Potential removal of particulate matter and nitrogen through roots of water hyacinth in a tropical natural wetland

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A natural shallow eutrophicated wetland receiving influx of domestic sewage and agricultural run-off of the watershed, heavily infested with water hyacinth, located in Ujjain city, Madhya Pradesh State, was studied to determine the role of dense growth of hyacinth in the removal of particulate matter attached to root system, and nitrogen as contained in the root attached particulate matter (RAPM) and in the plant tissue. The recorded hyacinth density was 79 plants per square metre with 1.549 kg dry plant tissue and adsorbing 663 g RAPM (about 42% of dry plant tissue), thus potentially removing it upon the mechanical harvest of the plants on per metre square basis. In addition to the significant amount of RAPM, the hyacinth plant harvest also brought about removal of 1.396 g of organic matter, 0.536 g of total nitrogen, 0.482 g of ammoniacal nitrogen, and 0.338 g of nitrate nitrogen per m^2 waterscape basis. In other words, when the hyacinth plants are manually/mechanically removed from the wetland, potentiality of total nitrogen removal is 37.32 kg through the plant tissue +5.36 kg nitrogen/hectare in the RAPM, besides 6630 kg/h of particulate matter through roots attachment (RAPM). The extensive root systems of the hyacinth provide a huge surface area for attached particulate matter and microorganisms, acting as 'suspended sediment layer' and rich in nitrogen. Thus, for an eutrophicated wetland receiving waste-water rich in particulate matter, the hyacinth growth has substantial potential for the removal of particulate matter and thus nitrogen through their attachment to roots, in addition to the nitrogen concentrated in the plant tissue.

ECOSYSTEM dominated by aquatic macrophytes are among the most productive largely as a result of ample light, water, nutrients, and the presence of plants that have developed morphological and biochemical adaptations enabling them to take advantage of these optimum conditions[1]. The high productivity of ecosystems dominated by aquatic macrophytes results in high microbial activity and consequently, a high capacity to decompose organic matter and other substances. Water hyacinth, *Eichhornia crassipes* (mart) solm, is a rapidly-growing aquatic macrophyte and is ranked eighth among the world's top ten weeds in growth rate[2,3]. Primarily it reproduces by vegetative propagation but seeds may be a major source of reinfestation once the parent plants have been removed. The plant community of this species develops a large canopy in the water body, which provides a good competitive edge over other floating plants, allowing no submerged plants and algal blooms to grow. The extensive root systems of the hyacinth provide a huge surface area for the attachment of particulate matter and the micro-organisms. The aim of this study was to explore if water hyacinth aquatic treatment system could be successfully used for suspended particulate matter (SPM) and nitrogen removal.

The Solasagar pond is a natural perennial water body in Ujjain city (23°12' N latitude, 75°42' E longitude, mean sea level 515.45 m), situated in the mid-western part of the country. The climate of the area is typically monsoonic; annual rainfall amounts to 1032 mm, confined mostly to rainy season, i.e. June to September; annual mean maximum and minimum temperatures were 31.4 and 16.5°C. The water body is shallow at the margins (0.25 m) and the depth gradually increases towards the central area, attaining a maximum depth of 3.5 m. The surface area of the pond is about 65918 m^2 during the rainy season when it is completely filled with water, and this recedes by 15% during the hot summer (maximum temperature 45°C). The pond supports natural water and also receives recurrent input of domestic waste water and agricultural drained water during the rainy season from the adjoining dense urban habitation and agricultural fields. The Solasagar pond is basically used for commercial production of water-chestnut (*Trapa bispinosa*, family Trapaceae) and fish farming. Every year the hyacinth appears in patches after the complete harvest of commercial water-chestnut plants during October–November. Before this, the hyacinth plants are regularly weeded out manually from the dense mat of Trapa. In November and subsequent months, the hyacinth spreads, initially slowly since the growth rate is limited by low-winter temperature in December (mean minimum temp, 7.3°C, mean maximum, 26.7°C) and January (mean minimum temp, 6.1°C and mean maximum 25.4°C), then grows rapidly, almost completely covering the pond surface area till February. There are, thus, two major sources of particular matter in the water body: (i) domestic wastewater and agricultural effluents carrying the particulate matter, and (ii) *in situ* generated particulate matter due to death and decay of wetland plants, organisms and bioturbation of bottom sediments.

Periodic sampling of hyacinth plants for RAPM and water column (50 cm root around) were carried out on 31 January, 15 February, 2 and 17 March and 12 and 17 April 1995. At each date, thirty-six plants were manually harvested from 1 m, 3 m and 5 m distance from shoreline inwards in the hyacinth-covered pond. For RAPM, thirty-six plants were pooled into nine bundles of four each. Each bundle of hyacinth plants was thoroughly washed, using a total six litres of water for the particulate matter attached to the roots. The root washings, containing leaf debris, molluscs, insects, etc. were discarded by sieving through 2 mm sieve. The supernatent of the sieved slurry was pipetted to analyse for ammonium and nitrate according to the method of Bremner and Keeney[4]. Fifty millilitre homogenized sample of this RAPM slurry in triplicates was oven-dried at 105°C for 24 h in glass crucible, weighed and computed for RAPM per plant and g/m^2 pond area bases by multiplying with the plant density. The oven-dried samples were powdered to 50 micron and analysed for total kjeldahl nitrogen[5] and organic matter by Walkley and Blacks rapid titration method. Water samples around root zones to a depth of 50 cm were analysed for ammoniacal and nitrate nitrogen by distillation method[4].

To investigate the possible role of bottom sediments in nitrogen release to the above-lying dense mat of hyacinth plants, the bottom sediments were sampled by Peterson grab sampler. The freshly-collected sediment samples were immediately sieved by 2 mm sieve to remove fresh leafy debris, pebbles, shells, etc. The sieved slurry was vacuum-filtered by Whatman no. 1 filter paper to separate out the residue as 'sediment' from the 'pore' – or 'interstitial water' collected in the form of filtrate. Fine-powdered oven-dried (105°C) sediment samples were analysed for total kjeldahl nitrogen (TKN) (Bremner and Keeney[4], semi microkjeldahl method). For estimation of microbial biomass nitrogen in sediments, fresh 2 mm sieved samples were fumigated with chloroform, and fumigation-incubation[6] method was followed. Pore- or interstitial water was analysed for ammoniacal and nitrate nitrogen similar to columner water of the pond. Table 1 reveals the nitrogen characteristics of pond bed (sediment's total nitrogen and microbial biomass nitrogen, sediment-bound interstitial water's ammoniacal and nitrate nitrogen) and overlying water column's ammoniacal and nitrate nitrogen.

Table 1. Nitrogen characteristics of wetland bed and overlying water column in the wetland area occupied by water hyacinth

Parameter	Under water hyacinth: Water column	Under water hyacinth: Wetland bed
Inorganic nitrogen (mg N/l)		
Ammoniacal nitrogen	4.2 (1.986)*	–
Nitrate nitrogen	4.3 (1.669)	–
Sediment-bound pore water (mg N/l)		
Ammoniacal nitrogen	–	10.9 (1.582)
Nitrate nitrogen	–	2.7 (0.329)
Bed sediment		
Total nitrogen (mg N/g dry weight)	–	3.6 (1.582)
Microbial biomass N (mg N/kg dry weight)	–	49.0 (6.228)
Organic carbon (mg C/g dry weight)	–	29.9 (10.890)

*Figures in the parenthesis are the standard deviation values; mean of seven samples.

Table 2. Potential removal of (*i*) particulate matter through hyacinth root (RAPM) and nitrogen, and (ii) plant tissue nitrogen in eutrophicated hyacinth pond

Parameter		Per plant	Per metre square wetland
ia)	Particulate matter (RAPM) removal through root (in g)	8.38 (1.7)*	663 (132)*
ib)	Nitrogen removal through RAPM (in mg) :		
	Total nitrogen (TKN)	6.78 (1.0)	536 (85)
	Ammonium nitrogen	6.12 (0.8)	482 (68)
	Nitrate nitrogen	3.75 (1.3)	338 (101)
ii)	Nitrogen removal through plant tissue (in mg)	46.00 (6.3)	3732 (82)
	Plant biomass (dry wt. in g)	19.60 (2.8)	1549 (26)

*Figures in the parenthesis are the standard deviation.

The pond receives suspended solids from the effluent sewage of the urbanized catchment area through piped supply and through nonpoint sources since a sizable population still lives in areas not served by public sewers, hence carrying clay particles from drained soils as well. The catchment area of the wetland also includes agricultural fields in which the nitrogen uptake efficiency of the crops grown is relatively poor in comparison to the amount of nitrogenous fertilizers applied. This has resulted into the possibility of increased losses of nitrate nitrogen from the terrestrial systems into water courses in surface run-off and leaching[7], thus the wetland under study has anthropic influences (urban + crop). The plant density recorded was 79 plants with fresh plant biomass ranging from 31 to 39 kg and dry weight 1.7 to 2.2 kg m^{-2} wetland surface, with 94.3% tissue moisture on dry weight basis. Under normal conditions, loosely-packed hyacinth can cover the water surface at relatively low plant densities: 10 kg m^{-2} wet weight, and can reach a maximum density of 50 kg m^{-2}, before growth ceases[2]. Hyacinth develops an extensive fibrous hairy root system (maximum length, 69 cm) hanging deep into the wetland and puts forth tall leaves above the water surface. The plant develops a large canopy which may provide a good competitive edge over other floating plants[8], and no submerged plants and algal blooms can grow under the hyacinth canopy. The hyacinth absorbs nutrients from the wetland through the central root system and not through the leaf as in duckweeds, *Lemna* and *Spirodela*.

Hyacinth has a significant role in the removal of suspended solids through their attachment to roots. Dense cover reduces wind and thermal mixing. Shading by the plant cover restricts algal growth, roots impede the horizontal movement of particulate matter, assimilate nutrients, produce plant litter and debris and other compounds, thus modifying the microclimate, hydraulic conductivity and suspended particulate matter[9]. Electrical charges associated with hyacinth roots are reported to react with opposite charges on colloidal particles such as suspended solids and cause them to adhere where they are slowly digested and assimilated by the plant and microorganisms[10]. In 1 m^2 wetland area, hyacinth plants weighing 1.549 kg dry weight, attach 663 g of particulate matter on root surface (about 42%) and thus potentially remove it; along with the removal of 1.396 g organic matter, 0.536 g total nitrogen, 0.482 g ammonium nitrogen and 0.338 g nitrate nitrogen (Table 2). The data, thus, reveal that RAPM, weighing 30% of total harvested plant dry weight on waterscape basis, plays an important role in the retrieval of total nitrogen (TKN) as well as of inorganic nitrogen (i.e. ammoniacal and nitrate nitrogen) which are immediately available for rapid hyacinth growth. In other words, when the hyacinth plants are manually removed from the wetland, potentiality of total nitrogen removal is 37.32 kg through the plant-tissue +5.36 kg N/hectare in RAPM, besides 6630 kg/h of particulate matter through root attachment (RAPM). The extensive root systems provide a huge surface area for attachment of particulate matter and microorganisms, and oxygen release through root-zone aerenchyma[10,11] may increase redox potentials for microbial decomposition of organic matter and nitrification rates[12,13]. Significant release of gas bubbles from the root zone system causes bioturbation to provoke RAPM to release attached ammonium and nitrate ions through mineralization for plant absorption. Macroorganic debris in the water could be expected to become part of the RAPM and bottom sediment, but recalcitrant residues such as humic substances and other colloids seem to be the only organic residues to find their way into the water column[14]. Organic residues from lysed cells and other products from plant and animal residues, diatom fructule fragments are prominent examples of suspended particulate matter. Clay minerals such as montmorillonite (particle size <1 μm) contribute a sizable part in the RAPM drained from watershed during the rainy season in the wetland. This clay has specific surface area: 286.8 sq m/g (ref. 15), and an immense potentiality to adsorb organic matter and positively charged ammonium ion.

Aquatic plants play a significant role in water treatment either by directly assimilating pollutants[16] or providing surfaces and suitable environment in the root zone for microorganisms to transform pollutants and reduce their concentrations[17]. The purposeful construction of wetland ecosystems is a new technology in which shallow water bodies are specifically engineered using macrophytes for waste water quality treatment[18,19]. These have now been recognized as an accepted low-cost techology in developed countries especially beneficial to small towns. The present study pinpoints that the extensive roots of hyacinth adsorb significant amount of particulate matter, and this RAPM in the densely-packed plant cover acts as a 'suspended sediment layer', rich in nitrogen and organic matter for immediate nutrient need of the plant, besides the water column and permanent bottom sediment layer. Floating hyacinth having buoyant roots further advocates its use as a tool in substantial removal of RAPM and nitrogen from the eutrophicated water body, if mechanically harvested as is the usual practice in India.

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