Effects of Water Treatment on Non-structural Carbohydrates in Different Organs of Elm Seedlings: Postprint

Authors: Wang Kai, Zhao Chengjiao, Lin Tingting, Yu Guoqing, Sun Ju, Wang Kai

Date: 2019-09-09T00:00:00+00:00

Abstract

Normal watering, mild, moderate, and severe drought treatments were established to analyze the variation characteristics of soluble sugars, starch, and non-structural carbohydrates (NSC) in different organs of two-year-old elm seedlings with extended treatment duration (15, 30, 45 d, and 60 d). The results showed: At 15 d of water treatment, with increasing drought severity, the soluble sugar content in leaves and fine roots exhibited a decreasing trend; leaf starch content was lowest under moderate and severe drought treatments at (18.35±0.06) mg・g-1; and soluble sugar content in stems and coarse roots under severe drought treatment was significantly lower than in other treatments. At 30 d of treatment, leaf starch and NSC contents showed an increasing trend with increasing drought severity, with leaf starch content reaching the highest value under severe drought treatment at (47.83±0.27) mg・g-1; starch and NSC contents in stems and coarse roots under mild drought treatment were significantly lower than under suitable water treatment. At 45 d of treatment, with increasing drought severity, the soluble sugar/starch ratio in fine roots showed a decreasing trend; leaf soluble sugar content, soluble sugar/starch ratio, and stem starch content under severe drought treatment were significantly higher than in other treatments. At 60 d of treatment, with increasing drought severity, the soluble sugar/starch ratio in leaves and fine roots gradually increased; soluble sugar, starch, and NSC contents in coarse roots under severe drought treatment were significantly higher than in other treatments, with NSC content reaching the maximum value of (68.88±1.01) mg・g-1. These results indicate that soluble sugar, starch, and NSC contents in different organs of elm seedlings exhibited differential responses with extended treatment duration, with NSC decreasing in various organs and accumulating in coarse roots. This provides a basis for water management of elm shelterbelts in the Horqin Sandy Land.

Full Text

Effects of Different Water Treatments on Non-Structural Carbohydrates in Different Organs of *Ulmus pumila* Seedlings in the Horqin Sandy Land

WANG Kai[1], ZHAO Cheng-jiao[1], LIN Ting-ting[1], YU Guo-qing[2], SUN Ju[3]

[1]College of Environmental Science and Engineering, Liaoning Technical University, Fuxin 123000, Liaoning, China
[2]Liaoning Institute of Sandy Land Improvement and Utilization, Fuxin 123000, Liaoning, China
[3]Shenyang Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110016, Liaoning, China

Abstract

Two-year-old *Ulmus pumila* seedlings were grown under suitable water, mild drought, moderate drought, and severe drought treatments. The soluble sugar, starch, and non-structural carbohydrate (NSC) contents in different organs of the seedlings were measured after 15, 30, 45, and 60 days of drought treatment. The results showed that on the 15th day of treatment, the soluble sugar contents in leaves and fine roots decreased with increasing drought level, and the starch content in leaves under moderate and severe drought treatments reduced to the minimum value of (18.35±0.06) mg · g^{1}. The soluble sugar contents in stems and coarse roots under severe drought treatment were significantly lower than those under other treatments. On the 30th day of treatment, the starch and NSC contents in leaves increased with increasing drought degree, and the starch content in leaves under severe drought treatment increased to the maximum value of (47.83±0.27) mg · g^{1}. The starch and NSC contents in stems and coarse roots under mild drought treatment were lower than those under suitable water treatment. On the 45th day of treatment, the ratio of soluble sugar to starch in fine roots decreased with increasing drought level. The soluble sugar content, ratio of soluble sugar to starch in leaves, and the starch content in stems under severe drought treatment were significantly higher than those under other treatments. On the 60th day of treatment, the ratio of soluble sugar to starch in leaves and fine roots gradually increased with increasing drought degree. The soluble sugar, starch, and NSC contents in coarse roots under severe drought treatment were significantly higher than those under other treatments, and the NSC content increased to the maximum value of (68.88±1.01) mg · g^{1}. These results indicated that soluble sugar, starch, and NSC in all organs of *U. pumila* seedlings responded differently with increasing treatment time. The NSC in each organ decreased and accumulated in coarse roots. This provides evidence for water management of *U. pumila* protection forests in Horqin sandy land.

Keywords: *Ulmus pumila* Linn.; seedling; organ; non-structural carbohydrate; Horqin sandy land

1 Materials and Methods

1.1 Study Area

The study was conducted at the Liaoning Technical University experimental base (42°42 N, 122°32 E) in the Horqin Sandy Land. The region has a temperate semi-arid continental monsoon climate with an average altitude of 345 m. The mean annual temperature is 6.82°C, with extreme minimum and maximum temperatures of -33.4°C and 43.2°C, respectively. Annual precipitation ranges from 400–550 mm, with 70% occurring from June to August. Annual evaporation is 1200–1450 mm. The soil organic matter content in the 0–20 cm layer is 5.72%-9.80%, and total nitrogen content is 7.73%-9.60% [16]. The area experiences frequent droughts, with average wind speeds of 3.2 m · s^{1}, maximum wind speeds exceeding 5 m · s^{1} for 240 days annually, and 154 windy days per year, mainly in spring. The natural vegetation includes *Pinus sylvestris* var. *mongolica*, *Pinus tabuliformis*, *Populus* spp., and *Ulmus pumila* [17].

1.2 Experimental Design

In May 2015, two-year-old *U. pumila* seedlings with uniform growth were selected and transplanted into plastic pots (30 cm diameter, 35 cm height, 17 kg soil capacity). The soil substrate was a mixture of local sandy soil and peat soil (2:1 v/v) with a field capacity of 17.52%, pH of 6.7, organic matter content of 7.79 g · kg^{1}, total nitrogen of 0.31 g · kg^{1}, total phosphorus of 0.11 g · kg^{1}, total potassium of 87.19 g · kg^{1}, available nitrogen of 6.01 mg · kg^{1}, available phosphorus of 3.58 mg · kg^{1}, and available potassium of 59.33 mg · kg^{1} [17].

After one year of cultivation, in May 2016, 64 healthy seedlings of similar size ((37.76±5.14) cm height, (0.44±0.08) mm stem base diameter) were selected for the drought experiment. Four water treatments were established based on field capacity: suitable water (W1, 80% field capacity), mild drought (W2, 60–55% field capacity), moderate drought (W3, 50–45% field capacity), and severe drought (W4, 40–35% field capacity) [13, 15]. Each treatment had 16 replicates. The pots were weighed daily at 18:00 to maintain target water content by replenishing the water loss. The experiment lasted for 60 days.

1.3 Sample Collection and Measurement

Five seedlings per treatment were randomly selected and harvested after 15, 30, 45, and 60 days of treatment. The plants were separated into leaves, stems, coarse roots (diameter $>$ 2 mm), and fine roots (diameter $<$ 2 mm). All samples were oven-dried at 105°C for 30 minutes, then at 70°C to constant weight, and finally ground into powder for NSC determination.

Soluble sugar content was measured using the anthrone colorimetric method [20], and starch content was determined by enzymatic hydrolysis followed by the same colorimetric method. NSC content was calculated as the sum of soluble sugar and starch contents.

1.4 Data Analysis

All data were analyzed using SPSS 20.0 software. Two-way ANOVA was used to examine the effects of drought level, treatment duration, and their interactions on soluble sugar, starch, NSC contents, and the soluble sugar/starch ratio. Duncan' s multiple range test was used for multiple comparisons among treatments at = 0.05 significance level.

2 Results and Analysis

2.1 Effects of Water Treatments on Non-Structural Carbohydrates in Leaves

On the 15th day of treatment, soluble sugar content in leaves decreased with increasing drought level, with W4 showing significantly lower values than other treatments (Table 1). Starch content under moderate and severe drought treatments decreased to the minimum value of (18.35±0.06) mg · g ^{1}. NSC content showed no significant differences among treatments.

On the 30th day, starch and NSC contents in leaves increased with drought severity, with starch content under severe drought reaching the maximum value of (47.83±0.27) mg · g ^{1}, which was significantly higher than other treatments. Soluble sugar content showed no significant differences among treatments.

On the 45th day, the soluble sugar/starch ratio in leaves under severe drought was significantly higher than in other treatments. Soluble sugar content under severe drought was also significantly higher than in other treatments.

On the 60th day, the soluble sugar/starch ratio in leaves increased with drought level. Soluble sugar, starch, and NSC contents under severe drought were significantly higher than those under suitable water treatment.

2.2 Effects of Water Treatments on Non-Structural Carbohydrates in Stems

On the 15th day, soluble sugar content in stems under severe drought was significantly lower than under other treatments. No significant differences were observed for starch or NSC contents among treatments.

On the 30th day, starch and NSC contents under mild drought were significantly lower than under suitable water treatment. The soluble sugar/starch ratio under severe drought was significantly higher than under other treatments.

On the 45th day, the soluble sugar/starch ratio under mild drought was significantly lower than under other treatments. Starch and NSC contents under mild drought were also significantly lower than under suitable water treatment.

On the 60th day, no significant differences were observed for any measured parameters among treatments.

2.3 Effects of Water Treatments on Non-Structural Carbohydrates in Coarse Roots

On the 15th day, no significant differences were observed for any parameters among treatments.

On the 30th day, starch and NSC contents under mild drought were significantly lower than under suitable water treatment.

On the 45th day, the soluble sugar/starch ratio under mild drought was significantly lower than under other treatments. No significant differences were observed for other parameters.

On the 60th day, soluble sugar, starch, and NSC contents under severe drought were significantly higher than under other treatments, with NSC content reaching the maximum value of (68.88±1.01) mg · g ¹.

2.4 Effects of Water Treatments on Non-Structural Carbohydrates in Fine Roots

On the 15th day, soluble sugar content decreased with increasing drought level, with W4 showing significantly lower values than other treatments. No significant differences were observed for starch or NSC contents.

On the 30th day, no significant differences were observed for any parameters among treatments.

On the 45th day, the soluble sugar/starch ratio decreased with increasing drought level. Soluble sugar content under severe drought was significantly higher than under other treatments.

On the 60th day, the soluble sugar/starch ratio increased with drought level. Soluble sugar content under severe drought was significantly higher than under other treatments.

[Figure 2: see original paper] Effects of different water treatments on non-structural carbohydrates in stems of *Ulmus pumila* seedlings

[Figure 3: see original paper] Effects of different water treatments on non-structural carbohydrates in coarse roots of *Ulmus pumila* seedlings

[Figure 4: see original paper] Effects of different water treatments on non-structural carbohydrates in fine roots of *Ulmus pumila* seedlings

3 Discussion

Non-structural carbohydrates serve as important osmotic regulators and energy sources for plants under drought stress [21]. Previous studies have shown that NSC content in plant tissues reflects the carbon balance status and drought resistance capacity [5, 7]. In this study, the responses of soluble sugar, starch, and NSC in different organs of *U. pumila* seedlings varied with drought duration and intensity.

During the early stage of drought (15 days), soluble sugar contents in leaves and fine roots decreased with increasing drought severity. This may be due to reduced photosynthesis and increased consumption of soluble sugars for osmotic adjustment [8, 26]. The decrease in starch content in leaves under moderate and severe drought suggests that starch hydrolysis was insufficient to compensate for the carbon deficit.

After 30 days of drought, starch and NSC contents in leaves increased with drought severity, indicating that *U. pumila* seedlings could maintain carbon assimilation and accumulate NSC under mild and moderate drought conditions [28]. However, the lower starch and NSC contents in stems and coarse roots under mild drought suggest carbon allocation priority to leaves for survival.

On the 45th day, the soluble sugar/starch ratio in fine roots decreased with drought level, suggesting that roots enhanced starch storage for long-term survival [33]. The accumulation of soluble sugar and starch in leaves under severe drought indicates that *U. pumila* could adjust carbon partitioning among organs to cope with prolonged drought.

By the 60th day, the significant accumulation of NSC in coarse roots under severe drought demonstrates that *U. pumila* seedlings prioritize carbon storage in roots for drought survival [10]. This strategy ensures carbohydrate supply for root growth and maintenance when soil water becomes available again [34]. The increased soluble sugar/starch ratio in leaves and fine roots reflects enhanced osmotic adjustment capacity under severe drought stress.

The differential responses of NSC components among organs suggest that *U. pumila* employs organ-specific carbon allocation strategies during drought. Leaves maintain soluble sugar levels for osmotic adjustment, while coarse roots serve as the primary NSC storage organ for long-term drought survival [32]. This finding provides a physiological basis for water management in *U. pumila* protection forests in sandy lands.

4 Conclusion

Drought stress significantly affected the contents and ratios of soluble sugar, starch, and NSC in different organs of *U. pumila* seedlings. The responses varied with drought duration and intensity. In the early stage, drought reduced soluble sugar contents in leaves and fine roots. During prolonged drought, *U. pumila* accumulated NSC in leaves and particularly in coarse roots. The organ-specific carbon allocation strategy, with coarse roots serving as the primary NSC storage site, enhances drought survival. These results provide scientific evidence for water management practices in *U. pumila* protection forests in the Horqin Sandy Land.

References

[1] IPCC. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change[M]. Cambridge: Cambridge University Press, 2014.

[2] Anderegg W R, Anderegg L D. Hydraulic and carbohydrate changes in experimental drought-induced mortality of saplings in two conifer species[J]. Tree Physiology, 2013, 33(3): 252-260.

[3] Richardson A D, Carbone M S, Keenan T F, et al. Seasonal dynamics and age of stemwood nonstructural carbohydrates in temperate forest trees[J]. New Phytologist, 2013, 197(3): 850-861.

[4] Salleo S, Trifilo P, Esposito S, et al. Starch-to-sugar conversion in wood parenchyma of field-growing *Laurus nobilis* plants: A component of the signal pathway for embolism repair[J]. Functional Plant Biology, 2009, 36(9): 815-825.

[5] Dietze M C, Sala A, Carbone M S, et al. Nonstructural carbon in woody plants[J]. Annual Review of Plant Biology, 2014, 65(1): 667-687.

[6] Xie H T, Yu M K, Cheng X R. Leaf non-structural carbohydrate allocation and C N P stoichiometry in response to light acclimation in seedlings of two subtropical shade-tolerant tree species[J]. Plant Physiology & Biochemistry, 2018, 124: 146-154.

[7] Zhou Chaobin, Wang Mengyao, Gong Wei. Relationship between ray tissue features and non-structural carbohydrates in xylem of *Haloxylon ammodendron*[J]. Arid Zone Research, 2018, 35(5): 1105-1110.

[8] Du Yao, Han Yi, Wang Chuankuan. The influence of drought on nonstructural carbohydrates in the needles and twigs of *Larix gmelinii*[J]. Acta Ecologica Sinica, 2014, 34(21): 6090-6100.

[9] Zhang Ting, Cao Yang, Chen Yunming, et al. Effects of drought stress on non-structural carbohydrates of *Robinia pseudoacacia* saplings at the end of the growing season[J]. Journal of Soil and Water Conservation, 2016, 30(5): 297-304.

[10] Kannenberg S A, Novick K A, Phillips R P. Coarse roots prevent declines in whole-tree non-structural carbohydrate pools during drought in anisohydric and isohydric species[J]. Tree Physiology, 2017, 38(4): 1-9.

[11] Shi Yufei, Jin Yonghuan, Jin Lanshu, et al. Study on the soil spatial variability of *Ulmus pumila* open forest in Horqin Sandy Land[J]. Arid Zone Research, 2015, 32(5): 897-902.

[12] Zhang Jiyi, Fu Dong, Wei Zhenzhen, et al. Determination of the ability of several tree and shrub species to endure and survive extreme aridity with methods of limited areas under field condition in Horqin Sandy Land[J]. Acta Ecologica Sinica, 2016, 26(2): 467-474.

[13] Wang Kai, Lei Hong, Liu Jianhua. Evaluation of drought-resistant physiological characteristics of roots and leaves for main afforestation tree species in Northwest Liaoning Province, China in spring[J]. Chinese Journal of Applied Ecology, 2016, 27(6): 1853-1860.

[14] Wang Kai, Lei Hong, Xia Yang, et al. Responses of non-structural carbohydrates of poplar seedlings to increased precipitation and nitrogen addition[J]. Chinese Journal of Applied Ecology, 2017, 28(2): 399-407.

[15] Xin Fumei, Yang Xiaolin, Zhao Kentian, et al. Effect of drought stress on characteristics of water consumption and photosynthesis for main arbor species in semi-arid valley of Lhasa[J]. Journal of Zhejiang University (Agriculture & Life Sciences), 2016, 42(2): 199-208.

[16] Wang Kai, Song Lining, Lv Linyou, et al. Fine root biomass vertical distribution character of main afforestation tree species in Horqin Sandy Land[J]. Bulletin of Botanical Research, 2014, 34(6): 824-828.

[17] Zhu Jiaojun, Kang Hongzhang, Li Zhihui, et al. Impact of water stress on survival and photosynthesis of Mongolian pine seedlings on sandy land[J]. Acta Ecologica Sinica, 2005, 25(10): 2527-2533.

[18] Hoch G, Popp M, Korner C. Altitudinal increase of mobile carbon pools in *Pinus cembra* suggests sink limitation of growth at the Swiss treeline[J]. Oikos, 2002, 98(3): 361-374.

[19] Buyssse J, Merckx R. An improved colorimetric method to quantify sugar content of plant tissue[J]. Journal of Experimental Botany, 1993, 44(267): 1627-1629.

[20] Guo Ruipan, Xin Zeyu, Wang Zhiqiang, et al. Effect of drought stress on non-structure carbohydrate metabolism of wheat and its relationship with drought resistance[J]. Acta Agriculturae Boreali-Sinica, 2015, 30(2): 202-211.

[21] McDowell N, Pockman W T, Allen C D, et al. Mechanisms of plant survival and mortality during drought: Why do some plants survive while others succumb to drought?[J]. New Phytologist, 2008, 178(4): 719-739.

[22] Liu Shuming, Sun Jiaqian, Deng Zhenyi, et al. Effects of drought stress on stomatal change in leaves of *Populus euphratica*[J]. Arid Zone Research, 2018, 35(5): 1111-1117.

[23] Xia Shangguan, Zhang Jinchi, Liang Shuying. Relationship between drought resistance and physiological change of three elm seedlings under water stress[J]. Journal of Nanjing Forestry University (Natural Sciences Edition), 2008, 32(3): 131-134.

[24] Li Yongjie, Li Jin, Xu Ping, et al. Physiological responses of *Lycium ruthenicum* seedlings to drought stress[J]. Arid Zone Research, 2014, 31(4): 756-762.

[25] Yoshimura K, Masuda A, Kuwano M, et al. Programmed proteome response for drought avoidance/tolerance in the root of a C3 xerophyte (wild watermelon) under water deficits[J]. Plant Cell Physiology, 2008, 49(2): 226-241.

[26] Sevanto S. Phloem transport and drought[J]. Journal of Experimental Botany, 2014, 65(7): 1751-1759.

[27] Dong Yanhong, Liu Binbin, Zhang Xu, et al. Responses of non-structural carbohydrate metabolism of cucumber seedlings to drought stress and doubled CO concentration[J]. Chinese Journal of Applied Ecology, 2015, 26(1): 53-60.

[28] Zhang Renhe, Xue Jiquan, Pu Jun, et al. Influence of drought stress on plant growth and photosynthetic traits in maize seedlings[J]. Acta Agronomica Sinica, 2011, 37(3): 521-528.

[29] Zhao Chao, Wang Haiyan, Liu Meizhen, et al. Effect of drought on the contents of soluble sugars, starch and enzyme activities in cassava stem[J]. Plant Physiology Journal, 2017, 53(5): 795-806.

[30] McDowell N G, Sevanto S. The mechanisms of carbon starvation: How, when, or does it even occur at all?[J]. New Phytologist, 2010, 186(2): 264-266.

[31] Nardini A, Casolo V, Dal Borgo A, et al. Rooting depth, water relations and non-structural carbohydrate dynamics in three woody angiosperms differentially affected by an extreme summer drought[J]. Plant Cell & Environment, 2015, 39(3): 618-627.

[32] McDowell N G. The mechanisms of carbon starvation: How, when, or does it even occur at all?[J]. New Phytologist, 2010, 186(2): 264-266.

[33] Wiley E, Helliker B. A re-evaluation of carbon storage in trees lends greater support for carbon limitation to growth[J]. New Phytologist, 2012, 195(2): 285-289.

[34] Piper F I, Fajardo A, Hoch G. Single-provenance mature conifers show higher non-structural carbohydrate storage and reduced growth in a drier location[J]. Tree Physiology, 2017, 37(8): 1-11.

[35] Sala A, Woodruff D R, Meinzer F C. Carbon dynamics in trees: Feast or famine?[J]. Tree Physiology, 2012, 32(6): 764-775.

Note: Figure translations are in progress. See original paper for figures.