Сибирский экологический журнал, 4 (2014) 593–599

УДК 574.5

Nutrient Removal by *Phragmites australis* (Cav.) Trin. ex Steud. in the Constructed Wetland System

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Статья поступила 24.11.2013

ABSTRACTS

Significant results are achieved with the use of semiaquatic vegetation for purification of municipal wastewater as well as other types of waste waters. The first constructed system for purification of municipal wastewater was made at the end of 1970s years in the United Kingdom, with semiaquatic plants playing the role of phytoremediation plants. In Serbia, municipal waste water purification based on constructed wetland system method was applied for the first time in the village of Gložan near Novi Sad and it was put in operation in 2004. The recipient of purified municipal wastewater has been the Danube River. Biological factors in this anthropogenic ecosystem are emergent plants, with dominance of the common reed. This emergent plant with its roles in phytofiltration and phytoaccumulation positively influences the quality of waters finally discharged into the Danube. The paper presents the results of nutrients (N, P, K), organic matter and total ash contents in dry matter of dominant plant species *Phragmites australis* (Cav.) Trin. ex Steud. in Gložan constructed wetland system in the period from 2004 to 2007.

Key words: nitrogen, nutrient removal, phosphorus, potassium.

Interest in the application of aquatic and semiaquatic vegetation in the process of purification of different types of waste water using constructed wetland systems (CWS) has been felt on the global scale in mid-1980s [Nuttall et al., 1997]. This method is a combination of biological, physical and chemical processes, which makes it quite functional, especially when it comes to small rural settlements [Lakatos, 1998]. The CWS method is based on the exploitation of the capacity of semiaquatic plants to take up and accumulate different substances from the substrate and water [Brix, 1994; Nikolić et al., 2003; Nikolić et al., 2007; Brisson, Chazarenc, 2009; Seo et al., 2010; García-Lledó et al., 2011; Calheiros et al., 2012; Ivanova et al., 2012]. At the same time it should be noted that these plants provide living conditions for aerobic microorganisms (rhizosphere), which play an important role in the process of decomposition of waste matter in the water and substrate. Interaction between macrophytes and microorganisms is the basis for the uptake of nitrogen because microbiological processes (ammonification, nitrification and denitrification) are of special importance for transformation of nitrogen and nitrogen-containing substances [White et al., 2011].

More than twenty years ago, in our country, Janković drew attention to different potentials of various aquatic and semiaquatic plants. Among other things, he mentioned their role in the processes of uptake, extraction and accumulation of nutrients and toxic substances, which makes them effective phytofilters and phytoaccumulators [Janković, Janković, 1990].

Certain advances have been made only after the implementation of European Union Directive 91/271/EEC of 1991, which dealt with the treatment of municipal waste waters and which put the method of constructed wetland systems into scientific focus. For the first time in Serbia (in the village Gložan) in 2004, a pilot project was launched whose title was "Purification of municipal waste waters by the wetland method". It was the first biological filter of municipal waste waters, with the Danube River as the ultimate recipient.

The wastewater treatment system in Gložan, with a total area of 1 ha, consists of three separate fields, located in a natural depression made by the Danube River, bordering with two drainage canals (B and B-12). Water purification unfolds in stages. In the first stage, the effluent passes through a rough grillwork and flows into first sedimentation field (field I). In the second stage, the treated water moves to purification field (field II), and in the third stage it comes to the field for improvement of purification effect (field III). After that, the purified water is pumped into the recipient canal B-12 [Josimov-Dunđerski, Belić, 2006].

Phragmites australis (Cav.) Trin. ex Steud., an emergent hydro-helophytic species, dominates in the studied treatment complex. It is the major biological component taking part in the purification of the communal wasterwater from the village of Gložan.

The objective of this paper was, based on the contents of macronutrients (N, P, K), organic matter and total ash in the dry weight of *Phragmites australis* samples taken from the CWS in Gložan, to describe the efficiency of this species in the uptake of nutrients from municipal sanitary wastewater.

MATERIAL AND METHODS

We analyzed the chemical composition of *Phragmites australis* (Cav.) Trine. ex Steud., the dominant plant species in the studied CWS, using standard methods [American Public..., 1995]. Plant material was collected in the periods August – September from 2004 to 2007, of all three fields of the CWS. The average number of individuals per square meter of reed in the first, second and third field was 250, 225 and 175, respectively. Chemical composition was determined in the inflorescences, leaves, stems and rhizomes with roots. The collected plant material was rinsed in distilled water, dried at 100 °C and ground. Total nitrogen in dry weight was determined by standard micro Kjeldahl method [Nelson, Sommers, 1973]. Contents of total (crude) ash and organic matter were determined after incineration at 450 °C. Concentrations of P and K were determined after incineration and treatment with HCl. Total phosphorus was determination by the spectrophotometric ammonium-molybdate-vanadate method [Gericke, Kurmies, 1952]. Potassium in the solution of the parent material was determined by flame emission spectrometry. Analysis of variance (ANOVA) was performed in order to determine significant differences among the examined parameters, between plant parts and fields of the CWS. The least significant difference test (LSD test) was made at the significance levels of 0.05 and 0.01.

RESULTS AND DISCUSSION

During growth and development, plants take up different elements and integrate them by anabolic processes. Intensity of uptake of certain nutrients is specific for each plant species, which is particularly expressed in hydrophytes as opposed to terrestrial plant species [Gerloff, Krombholz, 1966]. Some authors have claimed that there is an active uptake and accumulation of nutrients against the concentration gradient [Boyd, 1970]. In that way, a plant can accumulate certain elements in appropriate compartments, where their concentration can be significantly higher than the concentration in the external environment. Still, Odum [Odum, 1960] maintained that the accumulation of nutrients in the biomass is in correlation with the content of available nutrients in the external environment.

Dry matter of aquatic plants is characterized by a high content of mineral substances (ash), which often exceeds 60 % and plant dry weight [Stojanovic et. al, 1994]. Particularly high contents of ash can be found in submerged plants (hydro-helophytes). It should be noted here that the ashes contain not only mineral elements from plant cells, but also particles of sand, mud and incrusted matter (often calcium salts) from plant surface.

The analysis of chemical composition of the dominant plant species *Phragmites australis* (Cav.) Trine. ex Steud. included the contents of macronutrients (N, P, K), organic matter and total ash in samples gathered in the period 2004–2007. The 2004 data were taken as reference values, i. e., the values of the analyzed parameters before wastewater was pumped into the CWS. Mean values of the analyzed parameters, expressed in percentage in relation to dry mass, are shown in Fig. 1–5.

The lowest value of nitrogen (0.58 %) was recorded in reed roots and rhizomes in 2004, before municipal waste water was let into the system. Pajević et al. [2002] recorded a somewhat higher nitrogen content in reed rhizomes from Kovilj Swamp. The reed leaves, which is understandable from the physiological point, recorded highest nitrogen contents that ranged from 2.83 % (field III in 2004 and 2007), to as much as 4.27 % (field I in 2007; see Fig. 1). These data are consistent with those of Dinka [1986], but slightly higher in relation to those for reed leaves from list from Kovilj Swamp [Pajević et al., 2002] and our earlier results for reed leaves from a fishpond [Nikolić et al., 2007]. The higher nitrogen content in reed leaves from the CWS can be explained by the quality of the treated municipal wastewater, which con-

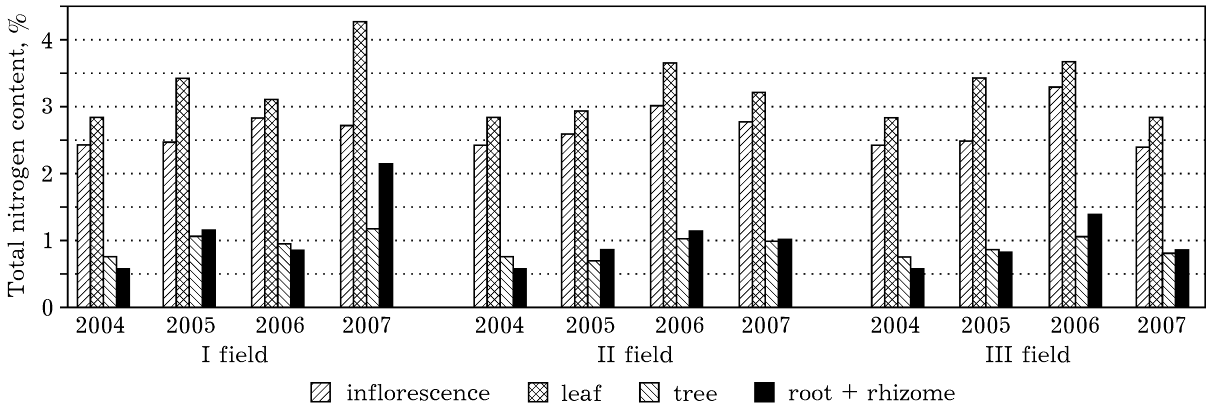

Fig. 1. Total nitrogen content (%) as related to dry matter in *Phragmites australis* (Cav.) Trin. ex Steud. in the CWS in Gložan, 2004–2007

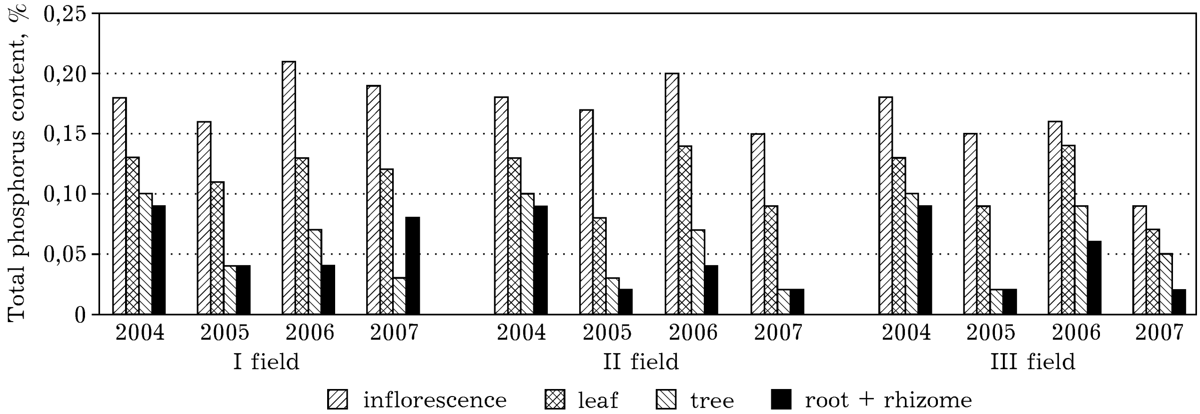

Fig. 2. Total phosphorus content (%) as related to dry matter in *Phragmites australis* (Cav.) Trin. ex Steud. in the CWS in Gložan, 2004–2007

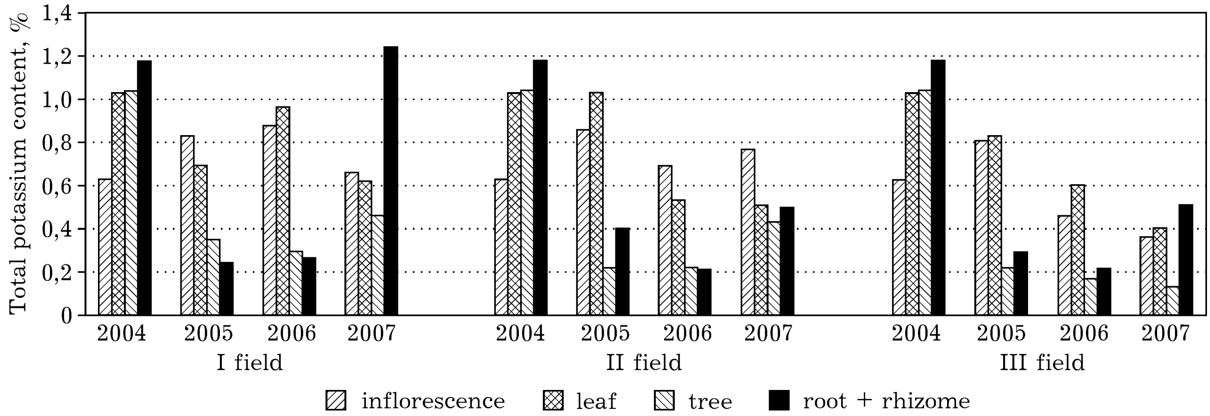

Fig. 3. Total potassium content (%) as related to dry matter in *Phragmites australis* (Cav.) Trin. ex Steud. in the CWS in Gložan, 2004–2007

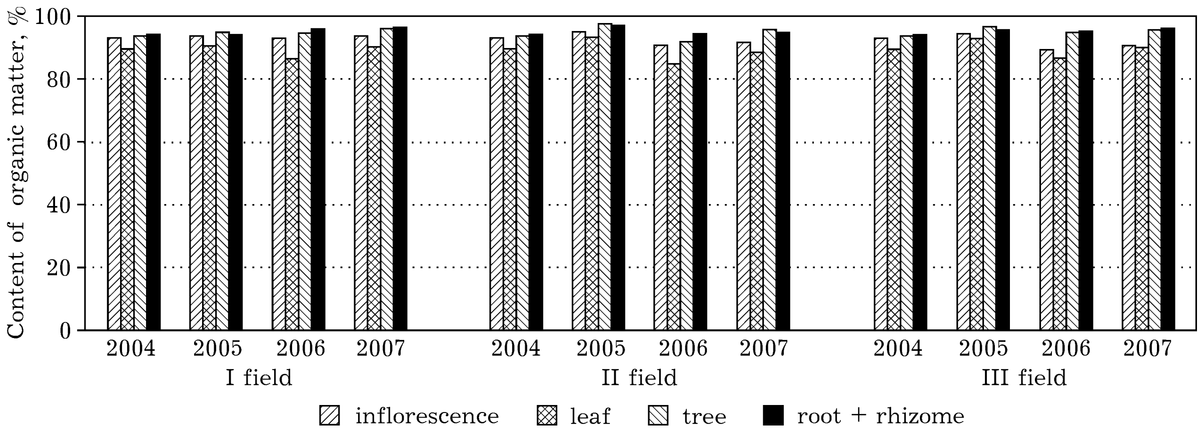

Fig. 4. Content of organic matter (%) as related to dry matter in *Phragmites australis* (Cav.) Trin. ex Steud. in the CWS in Gložan, 2004–2007

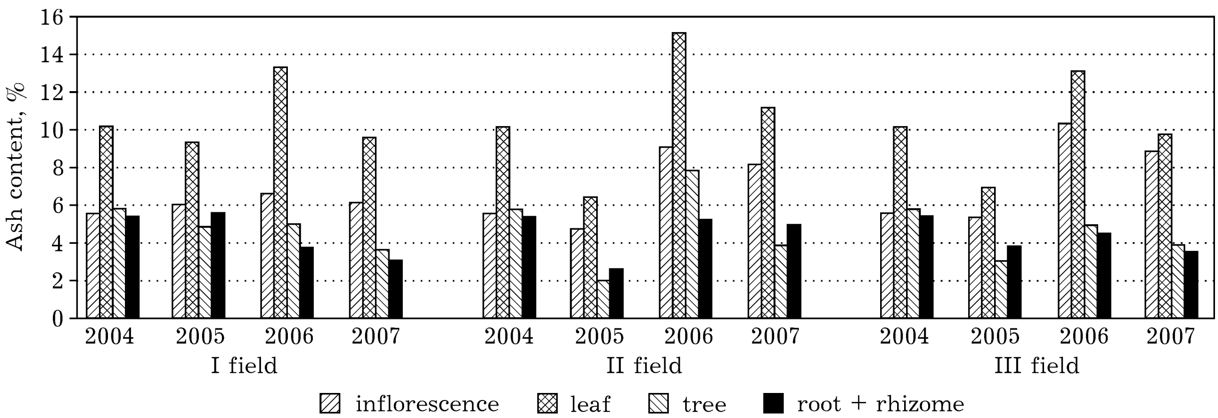

Fig. 5. Ash content (%) as related to dry matter in *Phragmites australis* (Cav.) Trin. ex Steud. in the CWS in Gložan, 2004–2007

tained a considerable organic load [Josimov-Dunđerski, Belić, 2006].

Here it should be mentioned that, in addition to macrophytes, microorganisms are quite active in the process of denitrification and they play an important role in the process of nitrogen extraction in CWSs [Lund et al., 2000].

Lowest phosphorus values (0.02 %) were recorded in the reed rhizomes and roots (fields II and III in 2005 and 2007); the highest value (0.21 %) was found in reed panicles (field I in 2006; see Fig. 2). Such distribution of phosphorus accumulation in various plant parts is characteristic for the reed [Pajević et al., 2002; Radak, 1995]. Considering the phosphorus contained in the substrate of CWSs in the forms of soluble and insoluble organic and inorganic complexes, the reed is a good phytoaccumulator, especially at the stage of intensive vegetation.

Potassium content varied from 0.13 % (the stem, field III in 2007) to 1.24 % (rhizomes and roots, field I in 2007; see Fig. 3) Similar results for the content of potassium in reeds were recorded by Pajević et al. [2002]. At the studied site, the largest range of variations in the potassium content in the analyzed reed parts was registered in 2007.

Organic matter content ranged from 84.85 % (leaves, field II in 2006) to 97.95 % (stems, fields II and III in 2005 see Fig. 4). The obtained data are slightly higher than those found in literature which claim that the average organic matter content in aquatic plants is about 80 % [Westlake, 1971; Duarte et al., 1986].

Ash content ranged from 2.05 % (stems, the field II in 2005) to 15.15 % (leaves, field II in 2006; see Fig. 5). Intensive deposition and retention of mineral substances by the substrate of this biological purifier are reasons for the lower values of total ash in the analyzed plant material in relation to the literature data [Nikolić et al., 2007; Portharaju, Hajra, 1995].

The analysis of variance at significance levels of 0.05 and 0.01 showed that all examined parameters, except potassium content, differed highly significantly in their contents in the analyzed plant parts (Table 1). Likewise, significant differences were also found between the studied years (Table 2).

The relatively high contents of N, P and K in some parts of *Phragmites australis* (Cav.) Trine. ex Steud. indicate that the reed is good phytoaccumulator of these important nutritive substances and that the purification system successfully keeps these substances, thus re-

Table 1

The significance of differences in the content of the examined parameters between different plant organs

Parameters	I-L	I-T	I-R+R	L-T	L-R+R	T-R+R	$LSD_{0.05}$	$LSD_{0.01}$
Organic matter	3.60*			5.73**	6.17**		2.809	3.759
Total N	0.60*	1.74**	1.65**	2.34**	2.25**		0.536	0.717
Total K							0.501	0.671
Total ash	3.59*			5.72**	5.99**		2.774	3.713
Total P	0.06**	0.11**	0.12**	0.5*	0.06**		0.042	0.056

N o t e. Empty – non significant; I – inflorescence, L – leaf, T – tree, R + R – root + rhizome

Table 2

The significance of differences in the content of the examine parameters between different years of research

Parameters	2004/2005	2004/2006	2004/2007	2005/2006	2005/2007	2006/2007	$LSD_{0.05}$	$LSD_{0.01}$
Organic matter				3.18*			2.809	3.759
Total N							0.536	0.717
Total K		0.61*					0.501	0.671
Total ash				3.17*			2.774	3.713
Total P	0.05*		0.05*				0.042	0.056

N o t e. Empty – non significant.

ducing their concentration in the waste water, which flows into the canal 12 B, and then into the Danube, the final recipient of these waste waters. Our results confirm previous results of other authors [Josimov-Dunderski, Belic, 2006] regarding the output values of the characteristic parameters in terms of the effectiveness of waste water purification in the Glozan CWS.

The system for municipal wastewater purification should be continually monitored and maintained, which in the first place implies a timely reed harvest and removal of plant residues, to preclude decaying plant residues from causing secondary pollution in the system.

REFERENCES

American Public Health Association/American Water Works Association/Water Environment Federation, Standard Methods for the Examination of Water and Wastewater 19th ed./ ed. M. H. Franson. Washington, DC 20005, 1995.

Boyd C. Chemical analyses of some vascular aquatic plants // Arch. Hydrobiol. 1970, Vol. 67, N 1. P. 78–85.

Brisson J., Chazarenc F. Maximizing pollutant removal in constructed wetlands: Should we pay more attention to macrophyte species selection // Sci. Total Environ. 2009. N 407. P. 3923–3930.

Brix H. Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives // Wat. Sci. Technol. 1994. Vol. 30, N 8. P. 209–233.

Calheiros S. C. C., Quitério V. B. P., Silva G., Crispim F. C. L., Brix H., Moura C. S., Castro M. L. P. Use of constructed wetland systems with *Arundo* and *Sarcocornia* for polishing high salinity tannery wastewater. http.//repositorio.ucp.pt/bitstream/10400.14/7449/3/Ccalheiros-JEM-2012.pdf, 2012, (accessed 08 January 2013).

Dinka M. Accumulation and distribution of elements in cattail species (*Typha latifolia* L., *Typha angustifolia* L.) and reed *(Phragmites communis* (Cav.) Trin. ex Steudel) living in lake Balaton. Proceedings EWRS/AAB 7th Symposium on Aquatic Weeds, 1986. P. 82–85.

Duarte C. M., Kalff J., Peters R. H. Patterns in biomass and cover of aquatic macrophytes in lakes. Canad // J. Fish. Aquat. Sci. 1986. Vol. 43, N 10. P. 1900–1908.

García-Lledó A., Ruiz-Rueda O., Vilar-Sanz A., Sala L., Bañeras L. Nitrogen removal efficiencies in a free water surface constructed wetland in relation to plant coverage // Ecol. Eng. 2011. N 37. P. 678–684.

Gericke S., Kurmies B. Die kolorimetrische Phosphorsäurebestimmung mit Ammonium-Vanadat-Molybdat und ihre Anwendung in der Pflanzenanalyse. Z. Pflanzenernährung, Düngung, Bodenkunde. 1952. Vol. 59, N 3. P. 32–35.

Gerloff G. C., Krombholz P. H., Tissue analysis as a measure of nutrient availability for the growth of angiosperm aquatic plants // Limnol. Ocean. 1966. N 11. P. 529–539.

Ivanova E. A., Anischenko O. V., Gribovskaya I. V., Zinenko G. K., Nazarenko N. S., Nemchinov V. G., Zuev I. V., Avramov A. P. Metal Content in Higher Aquatic Plants in a Small Siberian Water Reservoir // Contemp. Probl. Ecol. 2012. Vol. 5, N 4. P. 356–364.

Janković M. M., Janković M. Fitosanacioni pojasevi i ekopolja kao efikasni biofiltri u spontanim i antropogeno potpomognutim procesima sanacije i ciscenja zagadenih voda putem stepenaste eutrofikacije (Belts of phytosanation and ecofields as the efficient biophilters in the spontaneous and human – factored processes of sanation and cleaning of the polluted areas by means of steplike eutrophisation) // Ekologija. 1990. Vol. 25, N 2. P. 85–89 (in Serbian with English abstract).

Josimov-Dunderski J., Belić A. Stepen prečišćavanja otpadnih voda naselja Gložan (The degree of purification of waste water village Glozan). Tematski zbornik, Prečišćavanje otpadnih voda sistemom mokrih polja, Univerzitet u Novom Sadu, Poljoprivredni fakultet, Departman za uređenje voda. Novi Sad, 2006. P. 46–52 (in Serbian with English abstract).

Lakatos G., Hungary // Constructed Wetlands for Wastewater Treatment in Europe / ed. J. Vymazal, H. Brix, P. F. Cooper, M. B. Green, R. Haberl. Leiden, Netherlands: Backhuyis Publishers, 1998. P. 191–206.

Lund L. J., Horne J. A., Williams E. A. Estimating denitrification in a large constructed wetland using stable nitrogen isotope ratios // Ecol. Eng. 2000. Vol. 14, N 1–2. P. 67–76.

Nelson D. W., Sommers L. E., Determination of total nitrogen in plant material // Agron. J. 1973. N 65. P. 109–112.

Nikolić Lj., Stojanović S., Lazić D. Uloga trske (*Phragmites australis* (Cav.) Trin. ex Steud.) u procesu preciscavanja komunalnih otpadnih voda metodom mokrih polja (constructed wetlands systems) (Role of Bamboo (*Phragmites australis* (Cav.) Trin. ex Steud.) in communal wastewater purification process in constructed wetlands systems) // Contemporary agriculture. 2007. Vol. 51, N 3–4. P. 230–235 (in Serbian with English abstract).

Nikolić Lj., Stojanović S., Stanković Ž. Content of macro- (N, P, K) and micronutrients (Fe, Mn, Zn) in four promising emergent macrophytic species // Large Rivers. Vol. 14, N 3–4. P. 297–306.

Nuttall P. M., Boon A. G., Rowell M. R. Review of the design and management of constructed wetlands // Construction Industry Research and Information association (CIRIA). L., 1997.

Odum H. T. Ecological potential and analogue circuits for the ecosystem // Am. Sci. 1960. N 48. P. 1–8.

Pajević S., Vučković M., Stanković Ž., Krstić B., Kevrešan Z., Radulović S. The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia // Large Rivers. Vol. 13, N 1–2; Arch. Hydrobiol. Suppl. 2002; Vol. 141, N 1–2. P. 73–83.

Portharaju V., Hajra P. K. Studies on aquatic macrophytic production in two important lakes of Andhra Pradesh, India // Proc. 6th Intern. Conf. on the Conservation and management of Lakes-Kasumigaura '95, Tsukuba, Tsuchiura, Japan, 1995. P. 215–219.

Radak (Nikolić) Lj. Hemijski sastav dominantnih akvatičnih makrofita i mogućnost njihovog korišćenja (Chemical composition of dominant aquatic macrophytes and their utilization), Univerzitet u Novom Sadu, Centar za Univerzitetske studije, TEMPUS Studije, Novi Sad, P. 1–64 (Msc thesis). 1995 (in Serbian with English abstract).

Seo B. S., Park C. M., Song U., Park W. J. Nitrate and phosphate removal potentials of three willow species and a bald cypress from eutrophic aquatic environment // Landscape Ecol. Eng. 2010. N 6. P. 211–217.

Stojanović S., Butorac B., Vučković M., Stanković Ž., Žderić M., Kilibarda P., Radak (Nikolić) Lj. Biljni svet kanala Vrbas-Bezdan (The Plant World of the Vrbas-Bezdan Channel), Univerzitet u Novom Sadu, Prirodno-matematički fakultet, Institut za biologiju, Novi Sad, 1994 (in Serbian with English abstract).

Westlake D. F. Macrophytes. In: A Manual on Methods for Measuring Primary Production in Aquatic Environments / ed. R. A. Vollenweider. IBP Handbook N 12. Blackwell Scientific Publications Oxford and Edinburgh, 1971. P. 25–32/

White A. S., Taylor D. M., Albano P. J., Whitwell T., Klaine J. S. Phosphorus retention in lab and field-scale subsurface-flow wetlands treating plant nursery runoff // Ecol. Eng. 2011. N 37. P. 1968–1976.