P., Basnou, C., Hejda, M., Arianoutsou, M., Essl, F., Jarošík, V., Pergl, J., Winter, M., Anastasiu, P., Andriopoulos, P., Bazos, I., Brundu, G., Celesti-Grappow, L., Chassot, P., & Vilà, M. (2008). Alien flora of Europe: Species diversity, temporal trends, geographical patterns and research needs. *Preslia* **80**(1), 101–149.
- Li, G., Zhang, X., Huang, J., Wen, Z., & Du, S. (2018). Afforestation and climatic niche dynamics of black locust (*Robinia pseudoacacia*). *Forest Ecology and Management* **407**(1), 184–190. doi: <https://doi.org/10.1016/j.foreco.2017.10.019>
- Manninger, M. (2008). A növekedés és a csapadék összefüggései az alföldi mérések alapján (Tech. Rep.). Kutatói nap, tudományos eredmények a gyakorlatban, Alföldi Erdőkért Egyesület kiadványa, Szeged.
- Mantovani, D., Veste, M., Badorreck, A., & Freese, D. (2013). Evaluation of fast growing tree water use under different soil moisture regimes using wick lysimeters. *iForest - Biogeosciences and Forestry* **6**(4), 190–200. doi: <https://doi.org/10.3832/ifer0100-006>
- Mantovani, D., Veste, M., Boldt-Burisch, K., Fritsch, S., Koning, L. A., & Freese, D. (2015). Carbon allocation, nodulation, and biological nitrogen fixation of black locust (*Robinia pseudoacacia* L.) under soil water limitation. *Annals of Forest Research* **58**(2), 259–274. doi: <https://doi.org/10.15287/afr.2015.420>
- Mantovani, D., Veste, M., & Freese, D. (2011). How much water is used by a black locust (*Robinia pseudoacacia* L.) short-rotation plantation on degraded soil? Tagungsbeitrag zu: Jahrestagung der DBG Kommission IV.
- Mantovani, D., Veste, M., & Freese, D. (2014a). Black locust (*Robinia pseudoacacia* L.) ecophysiological and morphological adaptations to drought and their consequence on biomass production and water-use efficiency. *New Zealand Journal of Forestry Science* **44**(1), 29. doi: <https://doi.org/10.1186/s40490-014-0029-0>
- Mantovani, D., Veste, M., & Freese, D. (2014b). Effects of Drought Frequency on Growth Performance and Transpiration of Young Black Locust (*Robinia pseudoacacia*L.). *International Journal of Forestry Research* **2014**(1), 1–11. doi: <https://doi.org/10.1155/2014/821891>
- Megyés, A. (2013). Energianövény termesztési technológiák. Debrecen: Debreceni Egyetem, Agrár- és Gazdálkodástudományok Centruma.
- Rédei, K., Osvath-Bujtas, Z., Veperdi, I., et al. (2008). Black locust (*Robinia pseudoacacia* L.) improvement in Hungary: a review. *Acta Silvatica et Lignaria Hungarica* **4**(1), 127–132.
- Rédei, K., & Veperdi, I. (2009). The role of black locust (*Robinia pseudoacacia* L.) in establishment of short-rotation energy plantations in Hungary. *International Journal of Horticultural Science* **15**(3), 41–44. doi: <https://doi.org/10.31421/ijhs/15/3/832>
- Rolbiecki, S., Kasperska-Wołowicz, W., Ptach, W., Jagosz, B., Figas, A., Rolbiecki, R., Stachowski, P., Grybauskiene, V., Chmura, K., & Dobosz, K. (2019). Water Needs of Black Locust *Robinia pseudoacacia* L. in the First Three Years of Growing in the Reclamation Plantings in Poland. In A. Krakowiak-Bal & M. Vaverkova (Eds.), *Infrastructure and environment* (pp. 234–242). Springer International Publishing. doi: https://doi.org/10.1007/978-3-030-16542-0_30
- Sadras, V., & Milroy, S. (1996). Soil-water thresholds for the responses of leaf expansion and gas exchange: A review. *Field Crops Research* **47**(2), 253–266. doi: [https://doi.org/10.1016/0378-4290\(96\)00014-7](https://doi.org/10.1016/0378-4290(96)00014-7)
- Schwärzel, K., Zhang, L., Strecker, A., & Podlasly, C. (2018). Improved Water Consumption

Estimates of Black Locust Plantations in China's Loess Plateau. *Forests* **9**(4), 201. doi: <https://doi.org/10.3390/f9040201>

Veste, M., & Kriebitzsch, W.-U. (2010). Response of chlorophyll fluorescence, photosynthesis and transpiration in *Robinia pseudoacacia* L. to drought stress. *Verhandlungen der Gesellschaft für Ökologie* **40**(1), 26.

Veste, M., Mantovani, D., Kriebitzsch, W., & Freese, D. (2013). How efficient is the water use and biomass production of *Robinia pseudoacacia*? In *Agroholz 2013 conference*.

Wang, L., Wei, S., Horton, R., & Shao, M. (2011). Effects of vegetation and slope aspect on water budget in the hill and gully region of the Loess Plateau of China. *CATENA* **87**(1), 90–100. doi: <https://doi.org/10.1016/j.catena.2011.05.010>

Wang, Y.-L., Liu, G.-B., Kume, T., Otsuki, K., Yamanaka, N., & Du, S. (2010). Estimating water use of a black locust plantation by the thermal dissipation probe method in the semiarid region of Loess Plateau, China. *Journal of Forest Research* **15**(4), 241–251. doi: <https://doi.org/10.1007/s10310-010-0184-y>

Wu, Y.-Z., Huang, M.-B., & Warrington, D. N. (2015). Black Locust Transpiration Responses to Soil Water Availability as Affected by Meteorological Factors and Soil Texture. *Pedosphere* **25**(1), 57–71. doi: [https://doi.org/10.1016/S1002-0160\(14\)60076-X](https://doi.org/10.1016/S1002-0160(14)60076-X)

Yan, M.-J., Yamanaka, N., Yamamoto, F., & Du, S. (2009). Responses of leaf gas exchange, water relations, and water consumption in seedlings of four semiarid tree species to soil drying. *Acta Physiologiae Plantarum* **32**(1), 183–189. doi: <https://doi.org/10.1007/s11738-009-0397-x>