J. Hydrol. Hydromech., 72, 2024, 1, 15–24
https://doi.org/10.2478/johh-2023-0037

sciendo Journal of Hydrology and Hydromechanics Institute of Hydrology SAS

Soil moisture regime in lowland forests – quantity and availability of water

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Abstract: Water is one of the key ecological factors that has a great impact to development and productivity of lowland species such as *Quercus robur*. This paper deals with water regime influence to site conditions of these species and how actually changeable soil moisture affects *Q. robur*. Studied area includes a protective embankment built on the river bank in order to eliminate flooding effect, which means that all needs for water these associations provide from rainfalls and groundwater. Water regime was monitored during two critical years (extremely dry and extremely wet) on four soil types – Planosol, Fluvisol and Gleysol that belong to hydromorphic (three experimental plots) and Chernozem which belongs to automorphic soils (three experimental plots), respectively. It was studied the distribution of rainfalls and groundwater during the growing seasons and how it affects total and available water amount in the soil. The main focus should be given to available water, because it is located in capillary pores and plants can utilize it. Bearing in mind rainfalls makes just 15–20% of the total water amount in the soil it is much more significant to evaluate its proportion in available water. Based on obtained results, we can deduce that much more suitable site conditions for *Q. robur* are present on hydromorphic soils due to much greater proportion of groundwater.

Keywords: *Quercus robur*; Soil moisture; Available water; Groundwater; Precipitation.

INTRODUCTION

The possibility of determining the water regime in specific habitat conditions and defining the relationship between plant associations from one side and extremely wet or dry habitats from another side is of essential importance, not only for the normal growth and development of forest ecosystems, but also for planning the application of adequate management measures (Letić et al., 2006; Letić et al., 2014; Nikolić, 2016). It should be noted that species are rarely found in nature in their ecological optimum, i.e. in the locality where they can achieve the maximum production of organic matter. Expanding of populations of a certain species in some area is a consequence of their gradual adaptation to the present site conditions. One of the most important environmental factors for the functioning and survival of forest ecosystems is water.

Water balance in plants is one of the key factors responsible, not only for their growth and development, but also for basic metabolic activities maintaining (Donohue et al., 2007; Feng et al., 2012; Porporato et al., 2004). It should be emphasised that lack of water may impact a lot the length of the growing season and radial and height growth rate by trees, as well. Water balance is actually closely related to the quantity of water absorbed by the root system and the quantity of water released by transpiration from aerial parts of the plant (Nikolić Jokanović, 2021). Water is especially important in the belt of lowland forests that are usually located in flooding areas and in these ecosystems significant variations in the amount of the soil moisture affect vegetation succession (Hrvoľ et al., 2009; Nikolić and Jokanović, 2019). The water content in the soil is related to the mutual interaction of the solid, liquid and gaseous phases of water and soil, then to the movement of moisture in the soil, as well as to the processes related to the exchange of moisture between the soil and the surrounding environment (Gomez et al., 2009; Taiz et al., 2018). The water regime is a qualitative element that shows the available water supplies in the soil over the long period of time, and is expressed by the total amount of water that reaches the soil in different ways, as well as the amount that is available to plants (Nikolić, 2016).

The soil has the ability to absorb water, to let part of the free water pass through the depth of the profile and to retain water of different categories, and water constants are used to quantitatively determine certain water properties (Vučić, 1987). Water constants depend on the mechanical composition of the soil, the structure and content of organic matter, as well as on the implemented agro-technical measures, and for forest ecosystems the following are important: maximum soil water capacity, field water capacity for soil, water retention and wilting point (Kanianska et al., 2022; Kramer, 1944). Maximum soil water capacity is a constant that represents the water content in the soil when water saturation is in maximum fulfilling the micropores and they are theoretically equal to the total porosity. Maximum soil water capacity is undesirable because anaerobic conditions occur, which puts the plants in a state of stress and puts maximum pressure on the metabolic activities of the plants (Dragović, 1997). Field water capacity is a condition where micropores are filled with water and macropores with air, after maximum saturation and seepage of free water under the influence of gravity (Knežević and Košanin, 2007). Water retention is the amount of water that is in the capillary pores of the soil after the drainage of gravity water and the values of this water constant are often equal to the field water capacity (Belanović, 2012). The wilting point is the equilibrium state between the suction force of the root system and the soil particles and plants start to lose turgor (Vučić, 1987).

The investigation of the correlative relationship between the *Q. robur* habitat features and the water regime in the protected area of Srem forests (Serbia) is one of the initial steps in solving problem of *Q. robur* decline which makes a lot of damage to this economically and ecologically very valuable species (Letić et al., 2014; Medarević et al., 2009; Nikolić Jokanović et al., 2020). Soils are a dynamic system constantly under the influence of natural and anthropogenic factors (embankments building, construction of meliorative canals, etc.) which affect the modification of their characteristics and impact *Q. robur* as a species that grows in these site conditions.

Water absorption demands a very close contact between the plant root and soil particles – in case the volume of the roots and the root zone in the rhizosphere layer of the soil is greater, it will cause a greater possibility of absorption (Johansson et al., 2000). Root growth is mainly related to soil moisture sources that enable its intensive growth, while these root parts which are no longer actively involved in absorption die off (Nikolić, 2016). As a consequence, we have asymmetric root growth.

There are two main factors which affect water movement through the rhizosphere zone – soil structure and soil texture (Jeje and Zimmermann, 1979). According to its more expressed permeability, sandy soils tend to dry out quickly, unlike clayey soils whose capacity of receiving water and nutrients is very limited (Kramer and Boyer, 1995). Water movement is unconditionally related to capillary movement, infiltration, and filtration (Jezek and Blatt, 2017; Kim et al., 2014). Transport of water is possible both through unsaturated and saturated soil. Direction in which water moves and its speed depend on several factors: physical and chemical soil characteristics, organic matter content and the forces responsible for its movement (Lichner et al., 2023). In general, water movement is unconditionally connected with capillary forces, gravity, and hydrostatic pressure.

The main scope of the paper is to study how water regime impacts *Q. robur* site characteristics at protected area of Srem forests where the embankment building eliminated flooding influence, so these associations are mainly supplied with water from precipitation and groundwater. As for specific goals, they are mainly focused on determination of soil capacity for water uptake that is mostly dependent on water-air regime and physical and retention properties of the soil. In addition, specific goals also include variation of available water quantity in the soil during growing season.

MATERIALS AND METHODS

In a spatial-geographical sense, the area of lowland Posavina forests in Serbia covers an area of about 42,000 ha, i.e. it stretches between 44º37'53" and 45º11'37"north latitude (φ) and between 18°59'45" and 20º21'30" east longitude (λ), (Fig. 1). In this paper are analysed areas covered with forest vegetation where embankment building excluded the influence of surface flood waters and this affects changing of hydrological site conditions. The soils of the researched area belong to the alluvial plain of the Sava River, and their properties depend on the mineralogical and textural composition of the alluvial sediment deposited in this area. Water regime was investigated on four soil types – three belongs to hydromorphic and another one to automorphic soils. Based on the spatial analysis of the researched area and habitat characteristics, a total of six localities (experimental plots) were selected because permanent monitoring of groundwater level fluctuations was carried out there. Experimental plots were divided into two groups – the first one includes three units (1a – Planosol, 1b – Fluvisol, 1c – Gleysol) that are located on hydromorphic soil (Fig. 1, Table 1 and 2), while another group includes also three experimental plots (2a, 2b, 2c – all belong to Chernozem) situated on automorphic soil (Fig. 1, Table 1 and 2). According to WRB 2022 classification, experimental plots belong to following soil types: a1 – Haplic Planosol, b1 – Haplic Fluvisol, c1 – Mollic Gleysol, a2 – Luvic Chernozem, b2 – Luvic Chernozem, c2 – Calcic Chernozem, (Fig. 1, Table 2). At all selected areas were conducted field and laboratory work, and then statistical processing of obtained results.

Field research

This phase included several operations: opening of pedological profiles near present structures for permanent monitoring of groundwater level (piezometers); determination of soil types; taking samples for pedological analyses in damaged and undamaged state (in Kopecky cylinders) from the central part of each horizon on all pedological profiles (34 samples); during the growing season, once a month, soil samples were taken for current moisture analysis, from the central part of each horizon on all pedological profiles, and the localities where the samples were collected are located close to open pedological profiles (102 samples).

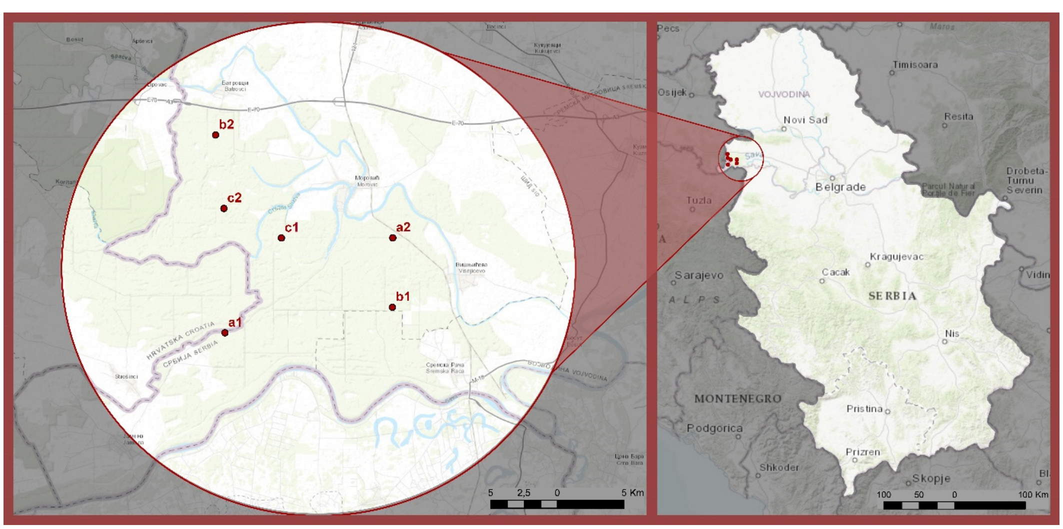

Fig. 1. Map of studied area with experimental plots.

Table 1. Water properties of investigated soils.

Experimental plots	Horizon	Depth	Specific density	Volume density	Total porosity	Water retention by pressures		
						33 kPa	625 kPa	1500 kPa
		cm	g/cm^3	g/cm^3	%vol.	% vol.	% vol.	% vol.
a1 Planosol	Ag	0–30	2.54	1.31	48.43	43.94	30.30	18.39
	Bt,g	30–70	2.60	1.52	41.54	40.20	30.83	13.30
	Cca	70–120	2.63	1.45	44.87	36.23	25.34	14.88
b1 Fluvisol	Aa	0–30	2.63	1.42	46.01	38.07	30.18	20.93
	Ab	30–65	2.65	1.59	40.00	38.52	30.57	20.82
	Cca	65–100	2.66	1.36	48.87	35.75	27.01	18.99
c1 Gleysol	Aa	0–50	2.60	1.39	46.54	41.50	25.94	18.88
	Gso	50–95	2.65	1.56	41.13	39.56	24.90	21.91
	GsoGr	95–120	2.64	1.64	37.88	36.73	27.60	21.99
a2 Chernozem	Amo	0–75	2.59	1.55	40.15	37.83	26.39	16.14
	Cca	75–110	2.62	1.20	54.20	33.46	22.97	16.51
b2 Chernozem	Aa	0–50	2.62	1.52	41.98	40.73	27.98	15.99
	AC	50–95	2.63	1.50	42.97	35.77	29.50	18.90
	Cca	95–120	2.65	1.51	43.02	36.53	22.31	21.27
c2 Chernozem	Amo	0–45	2.57	1.40	45.53	40.77	27.80	18.56
	AC	45–85	2.60	1.56	40.00	38.43	28.45	14.28
	Cca	85–130	2.62	1.34	48.85	34.75	23.36	18.84

Table 2. Display of vegetation and pedological profiles with remarked soil horizons.

Experimental plot **a1**
Haplic Planosol

Experimental plot **b1**
Haplic Fluvisol

Experimental plot **c1**
Mollic Gleysol

Experimental plot **a2**
Luvic Chernozem

Experimental plot **b2**
Luvic Chernozem

Experimental plot **c2**
Calcic Chernozem

Laboratory research

There were carried out a lot of laboratory analysis such as: mechanical soil texture (%) was determined by the pipette method, sample preparation with sodium pyrophosphate was performed according to Racz (1997); textural classes were determined using the Fore triangle (Soil Survey Manual 1955); determination of the specific density of the soil (g/cm^3) was performed according to the Albert-Bogs method with the use of xylene as an internal liquid (Bisić-Hajro, 1997); determination of the volumetric mass of the soil (g/cm^3) was carried out in Kopecky cylinders (100 cm^3), Burlica, (1997); determination of total porosity (% vol) was calculated from the values of specific and volumetric soil mass (Vučić, 1987); water retention at a pressure of 33 kPa was determined using Porous-plate accessories (Marinčić, 1997; Richards, 1947; Richards, 1965); water retention at a pressure of 625 kPa and 1500 kPa was determined using the Presure membrane kit (Marinčić, 1997; Richards, 1947; Richards, 1965); the useful water capacity is determined computationally from the difference of retained water at a pressure of 33 kPa and 1500 kPa (Knežević and Košanin, 2007); the current soil moisture content was determined using the thermogravimetric method (Vučić, 1987).

Determination of water quantity in the soil

The amount of water in the soil is determined on an area of 1 hectare (1 ha = 10.000 m^2) for a layer of thickness h expressed in meters. The total mass of the researched soil in an absolutely dry state is determined according to the following formula:

$$M_z = 10.000\ (\mathrm{m}^2) * h\ (\mathrm{m}) * \rho\ (\mathrm{g/cm}^3)$$
$$M_z = 10.000\ (\mathrm{m}^2) * h\ (\mathrm{m}) * \rho\ (\mathrm{t/m}^3)$$

where M_z – mass of the soil in absolutely dry state (t); h – thickness of the layer (m); ρ – volumetric soil density (g/cm^3).

Water amount in the soil can be calculated in the following way:

$$M_z / 100 = W/b$$
$$W = M_z * b / 100 = 10.000 * h * \rho * b/100 = 100 * h * \rho * b$$

where W – water quantity in the soil (m^3/ha); b – water content in soil in % from mass of absolutely dry soil (%).

If the layer thickness h is expressed in cm, then we have:

$$W = h * \rho * b = h * c$$

where $c = \rho * b$ is soil water content in % of the volume of absolutely dry soil.

The pedological profile consists of different horizons (there are different values of the depth of the horizon, volume mass and current soil moisture values), so the total amount of water in the pedological profile is obtained as the sum of the amount of water per horizon:

$$W = W_1 + W_2 + \ldots W_n$$

where W_1, W_2, …, W_n – water quantity in horizons 1, 2, …, n (m^3/ha).

Available soil moisture presents water which is between field water capacity and wilting point (under tension between 33 kPa and 1.500 kPa).

Quantity of available and total soil moisture was calculated as an average value for experimental plots on Planosol, Gleysol and Fluvisol (1a, 1b, 1c). The same procedure was applied for determining the quantity of available and total soil moisture for experimental plots on Chernozem (2a, 2b, 2c).

RESULTS AND DISCUSSION

If hydromorphic soils are analysed, during both investigated extreme periods, it can be stated that the greatest total soil moisture is found in Gleysol, then in Planosol, while the smallest total soil moisture was recorded in Fluvisol (Fig. 2). As for the available soil moisture on hydromorphic soils (Fig. 5), during both investigated extreme periods, the dominance of Gleysol can be established again, while the situation is slightly different between Planosol and Fluvisol – at the beginning of the growing season, during both critical periods, the larger amount of water available to plants is found in the Planosol, while in the later months, as the process of division and differentiation of cells is increasingly reduced, generally more water available to the plants is found on the Fluvisol. As for the variation of the total soil moisture going from the beginning to the end of the growing season on hydromorphic soils, during the wet period, a slight decrease in those values is observed starting from April and ending in September (Fig. 2). On the other hand, during the dry period, a bit more drastic fall of this parameter can be observed on the Gleysol during July, August and September, while on Planosol and Fluvisol the distribution is more or less constant during the whole vegetation season (Fig. 2). When it comes to available soil moisture, a significant fall in the Gleysol can be observed towards the end of the vegetation season in the wet period, while in the dry period this decreasing tendency on the Gleysol begins already in June (Fig. 5). For the remaining two types of hydromorphic soils, we have a gradual reducing trend of available soil moisture from the beginning to the end of the vegetation season, but it should be noted that the reduction of the value of this parameter is a bit more significant during the dry period (Fig. 5).

Regarding automorphic soils, if we analyse total soil moisture, during both extreme periods, the highest values were detected on c2, then in b2, while the lowest values were recorded in a2 experimental plot (Fig. 3). A completely identical tendency for Chernozem was also obtained for the available soil moisture – experimental plot c2 leads with the highest values, followed by b2, and the lowest values were found in a2 (Fig. 6).

Regarding the distribution of total soil moisture on this type of soil during the growing season, for both extreme periods, a gradual decrease in values can be observed starting from April and ending in September in all three experimental plots (Fig. 3). On the other hand, the tendency of the value of the available soil moisture to decrease is significantly more pronounced as the end of the growing season comes, especially during the dry period, in all three experimental fields (Fig. 6).

If we compare an average values of total and available soil moisture on both soil orders (Fig. 4, Fig. 7), we can deduce that these values are greater by hydromorphic soils for both growing seasons. As for the distribution of the total and available soil moisture on hydromorpic soils, during wet period, there were recorded constantly high values with a slightly decreasing tendention at the end of growing season, while during dry growing season, reduced values occurred beginning from July (Fig. 4 and Fig. 7). The analysis of an average values of total and available soil moisture on automorphic soils shows decreasing tendency by the end of growing season in wet period, while during dry period, there is a fall of these values from June until the end of growing season (Fig. 4 and Fig. 7).

If we analyse the graphical display of the groundwater level by month for the total vegetation season, during the wet year, it can be concluded that it rises almost to the surface of the soil on the hydromorphic soil type, while on the automorphic soil type it reaches its highest level in the period of the highest amount of precipitation (up to about 2 m deep) in the period June-July (Fig. 8).

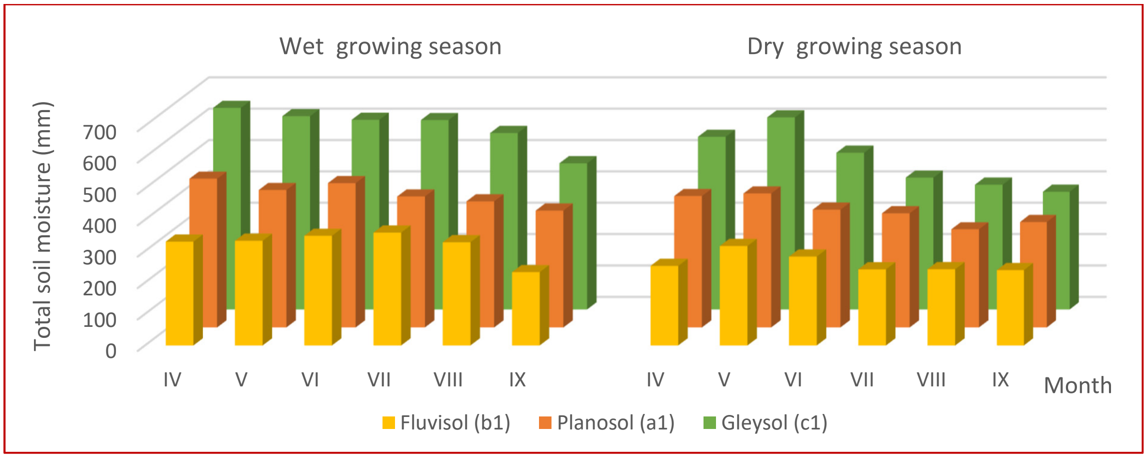

Fig. 2. Total soil moisture in Planosol, Fluvisol and Gleysol soils.

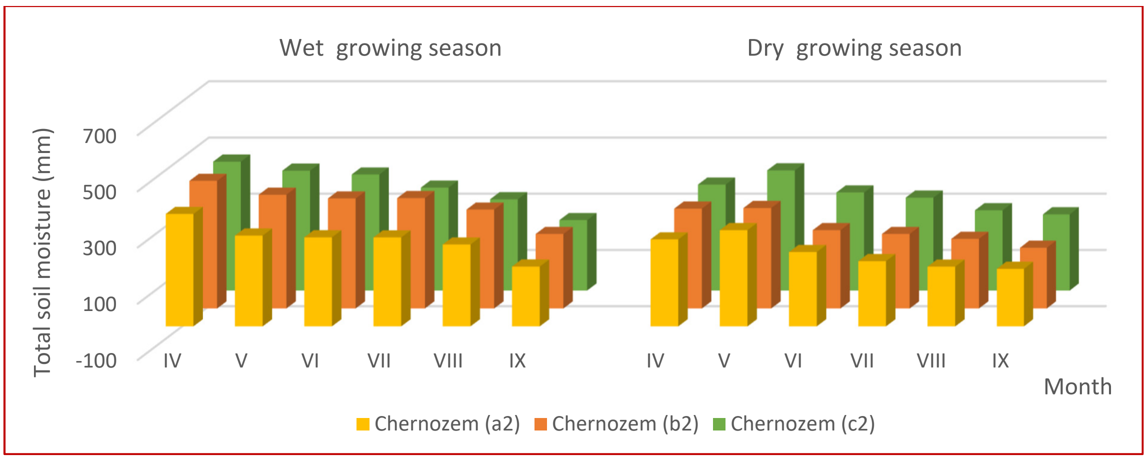

Fig. 3. Total soil moisture in Chernozem soils.

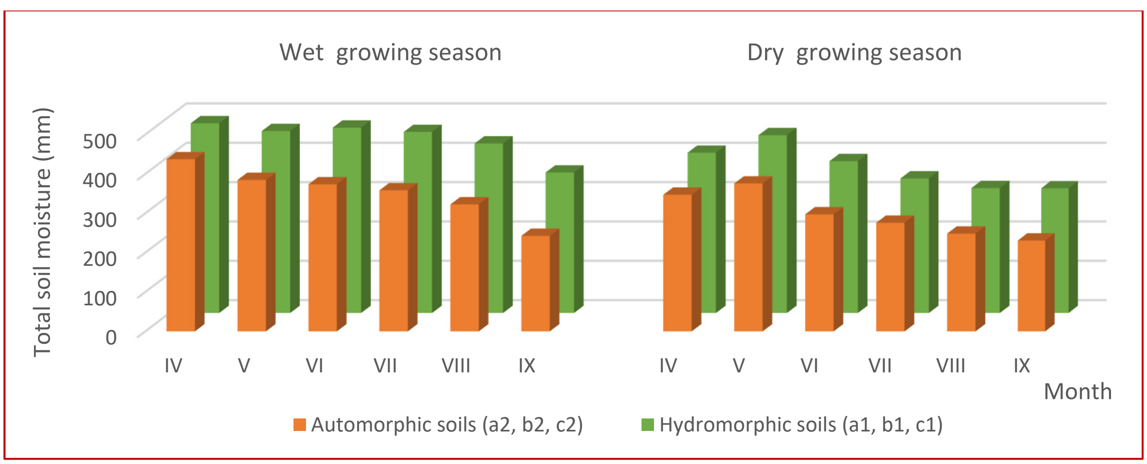

Fig. 4. Total soil moisture in automorphic and hydromorphic soils.

It should also be pointed out fluctuations of groundwater level on hydromorphic soils during the wet period are not so pronounced and that the lowest point to which they descend is registered on Gleysol at a depth of 2 m at the beginning of the vegetation period (Fig. 8).

On the other hand, on Chernozem, the groundwater level drops from 4 to 6 m deep at the beginning of the growing season (Fig. 8). The correlation between the amount of precipitation and the groundwater table is very pronounced, especially during the wet year - the smallest amount of precipitation is recorded at

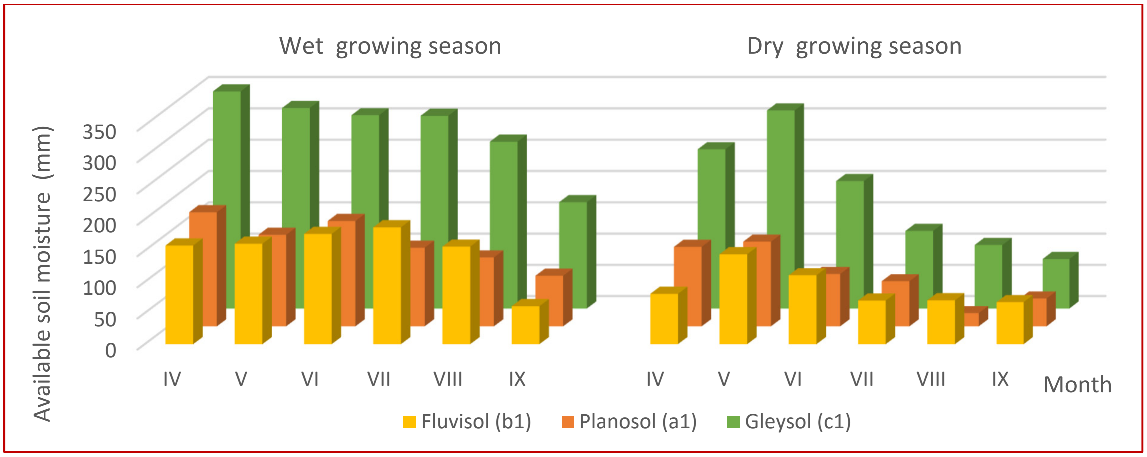

Fig. 5. Available soil moisture in Planosol, Fluvisol and Gleysol soils.

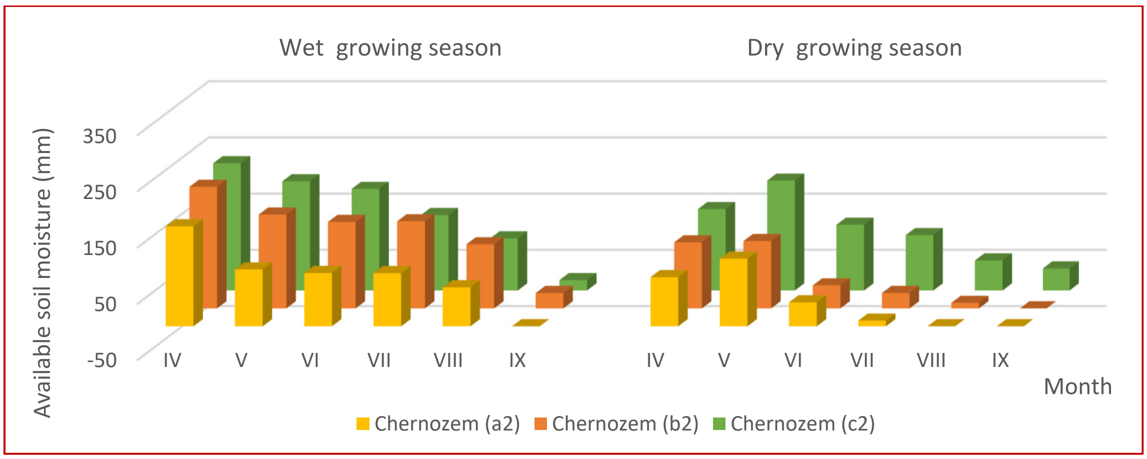

Fig. 6. Available soil moisture in Chernozem soils.

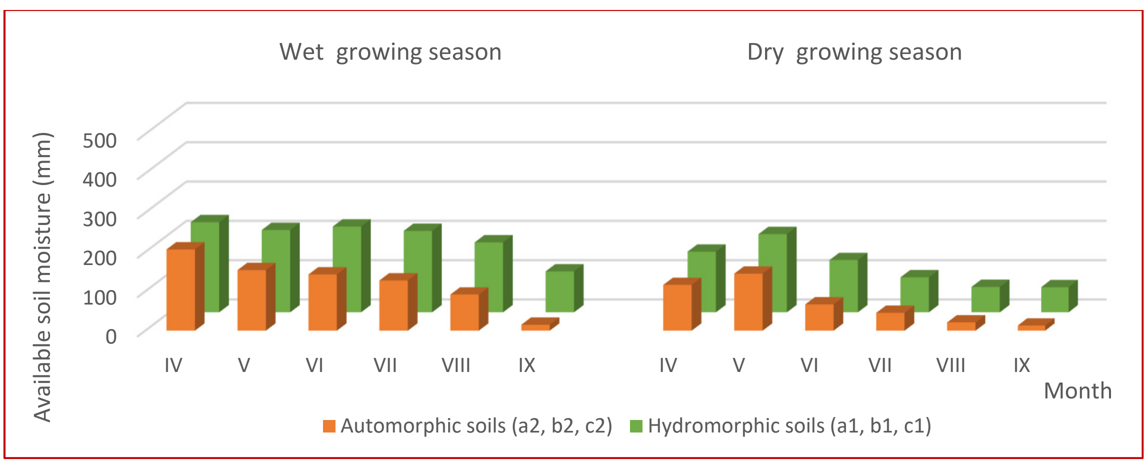

Fig. 7. Available soil moisture in automorphic and hydromorphic soils.

the beginning of the growing season (about 40 mm) and it coincides with the lowest groundwater level (Fig. 8). Then there is a significant increase in the amount of precipitation during May and June (100–110 mm), which causes the culmination of the groundwater level in all types of soil, and after that follows a reduction both in the amount of precipitation and groundwater level (Fig. 8).

As for the dry period (Fig. 8), a drastic reduction in the groundwater level can be observed in all soil types, especially in Fluvisol and Chernozem towards the end of the growing season (groundwater is at a depth of 5.5–6 m), while in Gleysol and Planosol the situation is a little bit more favourable and the lowest groundwater levels were detected in September (4–4.5 m).

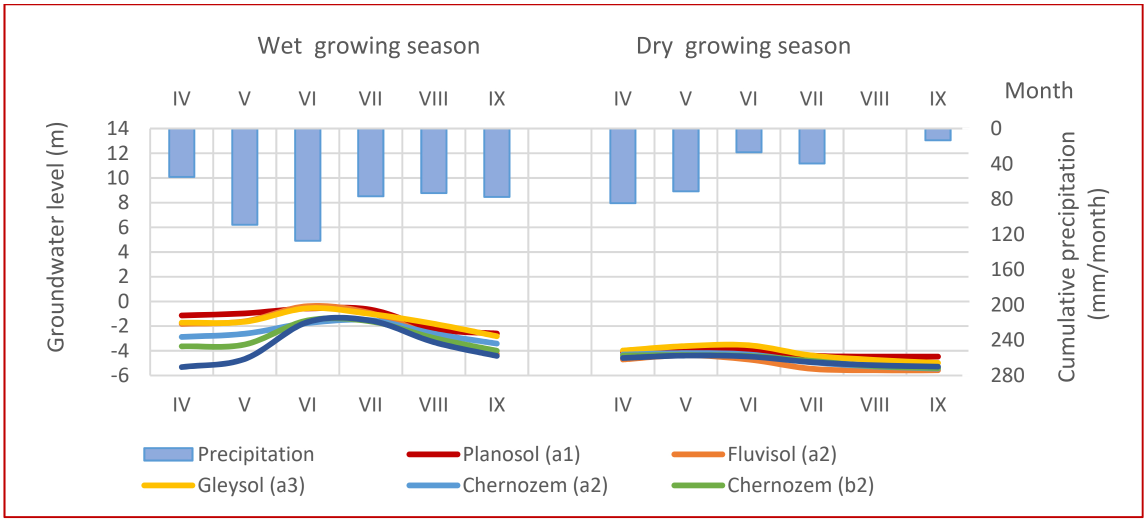

Fig. 8. Display of cumulative precipitation and groundwater distribution on experimental plots.

It should be emphasized that it is particularly important to determine the percentage of precipitation in the available soil moisture, since the precipitation that reaches the forest soil is used in various physiological processes by the plant (it makes up only 15–20% of the depth of physiologically active soil layer which the plant roots can reach). Namely, water from precipitation is retained in capillary and gravity pores, and water in the soil is also found in pores smaller than capillary pores and that water is inaccessible to vegetation. For this reason, it is most important to know the amount of water available to plants, as well as the percentage of hydrological components that make it up.

As above mentioned, due to embankment building and excluding of flooding, there are two factors which affect soil moisture – precipitation and groundwater. For that reason, percentage of precipitation related to available soil moisture was calculated for each month and then was determined an average value for all 12 months (growing season in wet and growing season in dry period). The analysis was conducted for three experimental plots on hydromorphic (a1, b1, c1) and for the other three experimental plots on automorphic soils, as well (a2, b2, c2).

Based on the obtained results, it can be determined that on hydromorphic soils (Gleysol, Planosol, Fluvisol), about 2/3 of the available water in the soil is groundwater, and only 1/3 is precipitation. On the other hand, on automorphic soils (Chernozem), the situation is completely reversed – 2/3 of the available water comes from precipitation, and just 1/3 from groundwater. Based on this, it can be determined that hydromorphic soils are significantly more favorable to the development and production characteristics of the oak, bearing in mind that this hygrophilous species mainly satisfies its needs for the main environmental factor – water from groundwater (Nikolić, 2016). This completely coincides with the fact that hydromorphic soils (Antic et al., 1982) have a light mechanical texture that determines their water-air properties, and on this type of soil, plants are supplied with water mainly through groundwater. As for the chemical composition, the alluvium in Serbia is more or less carbonate and due to the rough mechanical composition, the mobilization of nutrients is very slow and the supply of vegetation with food mainly comes through groundwater. When it comes to the ecological value of alluvial soils, it depends, first of all, on their mechanical composition and the length of groundwater retention in the profile (Antić et al., 1982; Ivanišević, 1993; Ivanišević and Knežević, 2008; Knežević and Košanin, 2007). On the other hand, the most important conditions for the formation of Chernozem are the temperature and soil moisture, which primarily originates from atmospheric precipitation. One of the main characteristics of Chernozem is that it contains significant amounts of organic matter that contribute to intensive humification of the soil profile which affects creating of a powerful humus-accumulative horizon. Despite belonging to the group of the most productive and fertile soils, Chernozems are less favorable to the development-production and ecological characteristics of hygrophilous species compared to hydromorphic soils.

Tuzinsky (2003) studied soil moisture regime in oak forests and established that variations of this element were most intensive during the growing seasons. This author also found that the amount of available water increases from the beginning of the hydrological year up to the spring according to water supplies that origin from snow melting, but also emphasised it depends a lot on climate characteristics (rainfalls and air temperature, before all) during researched period. Niu and Liu (2021) researched water use efficiency in natural oak forests in China exposed to drought stress and found that both spring and summer drought increased water use efficiency, while autumn drought reduced it which can be linked to leaf senescence. These authors also established that short-term droght did not endanger ecosystem function a lot, while long-term drought affected it significantly, before all in terms of evapotranspiration and water use efficiency. Kuster et al. (2012) investigated how air-warming and drought affect water regime and growth properties of young oak stands on two different forest soils and their results showed that these associations can cope with drought periods, but for some more reliable conclusions, more focus has to be given to interaction of drought (air-warming) and soil properties. As for adult oaks in natural forests, behaviour patterns as a response to drought are pretty different compared to young plants, but it can be assumed that these mature oaks are less vulnerable to droughts as they are able to develop long taproots that can provide water from deeper soil horizons (Hanson et al., 2001; Leuzinger et al., 2005).

As for mortality of lowland forests, Kapec (2006) remarked the 1962–1965 period as a time of severe decline and dieback of hygrophilous species situated in the Sava River's middle stream. Dubravac and Dekanić (2009) outlined the occurence of intensive sanitary fellings of pedunculate oak stems in Spačva (Croatia) for period 1996–2006 from two reasons: 1. mature stands are very sensitive to oak mortality and decline; 2. the greatest rate of mortality was recorded by oaks located at microtopographically lowest positions. Pilaš et al. (2007) found that groundwater level significantly affects decline and dieback of oak forests in Croatia, while many authors claimed that the most intensive decline and dieback of oak forests in Srem was related to low content of easily available water (Letić et al., 2014; Nikolić, 2016; Nikolić and Jokanović, 2019). Čermak and Fer (2007) explained the changing of root morphology by pedunculate oak with age and its linkage to mechanisms of water adsorption – young individuals are characterized by the taproot, while adults have heart-shaped root system, so the change in the manner of water uptake can only be related to environmental changes. Weemstra et al. (2013) emphasised that productivity and radial growth of several tree species including pedunculate oak can be dependent a lot on drought events. Gričar et al. (2013) observed the influence of micro-environmental conditions on variation of anatomical traits and annual growth width by floodplain oak forests and established a very significant correlation. In addition to this, detailed wood anatomical analysis can give us additional information about oak tree vitality (Gričar et al., 2014).

Soil can store the amount of water that is determined by its water capacity (Nikolić, 2016). In addition to physical and chemical characteristics, the amount of water in the soil is also influenced by the average duration of flooding or the level of groundwater in the growing season (Herpka, 1979). However, in addition to the quantity, the category of water is also important, which is expressed through water constants. Stored water in the soil is current moisture whose content fluctuates throughout the year. Since not all water in the soil is available for vegetation to use, there are different categories of accessible water, while borders of these categories are defines as water constants whose values can be quantified (Vučić, 1987).

Gravitational water occurs in the researched area as a result of heavy rains or as a result of a high level of groundwater, because the embankments prevent the flood waters of the Sava from overflowing. Capillary water is a very important category of water in the soil, which some authors (Ivanišević, 1993) define as the optimal soil moisture interval. This form of water in the soil is the most significant when it comes to water uptake by vegetation, however, not all capillary water is equally accessible to plants (Vučić, 1987) – water that is under tension between 33 kPa and 625 kPa is easily accessible, and that under tension between 625 kPa and 1,500 kPa is more difficult to access. The soil capacity for easily accessible water is the difference between the field water capacity and the lentocapillary capacity (Đorović, 2001; Vučić, 1987). However, woody species, including the pedunculate oak, can also use water that is under tension between 625 kPa and 1.500 kPa (Miletić, 1995). When all easily accessible water is wasted from the soil for evapotranspiration, and the soil humidity drops below the lento-capillary capacity, forest trees slow down transpiration and all other physiological processes, as well, such as photosynthesis, growing, organic matter producing, etc. (Miletić, 1995). Physiological processes in plants slow down all the more if the soil water tension is higher, ie if the humidity is lower. When the soil moisture drops to the wilting point, that is, when the soil water tension reaches 1.500 kPa (inaccessible water), most plants stop absorbing water from the soil.

In relation to the use of water by vegetation, three basic categories of water are distinguished: gravity, capillary and inaccessible water (Vučić, 1987). Water under tension of less than 33 kPa is gravity water and some of this water is rarely used by plants because it quickly disappears from the soil, causing the coarse gravity pores to fill with air. Longer stagnation of gravity water leads to the creation of anaerobic (reducing) conditions, which results in waterlogging, i.e., there is a difficult access of oxygen and disturbances in the respiration of the root system (Ivanišević, 1993). Also, this water has a harmful effect on several important processes in the soil - oxidation, nitrification and mineralization of organic matter, as well as aeration, on which oxidation-reduction processes in the soil depend.

CONCLUSIONS

The study deals with the impact of hydrological parameters on site characteristics of lowland *Quercus robur* forests in northern part of Serbia. Monitoring of groundwater level and precipitation quantity, and total and available soil moisture, as well, was carried out during growing season of two extreme years – wet and dry. There were selected four soil types – Fluvisol, Gleysol, Planosol (hydromorphic), and Chernozem (automorphic). There is a part of total soil moisture which is present in pores smaller than capillary, so it is inaccessible to plants. Therefore, the paper, before all, is focused on quantity and distribution of available soil moisture during growing season. In the paper was essentialy important to evaluate proportion of precipitation in available soil moisture both on hydromorphic and automorphic soil. Based on the obtained results, on hydromorphic soils, proportion of precipitation and groundwater in available soil moisture is 1:2, while on automorphic soil, the ratio is exactly the same but in favour of precipitation. We can deduce that hydromorphic soils are much more suitable for development and production of hygrophilous species such as *Q. robur* compared to Chernozem, especially during dry growing season. Obtained results may give a recommendation – for evapotranspiration and water balance calculation on alluvial sites a special attention should be paid to additional watering in the soil that originates from groundwater.

Acknowledgements. This paper was financed according to the project entitled: development and implementation of adaptation strategies to climate change in forest management (Adaptive Forest Management - Germany - Serbia) - ANKLIWA-DS.

REFERENCES

Antić, M., Jović, N., Avdalović, V., 1982. Pedologija. Faculty of Forestry, University of Belgrade, 403 p.

Belanović, S., 2012. Melioracije zemljišta – praktikum. Faculty of Forestry, University of Belgrade, 221 p.

Bisić-Hajro, D., 1997. Priručnik za ispitivanje zemljišta. Knjiga V, JDPZ, Beograd, pp. 92–93.

Burlica, Č., 1997. Priručnik za ispitivanje zemljišta. Knjiga V, JDPZ, Beograd.

Čermak, P., Fer, F., 2007. Root systems of forest tree species and their soil-conservation functions on the Krušne hory Mts. slopes disturbed by mining. J. For. Sci., 53, 12, 561–566.

Donohue, R.J., Roderick, M.L. McVicar, T.R., 2007. On the importance of including vegetation dynamics in Budyko's hydrological model. Hydrol. Earth Syst. Sci., 11, 983–995.

Dragović, S., 1997. Determining of soil water constants in: Researching methods and determining of physical soil properties. Jugoslawian Society for Soil Examination, Comission for Soil Physics.

Dubravac, T., Dekanić, S., 2009. Structure and dynamics of the harvest of dead and declining trees of pedunculate oak in the stands of Spačva forest from 1996 to 2006. Šumarski list, 7–8, 391–405.

Đorović, M., 2001. Osnove fizike zemljišta. Unija bioloških naučnih društava Jugoslavije, Beograd.

Feng, X., Vico, G., Porporato, A., 2012. On the effects of seasonality on soil water balance and plant growth. Water Resources Research, 48, 1–12. DOI: 10.1029/2011WR011263

Gomez, D., Aggase, A., Thiebaud, P., Delrot, S., Geros, H., Chaumont, F., 2009. Aquaporins are multifunctional water and solut transporters highly divergent in living organisms. Biochimica et Biophysica Acta, 1788, 6, 1213–1228. DOI: 10.1016/j.bbamem.2009.03.009

Gričar, J., De Luis, M., Hafner, P., Levanič, T., 2013. Anatomical characteristics and hydrologic signals in tree-rings of oaks (*Quercus robur* L.). Trees, 27, 6, 1669–1680. DOI: 10.1007/s00468-013-0914-9

Gričar, J., Jagodic, S., Šefc, B., Trajkovic, J., Eler, K., 2014. Can the structure of dormant cambium and the widths of phloem and xylem increments be used as indicators for tree vitality? Eur. J. For. Res., 133, 3, 551–562. DOI: 10.1007/s10342-014-0784-8

Hanson, P.J., Todd, D.E., Amthor, J.S., 2001. A six-year study of sapling and large-tree growth and mortality responses to natural and induced variability in precipitation and throughfall. Tree Physiology, 21, 345–358. https://doi.org/10.1093/treephys/21.6.345

Herpka, I., 1979. Ekološke i biološke osnove autohtonih topola i vrba u ritskim šumama Podunavlja. Institut za topolarstvo, Novi Sad.

Hrvoľ, J., Horecká, V., Škvarenina, J., Střelcová, K., Škvareninová, J., 2009. Long-term results of evaporation rate in xerothermic Oak altitudinal vegetation stage in Southern Slovakia. Biologia, 64, 3, 605–609.

IUSS Working Group WRB, 2022. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria. https://eurasian-soil-portal.info/wp-content/uploads/2022/07/wrb_fourth_edition_2022-3.pdf

Ivanišević, P., 1993. The impact of soil properties to growth of *Populus* x *euramericana* Guinier (Dode) *cl. I-214* and *Populus deltoides* Bartr. *cl. I-69/55* (Lux). PhD Thesis. Faculty of Forestry, University of Belgrade, 115 p.

Ivanišević, P., Knežević, M., 2008. Tipovi šuma i šumskog zemljišta na području Ravnog Srema – Monografija 250 godina šumarstva Ravnog Srema. JP Vojvodinašume, ŠG Sremska Mitrovica, Petrovaradin, pp. 87–103.

Jeje, A.Y.A., Zimmermann, M.H., 1979. Resistance to water flow in xylem vessels. Journal of Experimental Botany, 30, 4, 817–827. DOI: 10.1093/jxb/30.4.817

Jezek, M., Blatt, M.R., 2017. The membrane transport system of the guard cell and its integration for stomatal dynamics. Plant Physiology, 174, 2, 487–519. DOI:10.1104/pp.16.01949

Johansson, I., Karlsson, M., Johanson, U., Larsson, C., Kjellbom, P., 2000. The role of aquaporins in cellular and whole plant water balance. Biochimica et Biophysica Acta – Biomembranes, 1465, 1–2, 324–342. DOI: 10.1016/S0005-2736(00)00147-4

Kanianska, R., Benková, N., Ševčíková, J., Masný, M., Kizeková, M., Jančová, Ľ., Feng, J., 2022. Fluvisols contribution to water retention hydrological ecosystem services in different floodplain ecosystems. Land, 11, 9, 1510.

Kapec, D., 2006. The influence of dieback intensity, microrelief and Sava's flood water on the condition and the structure pedunculated oak's stands in management unit ''Žutica''. Šumarski list, 130, 9–10, 425–433.

Kim, H.K., Park, J., Hwang, I., 2014. Investigating water transport through the xylem network in vascular plants. Journal of Experimental Botany, 65, 7, 1895–1904. DOI: 10.1093/jxb/eru075

Knežević, M., Košanin, O., 2007. Praktikum iz Pedologije. Faculty of Forestry, University of Belgrade, 100 p.

Kramer, P.J., 1944. Soil moisture in relation to plant growth. Botanical Review, 10, 9, 525–559. http://www.jstor.org/stable/4353309

Kramer, P.J., Boyer, J.S., 1995. Water Relations of Plants and Soils. Academic Press.

Kuster, T.M., Arend, M., Bleuler, P., Günthardt-Goerg, M.S., Schulin, R., 2012. Water regime and growth of young oak stands subjected to air-warming and drought on two different forest soils in a model ecosystem experiment. Plant Biology, 15, s1, 138–147. DOI: 10.1111/j.1438-8677.2011.00552.x.

Letić, Lj., Ivanišević, P., Rončević, S., 2006. Effect of water regime on poplar cultivation. Glasnik Šumarskog fakulteta, 93, 105–119. https://doi.org/10.2298/GSF0693105L

Letić, Lj., Savić, R., Nikolić, V., Lozjanin, R., 2014. Effects of reclamation works on the state of pedunculate oak forests in Ravni Srem. Šumarstvo, 3–4, 117–129. UDK 630*116+630*181.31:582.632.2(497.113)

Leuzinger, S., Zotz, G., Asshoff, R., Körner, C., 2005. Responses of deciduous forest trees to severe drought in Central Europe. Tree Physiology, 25, 641–650. https://doi.org/10.1093/treephys/25.6.641

Lichner, Ľ., Šurda, P., Toková, L., Hološ, S., Kollár, J., Igaz, D., 2023. Impact of duration of land abandonment on soil properties. Journal of Hydrology and Hydromechanics, 71, 2, 148–155.

Marinčić, J., 1997. Priručnik za ispitivanje zemljišta. Knjiga V, JDPZ, Beograd, pp. 44–45.

Medarević, M., Banković, S., Cvetković, Đ., Abjanović, Z., 2009. Problem of forest dying in Gornji Srem. Šumarstvo, 3–4, 61–73. UDK 630*624: 630*4 (497.113)

Miletić, Z., 1995. Promene svojstava zemljišta kao posledica čiste seče šume kitnjaka i graba i šume sladuna i cera na Iverku. Master Thesis. Faculty of Forestry, University of Belgrade.

Nikolić, V., 2016. Watering regime influence on characteristics of pedunculate oak (*Quercus robur* L.) habitats in Ravni Srem. PhD thesis, Faculty of Forestry, University of Belgrade, 228 p.

Nikolić, V., Jokanović, D., 2019. Watering regime influence on sustainability of floristic structure of special nature reserve „Obedska bara“ In: Forests of Southeast Europe Under a Changing Climate Conservation of Genetic Resources. Springer International Publishing, pp. 459–477.

Nikolić Jokanović, V., 2021. Praktikum iz šumske hidrologije. Faculty of Forestry, University of Belgrade, 200 p.

Nikolić Jokanović, V., Vulević, T., Lazarević, K., 2020. Risk assessment of forest decline by application of geostatistics and multi-criteria analysis. Journal of Hydrology and Hydromechanics, 68, 3, 285–292. DOI: 10.2478/johh-2020-0013

Niu, X., Liu, S., 2021. Drought affected ecosystem water use efficiency of a natural oak forest in central China. Forests, 12, 7, 1–19. https://doi.org/10.3390/f12070839

Pilaš, I., Lukić, N., Vrbek, B., Dubravac, T., Roth, V., 2007. The effect of groundwater decrease on short and long term variations of radial growth and dieback of mature pedunculate oak (*Quercus robur* L.) stand. Ekologia (Bratislava), 26, 2, 122–131.

Porporato, A., Daly, E., Rodriguez-Iturbe, I., 2004. Soil water balance and ecosystem response to climate change. Am. Nat., 164, 5, 625–632.

Racz, Z., 1997. Priručnik za ispitivanje zemljišta. Knjiga V, JDPZ, Beograd, pp. 14–16.

Richards, L.A., 1947. Pressure membrane apparatus – construction and use. Journal of Agriculture Engineering, 28, 451–455.

Richards, L.A., 1965. Physical conditions of water in soil. In: Black, C.A. (Ed.): Methods of Soil Analysis, Part 1. American Society of Agronomy, Madison, Wisconsin.

Taiz, L., Zeiger, E., Moller, I.M., Murphy, A., 2018. Plant Physiology and Development. 6th Ed. Sinauer Associates, Oxford University Press.

Tuzinsky, L., 2003. Soil moisture regime in oak forest ecosystem. Silva Balcanica, 3, 1, 79–90.

Vučić, N., 1987. Vodni, vazdušni i toplotni režim zemljišta. Vojvođanska akademija nauka i umetnosti.

Weemstra, M., Eilmann, B., Sass-Klaassen, U.G., Sterck, F.J., 2013. Summer droughts limit tree growth across 10 temperate species on a productive forest site. For. Ecol. Manag., 306, 142–149. DOI: 10.1016/j.foreco.2013.06.007

Received 13 March 2023
Accepted 29 May 2023