Role of plants in constructed wetlands (CWS): a review

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ABSTRACT

Plants play major roles in constructed wetlands (CWs): they maintain the temperature, decrease wind speed and avoid re-suspension of nutrient and sludge, supply Surface for periphyton and bacteria and help in providing the required conditions for various biological, physicochemical processes within a constructed wetland for effective treatment of wastewater. Most commonly used plants are *Typha angustifolia*, *Phragmites australis*, different types of grass, and bulrush. This review paper studies plant types, including emergent herbaceous plants, and plant characteristics used for constructed wetlands, their phytology, plant nourishment and growth cycles, factors to selection in plant selection.

KEY WORDS: plants, constructed wetlands, nutrients, wastewater, treatment.

1. INTRODUCTION

Wetlands are transitional areas encompasses between land and water also known as wet soils, having plants that adapt well to wet soils. Land and water can merge in many ways; there is no appropriate single correct definition to suit all purposes. Dominant plants, wetlands can be classified into three groups: salt and freshwater swamps, marshes, and bogs. Swamps are flooded areas created by water-resistant ligneous plant and trees, marshes are created by soft-stemmed plants and bogs are created by ferns and acid-loving plants.

Constructed wetlands (CWs) are designed for utilizing wetland plants, soil and connected microorganisms to remove not needed element, from wastewater effluents. These are a low cost alternative to conventional ways of wastewater treatment.

CWs are engineered systems that are constructed to optimally utilize natural processes to treat wastewater. Type of wetland (surface or subsurface, vertical or horizontal flow) and it's type of operation (continuous, batch or intermittent flow), loading rate, selection of plants and wastewater characteristics will affect the treatment efficiency. Vegetated wetlands improved treatment efficiency in contrast to un-vegetated wetlands. Major Role of the Plants in the wetlands is to create attachment sites for microorganisms and release oxygen. Appropriate plant species selection increases the effectiveness of the desired treatment. Other objectives such as natural, decorative, recreational and inexpensive considerations for wetland developments may also affect the choice of type of plantings. Different types of CWs plants are free floating, rooted floating, emergent, submerge, shrub and the trees. Most commonly emergent herbaceous plants are used in CWs.

Characteristics of plants in CWs: The mechanisms by which plant populations boost treatment efficiency of CWs is still to be understood completely. However, types of plants native or exotic, level of tolerance to nutrient load, stage of plant growth, number, density, and spacing of plants, season of their germination, growth, and harvesting, oxygen supply to roots, type of microbial growth on root surface, affect the performance. A relationship between plant surface area and the density and useful performance of attached microbial populations have been proposed, but demonstrations of this relationship are yet to be proven. Following table no. 1 shows numbers of plants per meter square of area as reported in different studies.

Table.1. Number of Plants in Construction Wetlands per square meter of a sample area

Sample area Number	No. of Plants/M^2	Plants Details
1	5	Phragmittess
2	35	Typha
3	11	cattail, sedge, water grass, Asia crabgrass, salt meadow, cordgrass, kallar grass, vetiver grass and Amazon
4	50	Phragmites australis
5	3	Reeds
6	3	Wetland plants
7	4	Phragmittess
8	22	Cattail (Typha latifolia)
9	9	Phragmites australis and Typha orientalis
10	4	Canna, Phragmites and Cyperus
11	4	Phragmites australis

From above table it is summarised that there is no standards rules for density of plants or their spacing in wetlands, but majority of studies preferred average density of 4-5 emergent herbaceous plants plants/m^2 for management of the wastewater. However, a few constructed wetlands keep up the species composition and density distributions envisioned by their designers. Many of these changes in plant densities may be foreseeable and may have little apparent effect on treatment performance. Other changes, however, may result in poor performance and the resultant need for increased management. Table no.2 explains the factors for wetland plant selection.

Table.2. Factors to Consider in Plant Selection

Factors	Comments
Local experts	Take a consult from an experienced person from government agencies and private companies.
Native species	Rate of Survival will be high of native species.
Tolerant of High nutrient load under flooding condition	Select the plant which wills survive in continues flow of waste water.
Growth characteristics	Long lasting plants are generally preferred over annual plants because plants will continue growing in the same area and there is no concern about seeds being washed or carried away. For emergent species, persistent plants are generally preferred over semi-non-persistent plants because the standing plant material provides added shelter and insulation during the winter season.
Rate of growth	Slower growing plants will require a greater number of plants, planted closer together, at start-up to obtain the same density of plant coverage in the initial growing season.
Wildlife benefits	If the wetland is to be used for habitat of wildlife, select the plants that provide food, shelter for particular animal.

Advantage of Emergent Herbaceous Plants: Emergent wetland plants are key structural components of wetlands. Their various changes allow aggressive growth in flooded soils. These changes include following characters: lenticels that permit air to flow into the plants; aerenchymous tissues that allow gaseous convection all over the length of the plant, which provides air to plant roots; special morphological growth structures, such as supports, knees, or an air-filled root, that supply extra root aeration; adventitious roots for surface assimilation of gases and plant nutrients directly from the water column and extra natural tolerance to chemical by-products resulting from growth in anaerobic soil conditions. The most important function of emergent vegetation in free water surface (FWS) systems is providing support for increasing fluffy mass, deposition and filtration of suspended solids through idealized hydrodynamic conditions. Emergent wetland plant species also play a role in winter performance of FWS constructed wetlands by insulating the water surface from cold temperatures, trapping falling and drifting snow, and reducing the heat loss effects of wind. Limited information is available to show significant or constant effects of different plant species selection on constructed wetland performance. The wetland expertise is strongly encouraged to get information from experienced home wetland practitioners when selecting emergent herbaceous species to ensure selection of locally successful species.

Plant nourishment and Growth cycle: Wetland plants need optimum natural environment in each stage of their life cycles, together with germination and preliminary plant growth, normal seasonal growth patterns, and plant senescence and decay. A large variety of studies explain growth cycles, timing of seed release, overwintering ability, nutrient and energy cycling and other description and processes that provide wetland plant species with a competitive advantage in their natural habitats. An overview of important characteristics follows: emergent herbaceous wetland species planted early in the rising season in moderate climates generally multiply by vegetative reproduction to a maximum total standing biomass in late summer or early fall within a single rising season. This biomass may symbolize many growth and demise periods for individual plants during the course of the growing period or it may stand for a single emergence of plant structures, depending on types of species. For many species, seeds are developed at the same time with maximum standing crop and transported with maturation in the fall for early germination in the spring. For a few species having high lignin content, mainly cattail, bulrush, and common reed, much of the plant remains standing as dead biomass that gradually decays for the duration of the winter period. In FWS systems, this standing dead biomass provides additional structure for enhanced flocculation and sedimentation that is vital in wetland treatment performance all through the cycle.

Dead biomass standing and fallen, also is vital to root viability under flooded, in winter season it provides insulating film, in adding up the internal load on the system. Like others all plants, wetland plants also require many nutrients for healthy growth. Wetland plants consume macro-nutrients (Nitrogen (N) and Phosphorus (P)) and micro-nutrients (including metals) through their roots during active plant expansion. While municipal wastewater can supply sufficient quantities of these limiting nutrients, other type of contaminate water, including industrial wastewater, acid mine drainage and storm water, may not. N and P are key nutrients in life cycles of wetland plants. However, plant consume of N and P is not a significant mechanism for removal of these elements in most wetlands receiving partially treated municipal wastewater because N and P are taken up and released in the cycle of plant growth and death. Un-decomposed waste from dead organic matter provides storage space for P, metals and other relatively conservative elements. While uptake rates of N and P are potentially high, harvesting plant biomass to take out these nutrients has been limited to floating plant, in which the plants can be harvested with only short altering of scheme performance.

Plant Harvesting: Toet (2005), summarised that the harvesting done before cold was insignificant in wastewater treatment. Whereas Zheng (2014), guided that the plants are harvested in November before the cold winter by cutting upper parts of 20-30 cm over the ground but results show negligent effect in nitrogen removal. Whereas Sohair (2013), mention harvesting 10 cm from gravel base however no significance of harvesting is mentioned. Brix, enlighten there is insignificant role of harvesting in wetland for treatment of wastewater. There is a few research has been done for harvesting of wetland plants. From above discussion we summarised that harvesting is done before next growing season, Cutting is limited up to 20-30cm above the ground level, and there is insignificant role of harvesting in nutrient removal.

Summary of wetland plants for different pollutants removal: Following table no. 3 is the summary of 13 wetlands and the different variety of plants are utilised for treatment of wastewater.

Table.3. Details of pollutants removal by different plants species

Plants Details	Media/Soil	Type and Nature of wastewater	Pollutant name	Initial conc.	Pollutant removals
Foxtail Grass, Flax Lily, Banksia, and Bottlebrush	Pea gravel, sand, and loamy sand	Synthetic Strom water dosing and Treatment plant effluent for each media type, five mesocosms were planted with native vegetation, with the remaining five unvegetated barren, providing five replicates for each treatment.	NOx	3.60 mg/l	47-97%
			TN	5.04 mg/l	35-58%
			TP	4.51 mg/l	6-36%
Typha	Lockport dolomite	1.Treat sewage lagoon wastewater on a year round basis in a cold climate 2.The key features of these wetlands were sub-surface flooding, pulse or intermittent hydraulic loading, vertical flow and bottom drainage from root beds	TP	189 (mg/m2/d)	18%
	Queenston shale		TP	400-700 (mg/m2/d)	17-28%
	Fonthill sand		TP	105-331 $(mg\ m^{-2}\ day^{-1})$	5-58%
P. australis, *T. latifolia*, *P. hydropiper*, *A. sessilis*, *C. esculenta* and *P. stratoites*	The sub-surface flow CW used in this study having lined gravel beds supporting aquatic plants	A residential complex with 5000 person visiting every day and this CW is designed to treat the sewage generated from this complex which is about 5–6 MLD.	BOD TSS PO4-P NH4-N	155 (mg/l) 170 (mg/l) 5.75 (mg/l) 22.8 (mg/l)	90%, 65%, 76% 86%
J. effuses, *C. lurida*, and *D. acuminatum*	sand and clay	1.Nutrients from agricultural runoff- 2.A greenhouse experiment was conducted to study phosphorus retention rates in unvegetated and vegetated constructed wetland mesocosms	TP%		
			J. effusus	2.5(mg/l)	77%
			C. lurida	2.5(mg/l)	85%
			D. acuminatum	2.5(mg/l)	74%
			Mixed	2.5(mg/l)	82%
Phragmites australis	Type 1 beds contain coarser gravel while type 2 beds contain finer gravel. Type D beds have a lesser water depth	1. Previously screened urban wastewater flow to imhoff tank. 2. From imhoff tank to water will flow to CWs/ HLRs: 20, 27, 36 and 45 mm/d. Type A beds have an aspect ratio of 1:1, B of 1.5:1, C of 2:1 and D of 2.5:1.	D=0.27m		
			COD BOD ammonia and DRP	160-400(mg/l) 60-220(mg/l) 48-75.4(mg/l) 7-15.3(mg/l)	70-80 70-85 40-50 10-22
			Depth= 0.5m		
			COD BOD NH4 DRP	160-400(mg/l) 60-220(mg/l) 48-75.4(mg/l) 7-15.3(mg/l)	60-65% 50-60% 25-30% 2-10%
Common reed (*Phragmites australis*)	Gravel	Settled urban wastewater Intermittent and continuous feeding study No effects of intermittent and continuous because small size of wetland	COD ammonium	7.4-10(g/m2/d) 0.67-1.0(g/m2/d)	81% or (6 g/m2/d) 98% or (0.6-0.4g/m2/d)
common reed (*Phragmites*	Gravel	Synthetic wastewater was designed and used to simulate to	BOD, TKN and ortho-	300mg/l 60mg/l	89% 65%

australis and cattails, *Typha latifolia*).		the best the characteristics of domestic wastewater	phosphate (P- O43−)	10mg/l	60%
T.angustifolia, *P.australis*, *S. pungens*	Paxton fine sandy loam soil	wetland was designed to treat the milkroom parlor wastewater from 100 dairy cows, generating 2650 l /d and a BOD5 loading of 1500 mg /l with a resulting effluent of 30mg/l BOD5 and minimum retention of at least 12 days	TSS, BOD TP $NO3^-$ $NO2^-$	- 17.04(g/m2/d) 0.188(g/m2/d) - -	94, 85, 68, 60 and 53%
common reed (*Phragmites australis*) and (*Typha orientalis*; *Scirpus validus*; *Lemna minor*)	Soil	Domestic and small quantity of industrial wastewater The system consisted of a grill-separation tank, a holding bank, distribution ditches and constructed wetlands	SS BOD COD TC FC TP	102±21.6 (mg/l) 83.7±15.8 (mg/l) 249.4±52.2 (mg/l) 2.4×10^6 CFU/100lm 1.6×10^6 2.89±0.41 CFU/100lm	71.8% 70.4% 62.2% 99.7% 99.6% 29.6%
Club-rush, Cattail, Common water plantain, Reed canary grass, Meadowsweet Yellow flag, Compact rush	Arable land (Heavy clay)	Retaining agricultural nutrients in constructed wetlands—experiences under boreal conditions in south Finland	TSS TP DRP TN NOx-N NH4-N	29-530(mg/l) -- 47-730 (mg/l) 3100-9800(mg/l) 2400-7900(mg/l) 90-105 (mg/l)	5-72 % 6-67 % 3-33 % 7-40 % 8-38 % 50-57 %
cattails (*Typha latifolia*) with Scattered bulrushes (*Scirpus acutis*) along the borders.	Gravel	1.The village's municipal wastewater is treated by a two-cell sewage lagoon. 2.This treated water is further treated in CWs.	BOD ammonia and ammonium TKN TSS TP ortho-PO4 FCs and *E. coli*	3.62(mg/l) 0.11(mg/l) 1.67 (mg/l) 82.67 (mg/l) 0.33 (mg/l) 0.18 (mg/l) 82.77/100ml 64.85/100ml	34% 52% 37% 93% 90% 82% 52% 58%
Oenanthe javanica (Blume)	--	1.lab-scale FWS system to purify low-strength municipal sewage in winter 2.Initially the artificial wastewater was prepared by dissolving glucose, NH_4Cl and KH_2PO_4 in clarified river water for acclimatize for plants to CWs.	COD TP TP NH3	Loading rate(g/m2/d) 0.62±0.06 0.10±0.00 6.56±0.24 0.49±0.05	 40-61% 7-36% 16-30% 6–32%

From above table it can be summarized that Typha, Bulrush and common reeds are most commonly used mycrophytes in wetlands.

Future considerations: Plants have been used for wastewater treatments, to remove heavy metal and nutrient retention in construction wetlands. Following areas may be explored for future study.

a) To identify different wetland plants including aromatic plants and grasses to increase Fertility of soil through CWs.

b) Study the growth medical plants and their effects on wastewater treatment in CWs.

c) Grow the plants which may be directly utilized as commercial crops, such as manufacturing paper, tapping glue or rubber, lavender (ingredient for perfumes, soaps, and other cosmetics), timber for construction, henna for hands and natural fibres.

d) Use different combination of wetland plants and non wetland plants to aim for zero pollutants in effluents.

2. CONCLUSION

CWs are a natural substitute to technical methods for treatment of wastewater. This review presents the available knowledge on verities of plants in CWs, which may lead to better understanding and use in the treatment process. The CW plants for commercial purposes have to also be used for production of herbs and medicinal plants, fibres, rubber and henna etc. These new perspectives increase the possible use of plants in CWs and add to various factors to be thinking about when planning vegetation and management practices for CWs. However, for excellent treatment of wastewater our knowledge about the complex system involving the plants, microorganisms, soil matrix and other constituents in wastewater their dealings will be also required.

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