

Table 4. The influence of different methods of cultivation on trunk girth of North American hackberry in three years of cultivation

| fertilization (A) | | With geocomposite use | | | | | | | | | | | |
|------------------------|---------------|------------------------------|-----|------|-------------------|------------------------------|-----|-------------------|------------------|------------------------------|------|------|------------------|
| | | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) |
| | | PBM | PR | MF | | PBM | PR | MF | | PBM | PR | MF | |
| | | 2011 | | | 2012 | | | 2013 | | | | | |
| Trunk girth (cm) | with | 8.6 | 3.7 | 11.3 | 7.9 | 11.9 | 6.7 | 14.3 | 11.0 | 15.7 | 11.1 | 17.2 | 14.7 |
| | without | 8.3 | 4.7 | 10.7 | 7.9 | 10.5 | 5.7 | 15.6 | 10.6 | 13.9 | 9.1 | 18.5 | 13.8 |
| | \bar{x} (B) | 8.5 | 4.2 | 11.0 | | 11.2 | 6.2 | 15.0 | | 14.8 | 10.1 | 17.9 | |
| | | LSD (A) – n.s. | | | LSD (A) – 0.3 | | | LSD (A) – 0.4 | | | | | |
| | | LSD (B) – 0.6 | | | LSD (B) – 0.6 | | | LSD (B) – 0.5 | | | | | |
| | | LSD (A × B) – 0.8 | | | LSD (A × B) – 0.9 | | | LSD (A × B) – 0.7 | | | | | |

PBM – pine bark mulch, PR – living mulch with perennial ryegrass, MF – mechanical fallow
LSD – least significant difference, n.s. – not significant

Table 5. The influence of different methods of cultivation on number of side shoots of North American hackberry in three years of cultivation

| fertilization (A) | | With geocomposite use | | | | | | | | | | | |
|-----------------------------|---------------|------------------------------|------|------|-------------------|------------------------------|------|-------------------|------------------|------------------------------|------|------|------------------|
| | | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) |
| | | PBM | PR | MF | | PBM | PR | MF | | PBM | PR | MF | |
| | | 2011 | | | 2012 | | | 2013 | | | | | |
| Number of side shoots | with | 18.1 | 11.6 | 19.7 | 16.5 | 24.1 | 17.8 | 25.2 | 22.4 | 42.4 | 36.2 | 36.1 | 38.3 |
| | without | 16.5 | 14.5 | 18.2 | 16.4 | 17.7 | 16.1 | 18.0 | 17.3 | 35.2 | 25.5 | 49.1 | 36.6 |
| | \bar{x} (B) | 17.3 | 13.1 | 19.0 | | 20.9 | 17.0 | 21.6 | | 38.8 | 30.9 | 42.6 | |
| | | LSD (A) – n.s. | | | LSD (A) – 0.9 | | | LSD (A) – 1.1 | | | | | |
| | | LSD (B) – 1.2 | | | LSD (B) – 1.1 | | | LSD (B) – 3.3 | | | | | |
| | | LSD (A × B) – 1.6 | | | LSD (A × B) – 1.5 | | | LSD (A × B) – 4.7 | | | | | |

PBM – pine bark mulch, PR – living mulch with perennial ryegrass, MF – mechanical fallow
LSD – least significant difference, n.s. – not significant

Table 6. The influence of different methods of cultivation on length of side shoots of North American hackberry in three years of cultivation

| fertilization (A) | | With geocomposite use | | | | | | | | | | | |
|-------------------------------------|---------------|------------------------------|------|------|-------------------|------------------------------|------|-------------------|------------------|---------------------------|------|-------|------------------|
| | | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) | method of cultivation (B) | | | \bar{x} (A) |
| | | PBM | PR | MF | | PBM | PR | MF | | PBM | PR | MF | |
| | | 2011 | | | 2012 | | | 2013 | | | | | |
| Length of side shoots (cm) | with | 30.3 | 19.3 | 19.7 | 23.1 | 69.8 | 44.7 | 52.7 | 55.7 | 116.7 | 94.4 | 117.3 | 109.5 |
| | without | 33.1 | 17.0 | 31.3 | 27.1 | 44.6 | 19.0 | 50.9 | 38.2 | 113.6 | 77.5 | 123.9 | 105.0 |
| | \bar{x} (B) | 31.7 | 18.2 | 25.5 | | 57.2 | 31.9 | 51.8 | | 115.2 | 86.0 | 120.6 | |
| | | LSD (A) – 1.1 | | | LSD (A) – 1.3 | | | LSD (A) – 3.9 | | | | | |
| | | LSD (B) – 1.3 | | | LSD (B) – 1.6 | | | LSD (B) – 4.7 | | | | | |
| | | LSD (A × B) – 1.9 | | | LSD (A × B) – 2.3 | | | LSD (A × B) – 6.7 | | | | | |

PBM – pine bark mulch, PR – living mulch with perennial ryegrass, MF – mechanical fallow
LSD – least significant difference, n.s. – not significant

Fertilization had also a significant effect on numbers of side shoots during the second year and the third year of cultivation, where more side shoots were formed in fertilized trees. Taking into account the method of cultivation during the whole experiment the least number of side shoots was determined in plants cultivated with perennial ryegrass as living mulch and the largest number of side shoots was present in trees maintained in mechanical fallow. Factors interaction influenced the least number of side shoots in the second and the third year was living mulch with perennial ryegrass without use of fertilizer. There is no clear tendency with obtaining the largest number of side shoots during factors interaction. Number of side shoots between 2012 and 2013 with the most favorable weather course increased by approximately 20 shoots, while between the less favorable 2011 and temperate 2012 only by 1–6 shoots (tab. 5).

The results showed, that fertilized trees had longer side shoots in the second and the third year of cultivation. In all three years the most unfavorable cultivation method was living mulch with perennial ryegrass. Trees cultivated according to this method always had the shortest side shoots. The longest side shoots in the first two years had plants mulched with pine bark but in the third when using a mechanical fallow. In all three years of study the factors interac-

tion influenced the shortest side shoots in trees growing with perennial ryegrass as living mulch without use of fertilizer. There is no clear tendency with obtaining the longest side shoots during factors interaction. The increase in shoot length between 2011 and 2012 was at the level of 25 cm, while between 2012 and 2013, which had the most favorable weather course, has doubled (tab. 6).

In all the years of research a significant positive correlation between selected biometric features and total nitrogen content in leaves of North American hackberry was found. In 2011 it was observed that the increase of nitrogen content by 1% favored the vegetative development of tested tree – hackberry was higher by 51 cm, its trunk circumference increased by 8.7 cm and the number of side shoots grew by 7.7. The same change direction, but with a slightly greater features independence was also proven in 2012 and 2013. Trees height increased, respectively, by 87 and 92 cm, trunk girth by 11.3 and 7.8 cm and the number of side shoots 5.9 and 10.4. (tab. 7).

The analysis of linear correlation also showed a significant association between biometric features and soil salinity. The increase in salinity primarily resulted in shortening the side shoots (correlation coefficient r was respectively -0.491 in 2011, -0.564 in 2012 and -0.900 in 2013). Soil salinity was related

Table 7. Correlation coefficients and simple regression equations between biometric features of North American hackberry and foliar N content and soil salinity in years 2011–2013

| Treatment | Year | Plant height (m) | Crown diameter (m) | Trunk girth (cm) | Number of side shoots | Length of side shoots (cm) |
|--|------|---------------------------------|---------------------------------|---------------------------------|------------------------------|--------------------------------|
| Foliar N content (% of fresh weight) | 2011 | 0.536* $y = 0.51x + 1.31$ | -0.018 | 0.633* $y = 8.69x - 5.70$ | 0.557* $y = 7.69x + 4.42$ | -0.192 |
| | 2012 | 0.896* $y = 0.87x + 0.83$ | 0.265 | 0.893* $y = 11.3x - 8.77$ | 0.472* $y = 5.95x + 9.52$ | 0.420 |
| | 2013 | 0.813* $y = 0.92x + 2.11$ | 0.468 | 0.782* $y = 7.76x + 0.59$ | 0.485* $y = 10.4x + 19.1$ | 0.644* $y = 30.5x + 53.5$ |
| Soil salinity ($\mu\text{S}\cdot\text{cm}^{-1}$) | 2011 | 0.086 | -0.493* $y = -0.0076x + 2.7$ | 0.005 | 0.172 | -0.491* $y = -0.15x + 43.3$ |
| | 2012 | -0.502* $y = -0.005x + 3.32$ | -0.480* $y = -0.006x + 3.09$ | -0.781* $y = -0.108x + 30.5$ | -0.279 | -0.564* $y = -0.32x + 105$ |
| | 2013 | -0.809* $y = -0.015x + 6.49$ | -0.773* $y = -0.017x + 5.57$ | -0.734* $y = -0.122x + 36.3$ | -0.755 | -0.900* $y = -0.71x + 236$ |

* Significant correlation ($\alpha = 0.05$)

to the crown diameter to a lesser extent ($r = -0.493$ in 2011, -0.480 in 2012 and -0.773 in 2013). The concentration of soluble salts in the soil also contributed to a reduction in plant height and trunk girth – it was proven only in the last two years of study (tab. 7).

DISCUSSION

In all three years of cultivation the largest trunk girths of North American hackberry were observed in trees maintained in mechanical fallow. These results corroborate previous studies of Licznar-Małańczuk [2012], which found the best radial growth of trees, determined by trunk sectional area, in herbicide fallow and with agrotexile mulching. First two years of North American hackberry cultivation showed that trunk girth was not affected by the use of fertilizer and our results are similar to those obtained by Raese et al. [2007] where trunk girth was not affected by the different N rates of fertilizers. The significant effect of fertilization on this biometric feature in North American hackberry was observed in the second and third year of cultivation and fertilized plants had larger trunk girth than unfertilized. Moreover, in the second and third year, trees cultivated with fertilization were higher and had longer shoots in comparison to unfertilized plants. Lower values of this features obtained in the first year might be associated with too much fertilizer and/or retention of water and ions in the hydrogel matrix and thus the competition for resources between the hydrogel contained in the geocomposite and plants roots. In some cases most of the water retained in hydrogel is bound so strongly that plants cannot use it to gain but only to sustain vital functions [Jaroszuk-Sierocińska and Słowińska-Jurkiewicz 2008]. Furthermore, nutrition deficiencies resulting from the retention of the nutrients in the hydrogel may appear. Rowe et al. [2005] showed that in some cases acrylic polymers may act as ion exchange resins, which result in deficiencies of divalent ions, such as calcium, magnesium or iron. The cause is a strong binding between them and the carboxyl groups of the hydrogel thereby preventing those ions from uptake by plant roots. Such strong competition for nutrients can influence directly on plants growth.

The results of three years of research show that in the case of North American hackberry cultivation, the geocomposite interaction with fertilization in the first year had rather negative effect on the biometric features, especially on the measurement of the shoot length and height. However, this combination did not cause necrosis of seedlings contrary to Arevalo's [2009] results in which found a negative effect of hydrogels used simultaneously with fertilization on the survival of Canary Island pine seedlings.

The use of living mulches is a popular method to maintain the proper parameters of soil and reduce weed infestation and thus to obtain good quality crops with reduced labor input. In North American hackberry use of living mulch with perennial ryegrass had negative effect on all biometric features during all three years of study and the best biometric features were obtained by North American hackberry grown in mechanical fallow. As reported by Derr [2001], limited growth rates of trees, especially young ones, could be related to significant weed infestations in orchards. A similar effect is caused by the presence of living mulches that increase competition for water, nutrients and space within the root system [Hoagland et al. 2008]. Shoot length and total annual growth of examined trees were consistent with the data reported earlier by Licznar-Małańczuk [2012]. In both cases the least number of the shortest length of shoots were produced by trees growing with living mulches.

In cultivation of North American hackberry which the highest number of shoots in all years of study obtained while maintaining in mechanical fallow. This does not coincide with the result obtained by Matta et al. [1981], who noted that in the case of white fir trees mulching with black foil, colorless foil, straw, sawdust, black foil with straw, black foil with sawdust and without mulching produced statistically the greatest number of shoots. The highest trees of North American hackberry were observed in all years of cultivation in mechanical fallow, while the lowest were always trees growing with perennial ryegrass. On the other hand, research of Matta et al. [1981] showed no effect of mulching on the growth of Austrian pine and Scotch pine.

In North American hackberry fertilized plants were higher and had longer shoots, whereas the results obtained by Wrona [2011] show that nitrogen fertilization had no significant effect on tree growth in comparison to unfertilized ones. This reaction of North American hackberry may be due to a very strong retention of cations and anions supplied along with fertilizers in pine bark mulch, the uptake by perennial ryegrass roots and/or storage in its tissues, as well as retention in the hydrogel matrix contained in the geocomposite. Mulch, geocomposite and ryegrass compete in fact with North American hackberry for nutrients. Moreover, in North American hackberry cultivation the use of multi-nutrient fertilizer did not affect the superior growth of trees in the first year but increased tested features in the next two years of research. Similar are the results obtained by Treder [2006] which shows that at the beginning of the study the strongest growth was observed in trees fertilized with nitrogen fertilizer but finally the highest were trees fertilized with multi-nutrient fertilizer.

In all three years of studies a positive correlation between plant height and the content of N in leaves was found. Liang et al. [2014] in the research into larch also showed that tendency – trees with higher N content in needles were higher. In our research a positive correlations between trunk girth and foliar N content and between the number of side shoots and foliar N content were also found. It might be affected by better N nourishment and thus stronger vegetative growth. In all three years of studies a negative correlation between crown diameter and soil salinity was noticed. The research of Benyon et al. [1999] also shows the reduction of crown volume with increasing salinity in *Eucalyptus occidentalis* and *E. camaldulensis*. Moreover, in North American hackberry the crown diameter may be also affected by shoot length and in all three years of studies a negative correlation between soil salinity and shoot length was also found. Similar results were obtained by Bader et al. [2015], where shoot elongation of olive tree ‘Meski’ and ‘Ascolana’ declined sharply as salinity increased. Also the results of Incesu et al. [2014] confirm, that by increasing salinity level the shoot length of two persimmon rootstock *Diospyros kaki* and *D. virginiana* significantly decreased. In the second and the

third year of our studies a negative correlations between tree height and soil salinity, as well as between trunk girth and soil salinity were observed. In research conducted by Naeini et al. [2006] in pomegranate ‘Malas Torsh’ and ‘Alah Torsh’ the reduction of stem length with increasing salinity was also noted, while in *Tamarix chinensis* [Cui et al. 2010] two negative correlations were found: between plant height and salinity as well as between stem diameter and salinity.

CONCLUSIONS

1. Mechanical fallow in rows had the most preferably influence on growth parameters of North American hackberry.

2. Conversely, living mulch with perennial ryegrass had rather a negative impact on cultivation of the studied tree species.

3. There was found a positive correlation between biometric features and foliar N content, as well as negative correlation between biometric features and soil salinity.

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