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Water Hyacinths – Biomass and Water Purifying Potential for Agricultural Applications

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Authors' contributions

This work was carried out in collaboration between all authors. Author KD and JT read and approved the final manuscript.

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ABSTRACT

The growth of water hyacinths under outdoor and controlled laboratory conditions was examined using diluted cow manure as the chosen supplier of nutrients. The study showed that water hyacinth can be used for water purification. Ammonia appears to be the preferred source of nitrogen for the water hyacinths. Water hyacinth is able to survive severe weather conditions below 5ºC for a short amount of time.

Both studies showed that the water hyacinths grew very well during a 22-day study period. Results show that water hyacinths can gain a significant amount of biomass in a short period of time when grown in diluted cow manure. Plants could increase their biomass up to 3.75 and up to 4.0 times during an indoor laboratory study at 20ºC, resulting in over 500 t/ha of biomass production per year. Plant grown at water temperatures of 35ºC do not show an increase in plant biomass. Factors such as climate, contaminant concentration, retention rate, and weather conditions play an important role in plant growth and contaminate removal.

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1. INTRODUCTION

The Water Hyacinth *Eichhornia crassipes* (Mart.) Solms Fig. 1 is a non-native, invasive, free-floating vascular aquatic plant in the Unites States that originates from the Amazon basin, Brazil [1]. Water hyacinth was first observed in 1884 in Louisiana [1]. In the U.S. this plant is available for purchase as an ornamental plant for aquariums and water gardens [2]. Today water hyacinth can be found in over 50 countries and is known for its harmful effects [1,3]. Even in its country of origin water hyacinth represent a thread to the environment and need to be controlled [4] The plant can reproduce very rapidly and double its biomass in 6 to 18 days under Florida weather conditions [5]. Growth rates of water hyacinth are dependent on conditions such as weather, water temperature, and nutrition available for uptake. Growth rates per hectare of up to 377 metric tons (416 short tons) in Florida and up to 596 metric tons (657 short tons) of plant material in India have been reported [6,7]. About 500 tons of rotten plant material can be deposited yearly from one acre of water hyacinth. The dense growth mats of water hyacinth disturb native species and community structures as well can block waterways for navigation and irrigation [8].

Water hyacinth has been an aquatic nuisance in Florida for many years due to the plant's strong ability to invade and create highly dense monocultures in short periods of time. As a result, the state has lost biodiversity and vast amounts of money for controlling the invasive species. Dense mats have also been known to lead to fish kills as the high amounts of plant respiration and decaying biomass degrades the quality of water for fish and other aquatic life [9].

However, despite these negative effects from water hyacinth, there are many promising aspects of Water Hyacinths, including their ability to remove nutrients and purify domestic wastewater (WW) [11] as well as the ability to serve as a source of biomass for the production of biofuels. Floating Aquatic Macrophyte-based Treatment System (FAMTS) have been explored in the past for the purpose of removing and recovering nutrients in wastewater from an animal-based agriculture operations. These systems have high potential as they are able to treat the water through multiple methods including solid settling, plant uptake, biotransformation, and physio-chemical reactions. Also, these systems contain relatively simple technology and have low costs [12]. Water hyacinth in particular show promise as a model plant for FAMTS. According to a study, water hyacinth can be grown in undiluted wastewater whereas water lettuce and vetiver grass Pennywort could only survive in diluted wastewater. In addition, the report claims that water Hyacinths were more effective than both of these plants in removing nutrients, COD, solids, and salinity than the other two plants [13].

Fig. 1. Water hyacinth (*Eichhornia crassipes*) [10]

Water hyacinth has a water remediation capacity of over 90% for Nitrogen (N) and Phosphorous (P) contained in WW, including suspended solids (TS), Biological and Chemical Oxygen Demand (BOD) and (COD), *E. coli* (EC), Heavy Metals. However, factors such as climate, contaminant concentration, retention rate, and weather conditions play an important role in contaminating removal [12].

Water Hyacinth, as a result of their invasive nature and fast growth, have the potential as biomass feedstock for the production of biogas for electricity and heat. 300 to 400 l per 1 kg of dry mass are suggested stated by Maioli, Pulfer & Mitjans [14]. In addition, the sludge produced as a byproduct of anaerobic digestion contains high amounts of nutrients which makes it ideal fertilizer [15].

To assess the potential for water hyacinths for biomass production a laboratory study has been conducted to investigate the growth potential of Water Hyacinth using dilutes cow manure as growth media.

2. MATERIALS AND METHODS

The plants used for this study came from a fish pond where they were used as ornamental pants and to control water quality in Syracuse, NY, USA. The plants were originally obtained as ornamental plants from a nursery in Florid, USA.

The growth study was carried out, a) under natural conditions in a 15 gallon (56 litre) tank containing 50 litre of liquid, and b) under laboratory conditions in 2.5-liter tanks.

For all growth studies, cow manure was used and diluted 70 times with tap water. The pH of the diluted cow manure solution was 7.5. Table 1 shows the Manure nutrition content in the raw and diluted form:

Table 1. Manure data

Cow Manure	Raw [g]	Diluted [mg]
Nitrogen	4.976	71.086
Ammonia Nitrogen	1.426	20.371
Organic Nitrogen	3.550	50.714
Phosphorous	0.941	13.443
Phosphate equivalent P_2O_5	2.153	30.757
Potassium	2.260	32.286
Total Solids	128.913	1841.614
Density	950 g/l	999 g/l

The water hyacinth plant biomass yield was determined every 4 days for the first 16 days. Final measurements were taken after 22 days. Prior to weighing the plants were carefully dried with a paper towel. On the same day the pH value, humidity as well as air and water temperature were determined. The pH value and the water temperature were measured using the AP85 by Fisher Scientific. The air temperature and humidity were determined by using a wireless common weather station.

2.1 Growth under Natural Conditions

The growth study under natural conditions was carried out in a 15 gallon (56 litre) tank containing 50 litre of diluted cow manure. Five water hyacinth plants with a total fresh weight of 212.7 g were placed inside this tank and their biomass yield was recorded as described above. Air temperature, water temperature, and humidity were recorded daily. The water level was adjusted over the 22-day test phase with collected rain water to account for evaporation losses.

2.2 Growth under Controlled Laboratory Conditions

To determine the biomass yield of water hyacinth under controlled conditions a total of 9 plants with a total fresh weight of 140.2 g were used. Each plant was put in small plastic containers with 2.5 L of diluted cow manure. The radiation came from three LED grow lights which were timed to automatically switch on or off after 12 hours. Six of the containers with plants were kept at room temperature of 20ºC. To evaluate the influence of water temperature on biomass yield the other three containers were placed in a water bath at 35°C. The source of light came from Unifun 24 W LED grow lights. The grow lights were kept 60 cm above the water hyacinth tank and were switched on an off every 12 hours. The water level in the glass tank and the plastic containers was adjusted to its original level every other day to compensate for water loss due to evaporation.

2.3 Nutrient Analysis

Nutrient analysis for nitrogen ammonia, total nitrogen, reactive phosphorus and Chemical Oxygen Demand (COD) was done using a Hach DR 1900 portable spectrophotometer using the Hach Test'N Tube method 10031, 10127, 8000 respectively. For the COD analyses, the samples needed to be digested before analyses. For this step, a Hach CR2200 thermoreactor was used. A certified Laboratory was used to analyze the samples for day 1 and 10 for the study under natural conditions. Near Infrared Reflectance spectroscopy (NIR) was used for the analysis. The detection limit of the certified laboratory testing was 1 mg/l.

3. RESULTS AND DISCUSSION

The biomasses of the water hyacinths grown during the experiment are shown in Fig. 2. The total biomass of all outdoor-grown plants increased by 304% over a 22-day period from an initial weight of 212.7 g to 646.8 g. The weight of the plants grown under laboratory conditions increased by 208% from 140.2 g to 292.1 g for plants grown at a water temperature of 20ºC and 179% from 63.8 g to 114.6 g for the for plants grown at a water temperature of 35ºC.

3.1 Natural Conditions

The individual biomass gain for each plant grown under natural conditions in the outdoor tank is shown in Fig. 3. The recorded average outdoor air and the water temperature were 20.0ºC and 21.8ºC respectively. The recorded average humidity was at 69.3%. However, the outdoor air temperature fluctuated from a daily minimum temperature of 6 A.M. to a daily maximum temperature between 12:00 pm and 6:00 pm. The lowest and highest air temperatures recorded during the study was on day 14 with 5.8ºC at 6:00 am in the morning, and 32.6ºC at 12:00 pm noon, marking a significant weather change for day 15 to 22 of the study which resulted in an average water temperature drop of 4.2ºC from 23.5ºC to 19.3ºC, an average air temperature drop of 3.3ºC from 21.5ºC to 18.3°C, and an average humidity increase of 17.2% from 62% to 79.2%. Temperatures and humidity data are shown in the Fig. 3 represent the air and water temperature at 4:00 pm in the afternoon. The tank water had a pH of 7.5 ± 0.1 during the 22-day test phase.

Fig. 3 shows the individual plant grows during the 22-day test phase. About half of the total outdoor-grown biomass gain came from plant 5 which grew from an initial biomass weight of 85.9 g to 322.6 g which represents a 375.6% of biomass gain over the 22-day test phase. Plant 1 and 2 had the lowest biomass gain from an initial weight of 8 g and 25.1g to a final weight of 23.7 g and 74.5 g, which represents a biomass gain of 307.1% and 288.2% respectively. Plant 3 and 4 grew from an initial biomass weigh of 42.3 g and 63.9 g to a final weight of 115.3 g and 148.2 g, which represents a biomass gain of 272.6% and 231.9% respectively. The presented data show that water hyacinth had a significant grows rate during the 22-day test phase and can be a viable biomass resource, able to grow 3.5 times their biomass in 3 weeks, even with fluctuations in air and water temperatures as well as humidity.

Nutrient uptake under natural conditions by water hyacinth is shown in Fig. 4 in relation to biomass increase. Water samples were given to a certified laboratory for analyses. The total nitrogen concentration (Total N) in the outdoor diluted manure bath decreased by 96.2% from 133 mg/L to 5 mg/L over the course of this study. The Phosphorous (P_2O_5) concentration was measured at 9.5 mg/l. Potassium (K) decreased by 80% from 47.5 mg/l to 9.5 mg/l. No ammonia was detected in the collected water samples. These results correlate with finding by Sooknah and Wilkie using flushed dairy manure waste [11].

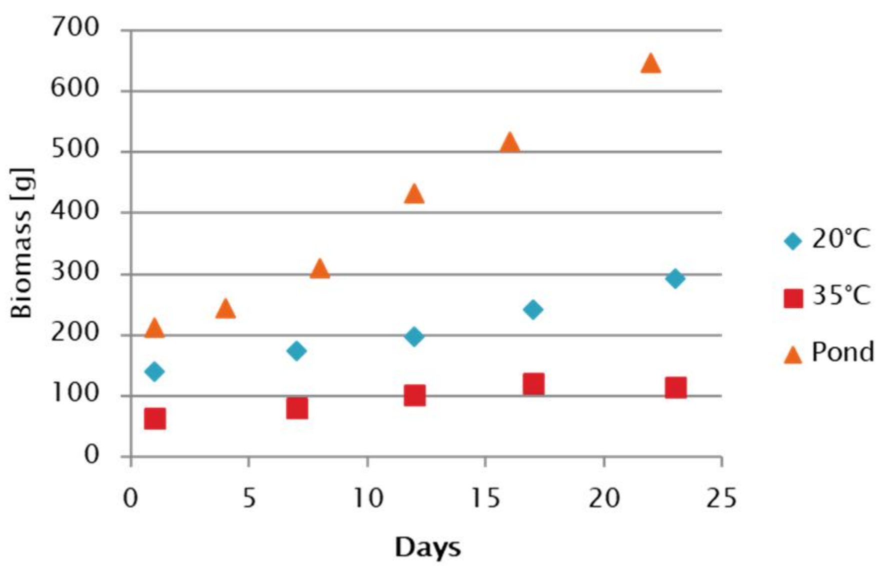

Fig. 2. Accumulated biomass yield of water hyacinth

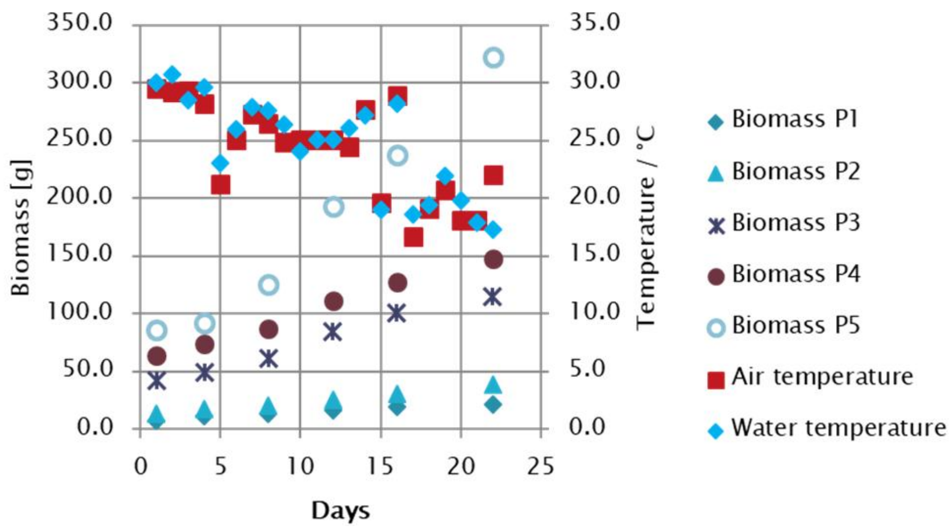

Fig. 3. Individual outdoor water hyacinth biomass yield

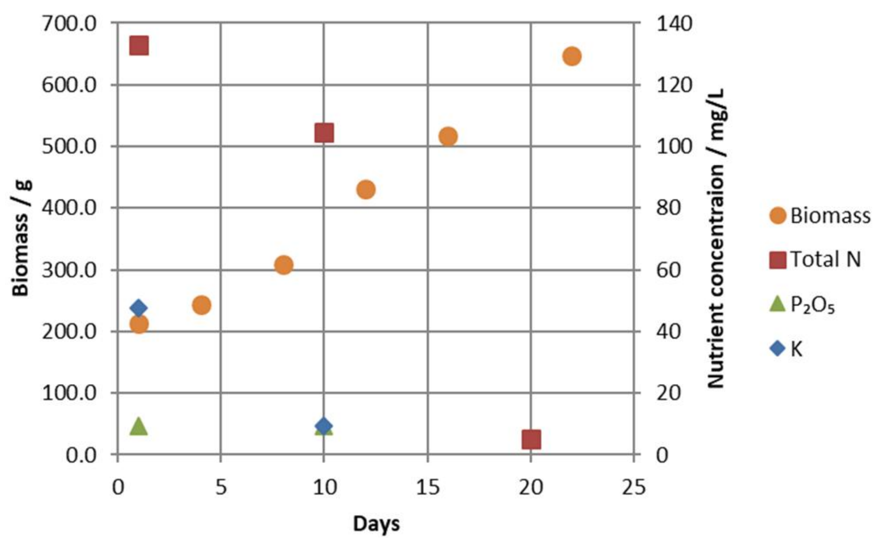

Fig 4. Nutrition uptake of water hyacinth under natural conditions

3.2 Laboratory Conditions

Fig. 5 shows the individual plant growth during the 22-day laboratory test. Six plants (plant 1 to 6) were kept at 20ºC and 3 plants (plant 7 to 9) were kept at 35ºC. The largest biomass gain at different water temperatures had plant 4 at 20ºC and plant 9 at 35ºC. The plants grew from an initial biomass weight of 10.9 g and 30.2 g to a final biomass weight of 45.3 g and 85.2 g which represents a 415.6% and 282.1% biomass weight gain. The lowest growth rate had plant 3 at 20ºC and plant 8 at 35ºC. The plants grew from an initial biomass weight of 69.1 g and 23.9 g to a final biomass of 103.6 g and 29.4 g which represents a 149.9% and 123.0% gain on biomass. Plant 1 and 2 at 20ºC had identical growth rates. The plants grew from an initial biomass weight of 8 g, 25.1 g to a final biomass weight of 23.7 g, 74.5 g which represents a 296.3%, and 296.8% biomass weight gain, respectively. Plant 5 and 6 at 20ºC and plant 7 at 35ºC grew from an initial biomass weight of 18.4 g, 8.7 g and 9.7 g to a final biomass weight of 29.1 g, 15.9 g and 19.8 g which represents a 296.3%, 296.8% and 204.1% biomass weight gain, respectively.

The presented data show that it is possible that water hyacinth grown under laboratory conditions can up to fourfold their biomass in 3 weeks if air and water temperature is kept at 20ºC. The presented data under laboratory condition shows that water hyacinth had a significant grows rate and can be considered a viable biomass resource.

Results from the laboratory study at a water temperature of 35ºC confirm that water temperatures above 30ºC growth is reduced. This finding is in accordance with the Australian Department of Primary Industries [16].

Water hyacinth nutrition uptake under laboratory conditions is shown in Fig 6 in relation to biomass increase for plant number 3 grown in 20ºC temperature conditions. Water samples were tested using laboratory bench testing. The nitrogen (Total N) decreased by 85.2% from 20.3 mg/L to 3 mg/L, whereas the ammonia (NH_3-N) concentration was under the detection limit of 0.5mg/l. over the course of this study. The total phosphorous equivalent (P_2O_5) concentration decreased by 80.8% and was measured at 30.8 mg/l and 5.9 mg/l at the beginning and the end of the study. The COD decreased by 72.3% from 234 mg/l to 65 mg/l during the study.

3.3 Other Results and Observations

Based on the laboratory testing, the primary source for plant growth is nitrogen, which was reduced in both studies. This could be explained why no ammonia was detectable. Initially water hyacinth uses ammonia as a primary source of nitrogen and then using other sources of nitrogen once the ammonia was depleted.

Water Hyacinth growth can be seen in Fig. 7 and 8. Fig. 7 shows the individual growth of a Water hyacinth plant before and after the 22 day out-door study. Fig. 8 shows the increasing plant cover of Water hyacinth plants in the growth container. Based on the total biomass production of the out-door grown Water hyacinth of 434.1 g in 22 days in the plastic container with 0.144 m² of surface area, an estimated 30.25 t/ha in 22 days, or 501.8 t/ ha per year can be produced. This correlates to literature finding of Schardt and Hasan [5,6].

In addition, it was observed that plants developed larger leaves under outdoor conditions. The maximum root length measured ranged between 30 cm and 60 cm.

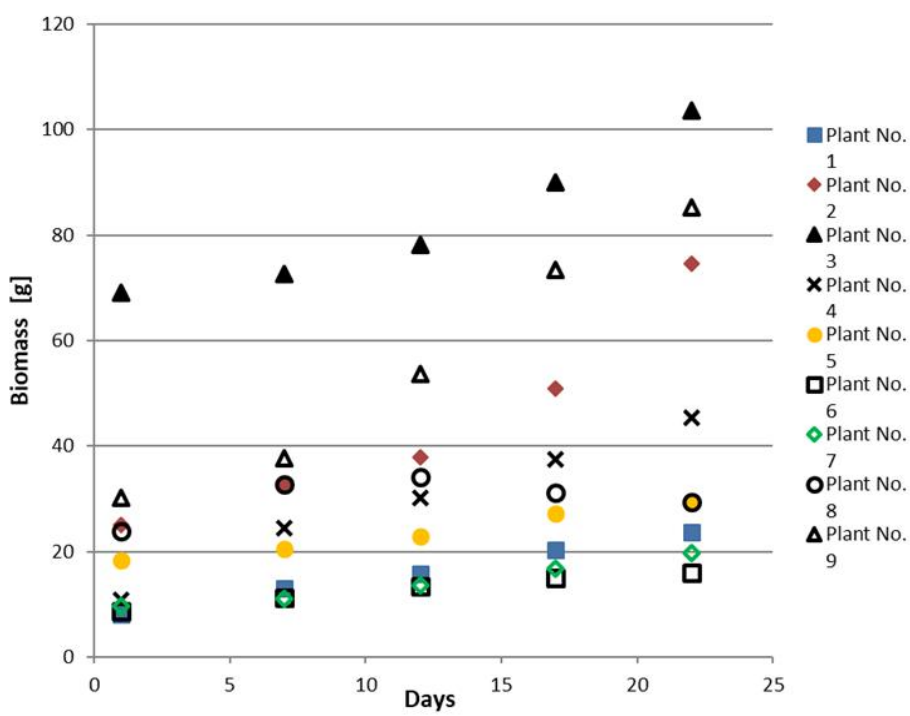

Fig. 5. Individual indoor water hyacinth biomass yield

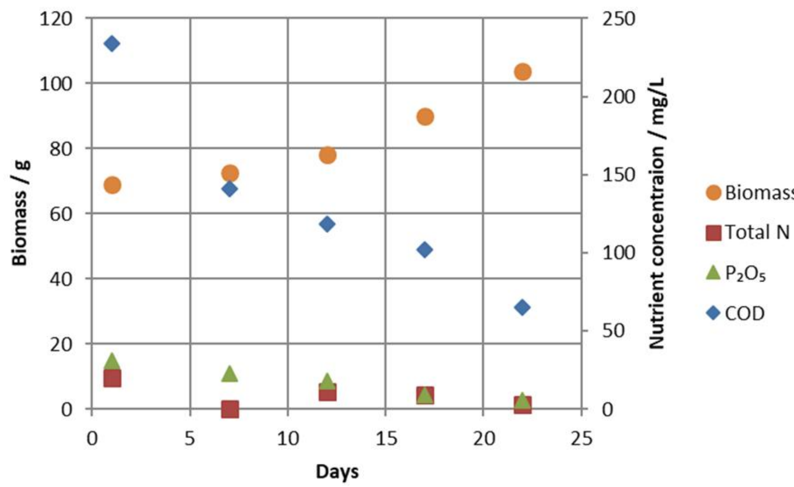

Fig. 6. Nutrition uptake of water hyacinth under laboratory conditions

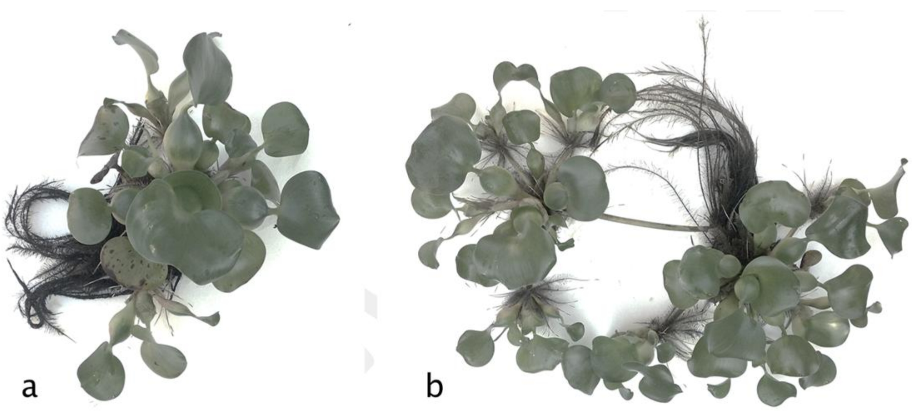

Fig. 7. Water hyacinth a) before and b) after growth study [17]

Fig. 8. Water hyacinth cover a) before and c) after growth study [18]

Water hyacinth left under outdoor conditions kept growing till the temperatures decreased to 10ºC. However, plant tends to survive weather conditions close to freezing and light snow as long as the water does not freeze, and a warmer weather period follows with temperatures above 10ºC. Under extreme weather conditions, the plant leaves colour changes to a pale green and yellow. However, if a plant is plants exposed to extreme weather conditions and snow fall and then put into a 20ºC environment the plant is able to recover.

4. CONCLUSION

Water hyacinth grew very well in both indoor and outdoor diluted manure baths. The results show that water hyacinths gain a significant amount of biomass in a short period of time when grown in diluted cow manure. Plants could increase their biomass 3.75 and 4.0 times during an outdoor study and indoor laboratory study. This can result in up to 500 t/ ha biomass production per year and correlates to literature finding of Schardt and Hasan [5,6].

Plant grown at water temperatures of 35ºC do not show an increase in plant biomass. The water hyacinths took up manure constituents from the diluted manure baths, thus assisting in water purification. A significant quantity of nitrogen was removed from both indoor and outdoor diluted manure baths. Ammonia appears to be the preferred source of nitrogen for the water hyacinths. Water hyacinths uptake other sources of nitrogen in the absence of ammonia. However, factors such as climate, contaminant concentration, retention rate, and weather conditions play an important role for plant growth and contaminate removal and need to be taken into consideration for further studies.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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17. Dölle K. Image: Water hyacinth a) before and b) after growth study.
18. Dölle K. Image: Water hyacinth cover a) before and c) after growth study.

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