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IS IT REALISTIC TO USE WATER HYACINTH FOR WASTEWATER TREATMENT AND NUTRIENT REMOVAL IN CENTRAL EUROPE?

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ABSTRACT

The use of *Eichhornia crassipes* (Mart.) Solms (water hyacinth) has been tested in experimental systems in South Moravia (Czech Republic). The results of these experiments showed that the maximum rate of dry matter production and water treatment capacity during the summer period attained values which were comparable to tropical and subtropical zones. However, the vegetative period within natural conditions in South Moravia (and probably in the lowlands of the whole of Central Europe) is approximately half the time of tropical and subtropical zones and is reflected in lower total yields. The main topics of experiments performed in 1991 were: an assessment of the temperature dependence of growth and reproduction of *Eichhornia crassipes* in conditions prevailing in South Moravia, and the possibility of extending the growing season. The experiments used effluent from the city of Brno municipal waste water treatment plant. A strong temperature limitation was ascertained on the growth of water hyacinth. The intense growth of *Eichhornia* was investigated after the average daily temperature had reached 18°C. It was possible to prolong the vegetative period of water hyacinth, and treatment of the effluent, by covering experimental basins with a polyethylene shelter.

KEYWORDS

Water hyacinth, growth characteristics, temperature dependence, water quality, waste water treatment, nitrogen removal, phosphorus removal.

INTRODUCTION

Water hyacinth *Eichhornia crassipes* (Mart.) Solms grows prolifically in tropical and sub-tropical waters around the world. It has a potential role in water quality improvement, feed production and a multitude of other uses (DeBusk and Reddy 1987). The water hyacinth process has gained increased attention as an "alternative and innovative" method for waste water treatment (EPA 1988). The long-range commercial success of the technology, however, rests upon performance and cost of the entire, integrated aquaculture system, and not the hyacinth process alone (Hayes *et al.* 1987).

Aquatic plant systems are engineered and constructed systems that utilize aquatic plants in the treatment of industrial or domestic waste water. They are designed to achieve a specific waste water treatment goal.

Eichhornia crassipes has been studied extensively for improving the waste water effluent from oxidation ponds and in integrated treatment systems. The major limitation on widespread use is their temperature sensitivity (EPA 1988).

Temperature is the most important limiting factor for growth and reproduction of water hyacinths. Biomass yields maximize when ambient air temperatures are in the range 25 to 30°C (Knipling *et al.* 1970, cit. Reddy and Sutton 1984). Data presented by Reddy and Bagnall (1981) indicate that when the average minimum temperature reaches 10°C, productivity of water hyacinth approaches zero.

Many experimental results and practical experiences have been reported from tropical and subtropical areas (Little 1979, Wolverton 1979, DeBusk *et al.* 1981, Gopal and Sharma 1981, Dinges 1982, Reddy and Sutton 1984, etc.). Some experiments were also performed in temperate climatic conditions (Kvet *et al.*, 1982, Leciánová 1984, Žáková 1984, 1991, Urbanc-Bercic and Gaberšcik 1989, Žáková and Véber 1991, etc.). Results of these experiments showed that in Central Europe the use of *Eichhornia* for waste water treatment and nutrient reduction is possible, but only under special circumstances.

Urbanc-Bercic and Gaberšcik (1989) reported that light and temperature determine the length of *Eichhornia* vegetative period in temperate climates. Seasonal changes affect plant photosynthetic activity. An experiment at the Škofja Loka municipal waste water treatment plant (Slovenia) showed that during long and severe winters water hyacinth is unable to thrive. In order to maintain an adequate inoculum of water hyacinths for the next growing period, the plants have to be protected either by covering the ponds with "Plexiglass" tunnels or by transferring them to the greenhouse.

Kvet *et al.* (1982) and Leciánová (1984) studied the growth characteristics and capacity for waste water treatment of water hyacinths in the unfavourable climatic conditions of South Bohemia and North Moravia, producing promising results.

Our former experiments (Žáková 1991, Žáková and Véber 1991) were performed in more favourable climatic conditions in some natural reservoirs and also in four water treatment plants in South Moravia (Czech Republic). Growth characteristics of water hyacinths were investigated during the period 1982 to 1991. Within natural conditions in Nové Mlyny Reservoir, South Moravia, the average daily production for the period July–October (73 days) was 7.9 $g.m^{-2}. d^{-1}$ dry matter (yearly production 127 $t.ha^{-1}$), in the Odrovice Impoundment the average daily dry matter production (June–July, 42 days) was 8.9 $g. m^{-2}. d^{-1}$. The water hyacinths grew well in biologically treated waste waters from municipal water treatment plants of Brno, Kurim, Hodonín and Uherské Hradište. The average daily production within effluent from the city of Brno waste water treatment plant was 14.7 $g.m^{-2}. d^{-1}$ (July–September 1985, 56 days without harvesting), and 17.6 $g.m^{-2}. d^{-1}$ (July–October 1988, 109 days, with harvesting: July–August weekly, September–October bi-weekly). Maximum net daily production of 29.5 $g.m^{-2}. d^{-1}$ dry weight occurred during August 1986 (Žáková 1988). The length of growing season amounted to 100 days in natural localities, more than 120 days in moderately heated, biologically treated, waters (depending on actual conditions). During winter an adequate inoculum of plants was transferred to greenhouse (approximate optimum temperature 10–18°C, light intensity more than 18 $W.m^{-2}$ FAR). Nutrients were very quickly consumed by the water hyacinth in stagnant water conditions. Water quality was improved by up to three quality classes (according to CSN 1989). From the secondary effluent it was possible to remove ammonia-N completely, nitrate-N up to 95%, total phosphorus by 94%, dissolved phosphorus by 80%, potassium by 94%, non-dissolved matter by 97%, BODs by 93%, COD by 87%, so as to increase the DO-concentration by 185% using shallow experimental basins with horizontal flow and retention time from 17 hrs to 6 days. These experiments showed that for efficient water treatment it was necessary to harvest regularly the biomass and remove the sludge sediment. The water hyacinth removed also heavy metals and other contaminants (pesticides, PCB). These contaminants were partly accumulated within the biomass, partly in sludges on the bottom of experimental basins. Experimental feeding of biomass to rams, rabbits, geese and nutria (*Myocastor coypus*) did not impair the health of the animals (Vesely 1991).

The average daily dry matter production of *Eichhornia* in South Moravia during the summer period (Žáková 1988) was comparable with values given for experimental systems in tropical and subtropical zones. For example, Reddy and Sutton (1984) reported 13–20 $g.m^{-2}. d^{-1}$, DeBusk and Reddy (1987) 24–3.8 $g.m^{-2}. d^{-1}$, Oki and Ueki (1987) 9.9–35.23 $g.m^{-2}. d^{-1}$. However, the most optimistic growth estimates by Wolverton and McDonald (1976) in warm sewage effluents are substantially higher, 56–180 e.g. $g.m^{-2}. d^{-1}$ dry weight.

METHODS

The experiments reported here were performed from April to November 1991 at the municipal waste water treatment plant in Brno (South Moravia, Czech Republic). Secondary effluent was applied to 2 experimental basins with horizontal flow containing water hyacinths (area of each basin was 2.3 m^2, depth 20 to 25 cm). One basin was protected by a polyethylene shelter. Flow was about 30 $ml.s^{-1}$ and retention time approximately 17 hrs. Standing crop measurements and plant harvests were performed weekly from April to August, bi-weekly from September to November. An average plant density after harvest of 4 $kg.m^{-2}$ fresh weight was maintained.

Characteristics of climatic conditions in the model region. Climatically it is a warm to mild warm region (mean annual temperature 7 - 9°C). The period with average daily temperatures above 10°C represents 170 to 180 days in a year, the period with average daily temperatures below 0°C is 100 to 110 days, and snow cover lasts about 50 days. Total annual precipitation is about 600 mm and the sum of precipitation during the vegetative period is about 300 to 350 mm. Winters are mild to mild cold and periods of sunshine are relatively short. Yearly sum of global solar radiation above canopy amounts to values from 322 to 386 $J\ cm^{-2}$ (Penka *et al.* 1985, Novotny *et al.* 1987).

Growth characteristic measurements:

- standing crop (fresh weight in kg in each basin),
- crop growth rate CGR (dry weight, $g.\ m^{-2}.\ d^{-1}$),
- relative growth rate RGR ($g.\ g^{-1}.\ d^{-1}$).
- doubling time (d).

Physical and chemical investigations:

- biomass composition (mainly dry weight, N and P content),
- chemical composition of water (according to CSN 1978-84),
  water temperature (with use of automated electric thermometer),
- air temperature, light intensity.

Crop growth rate and N and P elimination were all calculated from the measurement of fresh weight increase and average biomass composition.

RESULTS

Chemical composition of the inflow water in experimental basins is characterised by the mean values from daily measurements in the waterworks laboratory Brno – see Table 1.

Dry weight of water hyacinth ranged from 4.7 to 7.4%, nitrogen content from 3.7 to 5.0% and phosphorus content from 0.27 to 1.65%.

TABLE 1. Physical and Chemical Characteristics of the Inflow Water into Experimental Basins – Secondary Effluent Waste Water Treatment Plant Brno, April–October 1991

Parameter	Unit of measurement	Number of measurments	Mean	Range
Temperature	°C	25	17.4	14.5 - 21.2
Hydrogen ion	pH unit	44	7.2	6.3 - 7.5
Conductivity	µS.cm^{-1} at 20°C	27	737.23	492.0 - 911.0
BOD_5	mg O_2 . l^{-1}	122	16.08	4.0 - 63.0
COD	mg O_2 . l^{-1}	95	51.12	19.0 - 109.0
DO	mg . l^{-1}	25	3.33	1.70 - 4.90
Total P	mg . l^{-1}	13	1.82	0.4 - 18.4
Total N	mg . l^{-1}	13	14.82	12.2 - 26.4
NH_4	mg . l^{-1}	22	18.57	13.8 - 32.1
NO_3	mg . l^{-1}	13	0.68	0.01 - 3.30
NO_2	mg . l^{-1}	13	0.09	0.01 - 0.40

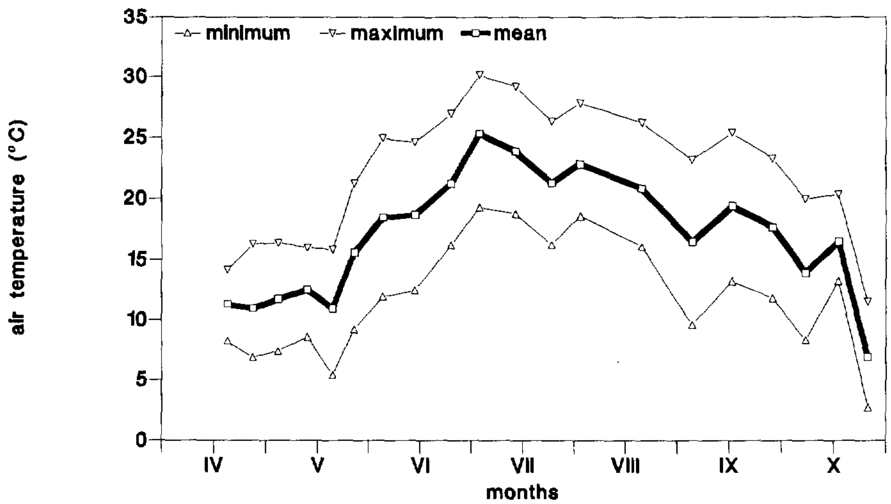

Fig. 1. Maximum, minimum and mean air temperatures for the period of experiments (April–October 1991).

Maximum, minimum and mean air temperatures in the period of our experiments (April–October 1991) are shown in Fig. 1. There was a strong relationship between the water temperatures in the shallow experimental basins (about 20 to 25 cm) and the average ambient air temperatures (see Fig. 2).

Optimum water temperature for the water hyacinth (above 25°C) was reached in the experimental basins only in a short period from the end of June to the beginning of July. Temperature dependence of the relative growth rate (RGR) and crop growth rate (CGR) was very distinct (see Figs 3 and 4). The more intense growth of water hyacinth was ascertained above 18°C.

Annual values of the crop growth rate and the doubling time from our former experiments in the same locality (secondary effluent, Waste Water Treatment Plant Brno, 1986, see Žáková 1991) are shown in Fig. 5. These investigations showed that maximum CGR values, comparable with those found in tropical and subtropical regions, were reached in August. The maximum crop growth rate amounted to about 15 mg. m^{-2}. d^{-1} dry matter and a doubling time of 6.8 days (plant density was about 10 kg. m^{-2}).

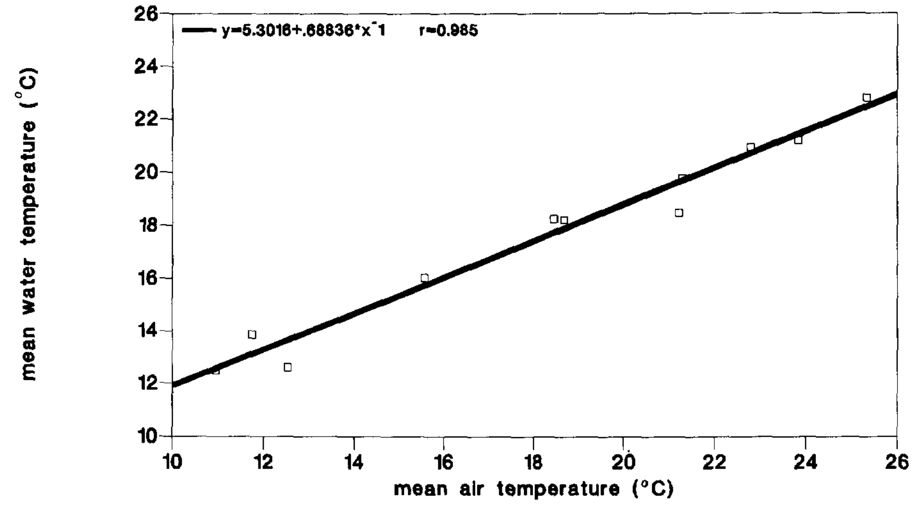

Fig. 2. Relation between mean air temperature and mean water temperature in experimental basins (April–October 1991).

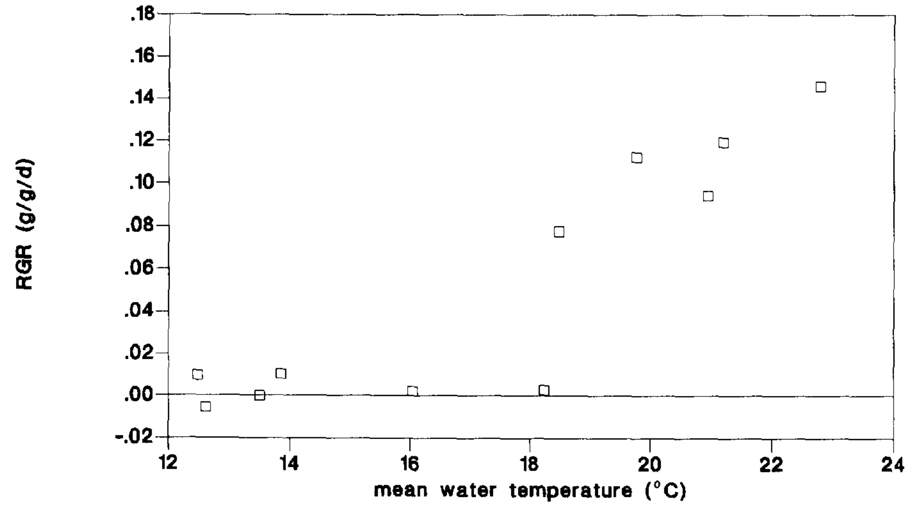

Fig. 3. Relation between mean water temperature and relative growth rate of the water hyacinth (April - October 1991).

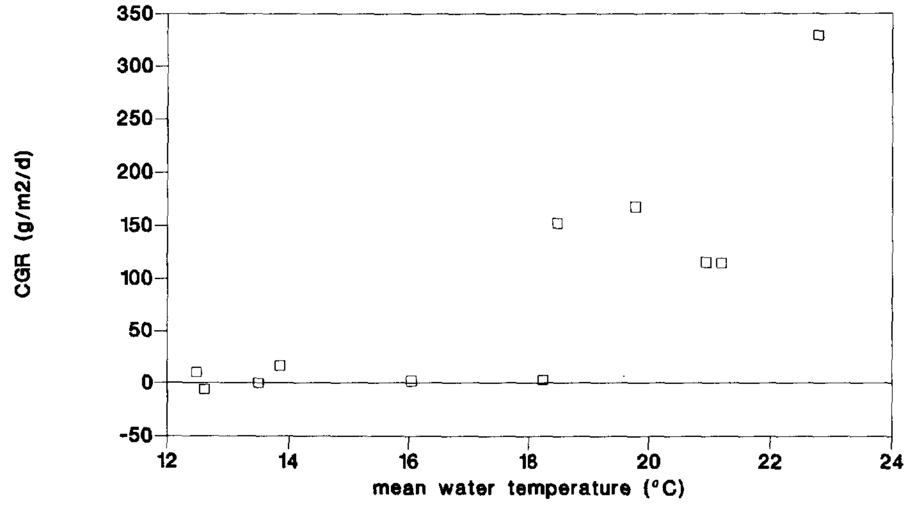

Fig. 4. Relation between mean water temperature and crop growth rate of the water hyacinth (April–October 1991).

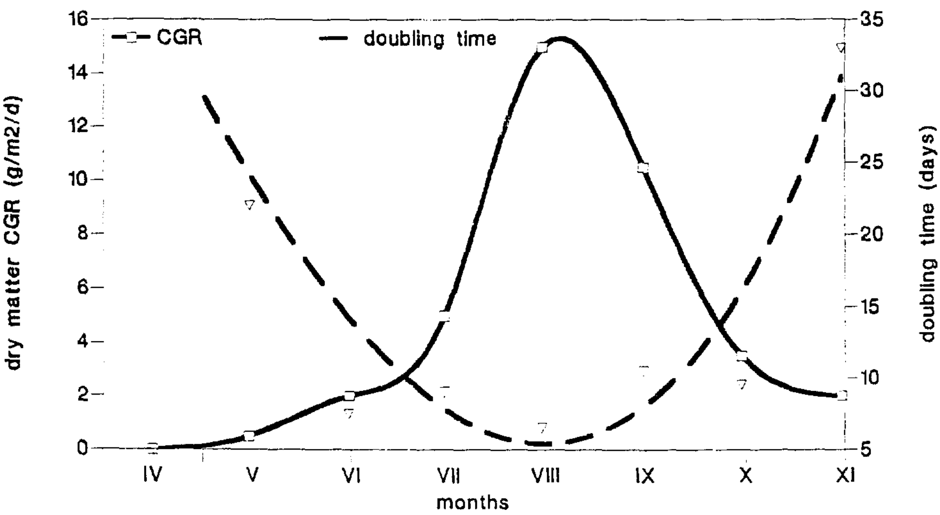

Fig. 5. Crop growth rate and doubling time of water hyacinth in secondary effluent (Waste Water Treatment Plant Brno) in 1986 (Žáková 1991).

The average daily dry weight production (crop growth rate CGR) of *Eichhornia* fed with secondary effluent from the Waste Water Treatment Plant at Brno calculated for the whole experimental period (May - October 1991, 160 days) was 6.6 $g.m^{-2}$ d^{-1}; in the summer period (June - August 1991, 60 days) it was 12.4 $g.m^{-2}$ d^{-1}. The total yearly fresh biomass production (160 days) was 21.1 kg. m^{-2} (211 t. ha^{-1}); total yearly dry matter production was 1.056 $kg.m^{-2}$ (10.56 t. ha^{-1}).

The results of investigations focussed on the possibility of extending the water hyacinth growing season by covering the experimental basins with polyethylene covers are shown in Table 2, and Figs 6 and 7.

TABLE 2. Growth Characteristics of Water Hyacinth and Nutrient Removal in Experimental Basins with and without Polyethylene Covers (Secondary Effluent – Waste Water Treatment Plant Brno), April–October 1991

Parameter	Unit of measurment	Basin without cover	Basin with cover
Crop growth rate (fresh weight)*	g. m^{-2}. d^{-1}	132.0	176.0
Crop growth rate (dry weight)*	g. m^{-2}. d^{-1}	6.6	8.8
Calculated N removal	mg. m^{-2}. d^{-1}	264.0	352.0
Calculated P removal	mg. m^{-2}. d^{-1}	66.0	88.0

* average daily production for the whole period - 160 days
Nutrient removal was calculated from the average content in the dry matter (4% N, 1% P).

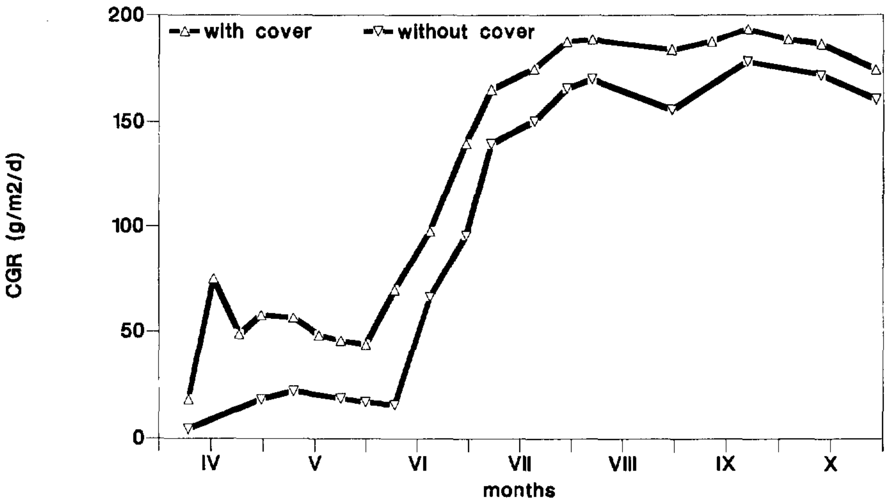

Fig. 6. Crop growth rate (fresh weight) of water hyacinth in experimental basins with and without polyethylene covers, April–October 1991 (secondary effluent – Waste Water Treatment Plant Brno).

In the experimental basin with polyethylene shelter the average daily dry weight production (CGR) calculated for the whole experimental period (160 days) was 8.8 $g.m^{-2}$. d^{-1}, average daily production in the summer period (June - August 1991, 60 days) was 14.3 $g.m^{-2}$ d^{-1}. The total yearly fresh biomass production was 28.2 $kg.m^{-2}$ (281.6 t. ha^{-1}), the total yearly dry matter production 1.408 $kg.m^{-2}$ (14.8 t. ha^{-1}).

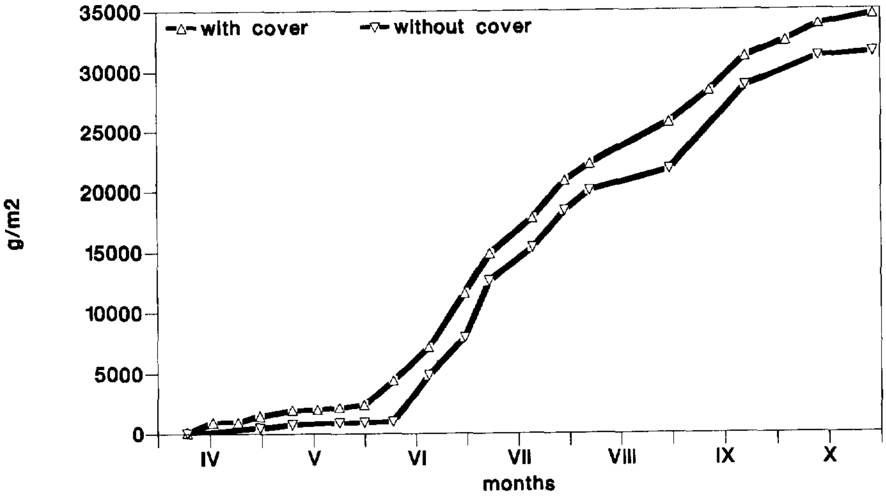

Fig. 7. Total fresh weight of water hyacinth in $g.m^{-2}$ in experimental basins with and without polyethylene covers, April–October 1991 (secondary effluent Waste Water Treatment Plant Brno).

In the basin with polyethylene cover the period of growth rate (RGR) above 0.06 d^{-1} (an appropriate value for field conditions used in the model for predicting nutrient removal of water hyacinth by Stewart *et al.* 1987) was observed to be longer by about 20 days (55 days without cover, 75 days with cover). The yearly dry matter production in the covered basin was about 33.3% larger (1.408 $kg.m^{-2}$) than in the open basin (1.056 $kg.m^{-2}$). Calculated nitrogen removal was increased in the basin with polyethylene cover by about 14.1 $g.m^{-2}$ and phosphorus removal by about 3.52 $g.m^{-2}$.

A doubling time for water hyacinth of less than 10 days was observed in the summer period from June till August (in the covered basin about 10 days earlier than in the open one). In the period of maximum summer temperatures (June and July) the maximum relative growth rate was approximately 0.150 $g.g^{-1}$. d^{-1}.

CONCLUSIONS

From our experiments focussed on the temperature dependence of the growth and water treatment capacity of water hyacinth under the conditions in Central Europe, and on the possibility of prolonging the vegetative period of water hyacinth, we can draw following conclusions.

- The temperature dependence of relative growth rate (RGR) and crop growth rate (CGR) of water hyacinth was very strong.
- The more intense growth of water hyacinth was investigated above 18°C.
- In the experimental basin with polyethylene cover the period of active growth (RGR above 0.06 d^{-1}) of water hyacinth was observed to be longer by about 20 days (55 days without cover, 75 days with cover).
- The biomass production in the covered basin was about 33.3% bigger (8.8 $g.m^{-2}$. d^{-1} dry matter) than in the open basin (6.6 $g.m^{-2}$. d^{-1} dry matter). Calculated yearly nitrogen removal was increased in the basin with polyethylene cover by about 14.1 $g.m^{-2}$ and phosphorus removal by about 3.52 $g.m^{-2}$.

- The practical application of water hyacinth systems for waste water treatment and nutrient removal in South Moravia (Czech Republic) is realistic, but only for specific applications (for example for heated waste waters containing high concentrations of nutrients or for small seasonal summer residences).

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REFERENCES

EPA (1988). Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment. Design Manual. Center for Environmental Research Information, Cincinnati, OH, 83 pp.

CSN (1989). Klasifikace jakosti povrchovych vod. Vydavatelství norem, Praha. (In Czech)

CSN (1978-84). Chemicky a fyzikální rozbor povrchové vody (cásti 1 - 50), Vydavatelství norem, Praha. (In Czech)

CSN (1978-79). Biologicky rozbor povrchové vody (cást 1-8). Vydavatelství ÚNM Praha. (In Czech)

DeBusk, W. F. and Reddy, K. R. (1987). Density requirements to maximize productivity and nutrient removal capability of water hyacinth. In: K. R. Reddy and W. H. Smith (Eds.) *Aquatic Plants for Water Treatment and Resource Recovery*. Magnolia Publishing, Orlando, FL, pp. 673-680.

Dinges, R. (1982). Natural Systems for Water Pollution Control. Van Nostrand Reinhold, New York, NY, 245 pp.

Gopal, B. and Sharma, K. P. (1981). Water Hyacinth (*Eichhornia crassipes*) the Most Troublesome Weed of the World. Hindasia Publ., New Delhi, 128 + 91 pp.

Hayes, T. D., Isaacson, H. R., Reddy, K. R., Chynoveth, D. P. and Biljetina, R. (1987). Water hyacinth systems for water treatment. In: K. R. Reddy and W. H. Smith (Eds.) *Aquatic Plants for Water Treatment and Resource Recovery*. Magnolia Publishing, Orlando, FL, pp. 121-139.

Kvet, J., Leciánová, L., Véber, K. (1982). Zkušenosti s kultivací vodního hyacintu v odpadních vodách. In: *Vyznam makrofyt ve vodním hospodárství, hygiene vody a rybárství*, Dum techniky C. Budejovice, pp. 101-105. (In Czech)

Leciaynová, L. (1984). Vodohospodárské vyuzití vodního hyacintu v klimatickyách podmínkách CSSR. *Vodní hospodárství* 5, rada B, 121-126. (In Czech)

Little, E. C. S. (1979). Handbook of utilization of aquatic plants. *FAO, Fisheries Technical Paper* No. 187, Rome, 176 pp.

Novotny, S., Bernardová, I., Matejícek, J., Pavlovsky, L., Sochorec, J., Vlcek, V., Žíaková, Z. (1987). Moravské vodohospodárské soustavy. Povodí Moravy Brno ve SZN Praha, 256 pp. (In Czech)

Oki, Y. and Ueki, K. (1987). Biomass production of water hyacinth cultured in an aquaculture system in Japan. In: K. R. Reddy and W. H. Smith (Eds.), *Aquatic Plants for Water Treatment and Resource Recovery*. Magnolia Publishing, Orlando, FL, pp. 665-671.

Penka, M., Vyskot, M., Klimo, E., Vašícek, F. (Eds.) (1985). Floodplain Forest Ecosystem. Academia, Praha, 468 pp.

Reddy, K. R. and Bagnall, L. O. (1981). Biomass production of aquatic plants used in agricultural drainage water treatment. In: *Int. Gas Res. Conf. Proc.*, pp. 376-390.

Reddy, K. R. and Sutton, D. L. (1984). Water hyacinths for Water Quality Improvement and Biomass Production. *J. Environ. Qual.* 13: 1-8.

Stewart III, E. A., Haselow, D. L., Wyse, N. M. (1978). Review of Operations and Performance data on Five Water Hyacinth based Treatment Systems in Florida. In: K. R. Reddy and W. H. Smith (Eds.), *Aquatic Plants for Water Treatment and Resource Recovery*. Orlando, FL, Magnolia Publishing, pp. 279-288.

Urbanc-Bercic, O., Gaberšcik, A. (1989). The influence of temperature and light intensity on activity of water hyacinth (*Eichhornia crassipes* (Mart.) Solms.). *Aquatic Botany*, 35; 403-408.

Vesely, Z. (1991). Možnosti krmivárského využití vyprodukované biomasy z dočištovacích systému. In: Žáková: Vyzkum možností snižování eutrofizace...., *Research Report, TGM Water Research Institute* Brno, cást 4, etapa 2, 10 pp. (In Czech).

Wolverton, B. C. (1979). The water hyacinth. *Mazingira* 11, 59-65.

Wolverton and McDonald (1976). Water Hyacinths for the Removal of Phenois from Polluted Waters. *Aquatic Botany*, 2.

Žáková, Z. (1984). Vyzkum trofickych pomeru a možností umelé oligotrofizace povrchovych vod v povodí dolní Dyje, Jihlavy a Svratky. *Research Report, TGM Water Research Institute* Brno, 72 pp.. (In Czech)

Žáková, Z. (1988). Overení možnosti aplikace novych biotechnologickych postupu pro snížení prísunu živin a cizorodych látek do vodních zdroju v Jihomoravském kraji. *Research Report, TGM Water Research Institute* Brno, 82 pp.. (In Czech)

Žáková, Z. (1991). Vyzkum možností snižování eutrofizace vybranych nádrží ekologickymi a biotechnologickymi procesy. Cást 4: Vyzkum a overování ekologickych a biotechnologickych zpusobu odstranování živin z vody. Etapa 01. *Research Report, TGM Water Research Institute* Brno, 39 pp.. (In Czech)

Žáková, Z., Véber, K. (1991). Biologické základy pestování a využívání vodního hyacintu v CSFR. *Studie CSAV* 3, Academia, Praha, 88 pp.