Role of Soil and Plants in Phosphorus Retention in Constructed Wetlands with Special Focus on Lateritic Soil: A Review

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ABSTRACT: Phosphorus (P) is often the major limiting nutrient in freshwater systems. Due to the absence of any gaseous component in the different forms in the conversion cycle, phosphorus tends to move to the sediment layer in natural systems, becomes fixed, and unavailable to the ecosystem. This paper reviews the work done on constructed wetlands to understand phosphorous retention by wetland soils and role plants in the same. Special focus is on the lateritic soils due to their P-retention capacity. Various studies on the tropical soils have reported significant influences of tropical weathering and leaching processes on the mineral-chemistry and morphology of lateritic materials; leading to deficiency of Nitrogen and Phosphorus but sufficient amount of potassium for plant development. This study reviews the processes and factors adaptable for P retention in soil & physico-chemical separation of phosphorus.

KEYWORDS: Constructed wetland, Phosphorus, Fertility of soil, Plant Nutrients, Eutrophication, Factors for P Retention, Laterite soil.

1.0 INTRODUCTION

Wetland is area consisting of land and water. The term "natural wetlands" comprises a broad range of wet environments, including marshes, bogs, swamps, wet meadows, tidal wetlands, floodplains, and ribbon (riparian) wetlands along stream channels [1]. Constructed wetlands are designed and constructed to mimic natural wetland systems for treating wastewater. These systems have active interrelation between vegetation, substrates, soils, microorganisms and water, utilize physico-chemical-biological mechanisms to remove various pollutants and enhance the water quality [2, 3, 4, 5]. Conventional and modern wastewater treatment technologies such as activated sludge process (ASP), membrane bioreactors and film separation are expensive and not entirely feasible for a small community and remote area [6], compelling to look for low-cost and efficient alternative technologies for wastewater treatment. Constructed wetlands (CWs) provide green, low-energy, low capital and operational cost, low maintenance alternative to conventional wastewater treatment systems, especially for small communities and remote areas [7][8].

In activated sludge treatment process operation & maintenance (O & M) cost for per million litters per day (MLD) treatment of sewage is estimated as Rs 30,000 per month and 2.6 Kilo Watt of electricity is required for the treatment of sewage. Activated sludge plant (ASP) is 450 m^2 /MLD and capital cost for the treatment is Rs. 68 lacs/MLD (CPCB, 2013).

In China per M^3 sewage treatment is 28.82 US$ and O&M cost 0.022 $ using CWs and sewage treatment is 115 US$ and O & M cost 0.116$ using ASP [9].Hammer (1990) suggested that the cost of CWs can vary 1/10 to 1/2 of ASP. However, the Waste stabilization pond(WSP) attained a better removal for NH4þeN. The total annual cost estimates consisting of

capital, operation and maintenance costs had little difference between both systems. Mburu et al.,[10] identified for HSSF-CW 37,047 and For WSP 35,525.Area for 2700 PE 22,350 m2 and for HSSF-CW 9287.1 m2. EurosHowever, the evaluation of the capital cost of either system showed that it is largely influenced by the cost of land and the required construction materials. The HSSF-CW showed less land requirement per unit volume of treatedwastewater compared to that of the WSP. Hence, one can select either system in terms of treatment efficiency. When land is abundantly available, other factor including the volume of wastewater to be treated and the economies of scale, determine the final costs.

Hence, Conventional wastewater treatment focuses on removal of BOD, and nutrients, N and P, removal is not a priority, leading frequently to problem of eutrophication and algal blooms in the receiving water bodies [11]. Phosphorus limits eutrophication in most fresh water systems [12]. Various human activities have sped up the eutrophication process, changing the geochemical cycles. Nutrients can enter aquatic ecosystems via non- point sources resulting from anthropogenic origins such as: (a) Domestic, municipal and industrial discharges, (b) fertilizers runoff from agricultural land (c) Diffuse sources in catchment areas. Non point sources generally are of greater significance than point sources since they are larger and more difficult to control. Coastal lagoons and shallow estuaries with prolonged water residence times, low flushing rates, and high human development in coastal watersheds are most susceptible[13]. Excessive input of nutrients of human origin has rendered Mediterranean coastal lagoons eutrophic [14]. CWs have been reported to effectively absorb both nitrogen (N) and phosphorus (P) generated from the waste treatment plant [15]. CWs have been used for wastewater treatment for more than fifty years [16]. Free surface water CWs provide a relatively cheap and potentially effective option between tertiary wastewater treatment plants and natural wastewater treatments [17]. We hope that this study will provide better understanding of the processes that control P cycling. The aim of this article is to: (1) Present a review of the processes and factors regulating P retention in streams and wetlands soil and (2) Identification of wetlands plants for P retention.

2.0 Transformation of Phosphorus in CWs:

Petersson and Jansson [18] & Broberg and Persson [19] showed Phosphorus containing particles are released to natural waters from three important sources: 1). biologically created cells of plants, bacteria and animals 2). Weathering substance such as primary or secondary mineral deposits and 3). Direct precipitation of inorganic phosphorus. Forms of P are classified as: soluble reactive P (SRP), dissolved organic P (DOP), particulate organic P (POP) and particulate inorganic P (PIP) [12]. Particulate phosphate is deposited onto the CWs system sediment by sedimentation or entrapped within the growing macrophyte stem and attached onto biofilms [20]. SRP may be sorbed onto plant biofilms in the water column, onto the wetland sediments, and onto biofilms in the floating plant litter. The exchange of soluble phosphate between sediment pore water and the overlying water column by diffusion and sorption or desorption processes is a main pathway for soluble phosphates in wetlands [21]. In the sediment pore water, these phosphates may be precipitated as the insoluble ferric, calcium, and aluminum phosphates or adsorbed onto clay particles, organic peat, and ferric and aluminum ox-ides and hydroxides [22]. When the pH is above seven, precipitation as calcium phosphates occurs and may occur within the sediment pore water or in the water column near active phytoplankton growth.[23].

The sorption of phosphorus on clays occur when both the chemical bonding of the negatively charged phosphates with positively charged clay [24]. Phosphate released into water depends upon redox potential, this released phosphate bound with Fe or Al both in the sediment and in the suspended solids[25]. Oxidation conditions vary the chemical binding of phosphorus is explain by the sediment's redox potential [26]. Moor and reddy [27] showed the Near the suface redox potential is 550 mV where as a few centimetre below redox potential is 220mV. Thus phosphate is released to the wetland through redox potential. Under anoxic conditions, for example, the ferric compound is reduced to the more soluble ferrous compound and phosphate is released [28]. Whereas Bakry and A. Razaq summerised anoxic conditions by hydrolysis phosphates may also be released from ferric and aluminum phosphates. Phosphate sorbed to clays and hydrous oxides may also be resolubilized through the exchange of anions [29]. The release of phosphate from insoluble salts will also occur if the pH decreases as a result of the biological formation of organic acids, nitrates, or sulphates. However, Over time, a significant fraction of the initially removed phosphate will become bound within the sediments and fixed to the system. At the start-up of a FWS system, the phosphorus removal will be high owing to the initial reactions with the soils of the wetland. This removal mechanism is finite and essentially disappears after this period [1]. Moreover, substrate sorption may play the most important role in absorbing various pollutants such as phosphorus Ju et al. [30] Selection of suitable substrates to use in CWs for industrial wastewater treatment is an important issue. A few studies has been done in phosphorus retention in lateritic soil using different type of wastewater.

3.0 Formation of lateritic soil and its characteristic:

The Laterite is a latin word from Bricks [31]. The term laterite material is reddish, tropically weathered residual and non-residual soils.[32]. Laterites are formed by the decomposition of the rock, removal in solution of silica and bases and accumulation of Aluminum of iron sesquioxides, titanium, magnesium, clay and other amorphous products generally a course grained material with ninety percent or more of these Laterite constituents is termed Laterites [33]. Singh et al., [34] have mentioned Laterite soils are typically formed under tropical climate experiencing alternate wet and dry seasons. Laterites contents high proportion of iron and aluminium oxide and it's allow the phosphorous to readily adsorb, and be re moved from the water column [35]. laterites is numerous poorly crystalline and amorphous phases are present in substantial weight fractions [36]. Amorphous Fe and Al helps in Phosphorus sorption [37]. Laterite is mixture of various proportions of goethite, Himatite, Gibssite, Beohmite, Kaolin, leucoxene, anatase, and rutile of a few amounts [38]. In India total area of about 248,000 sq. kilometres covered by Laterite [39]. The soils are limited in depth by gravel and lateritic formations and are suffering from crusting and compaction. With few exceptions, the soils have a low inherent fertility [40]. Bourgeon [41] considered laterites/lateritic soils as characteristic of the coastal hinterland of Western Karnataka.

Following table show mineral analysis of laterite of Raipur by powder X-ray diffraction (XRD) using X'Pert Pro XRD Systems Measurements were made in reflection geometry with the sample surface at an angle of 2 ∘ to the incident beam.

Table 1: mineral analysis of laterite

Sr. No.	Material	Percentage concentration
1	SiO_2	50.55
2	Al_2O_3	15.37

3	Fe_2O_3	25.48
4	CaO	7.06
5	MgO	2.56
6	Na_2O	0.45
7	K_2O	1.04
8	Cl	0.61
9	SO_3	1.40
10	TiO_2	0.63
11	Mn_2O_3	0.045
12	P_2O_5	0.058

From above table it is summarised that laterite content 50% of silica, 15% of aluminium oxide and 25% of iron oxide, these oxides will helps for P retention in soil.

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Table 2: fertility parameters of Laterite soil in Raipur

Sr. No.	Parameters	Results		Comments
		Location 1	Location 2	
1	pH	6.4	6.3	Slightly acidic soil
2	Available N in Soil	288.5kg/ha	175.61kg/ha	low -Medium
3	Available P in Soil	12.36kg/ha	10.84kg/ha	low
4	Available K in Soil	293.44kg/ha	181.44kg/ha	High
5	Available Organic matter in Soil	0.315 %	0.54%	low

Coarse texture, soft, friable - Red due to presence of iron oxide formed due to leaching. Potash removed from top soil leaving alumina and iron oxide. Organic matter content of the soil is very low (<0.5%), which indicates low presence of Carbon for plant's growth and also indicate Less numbers of bacteria available for plant's lifecycle growth and death. Low fertility due to acidity and low moisture retention.

4.0 Factors Affecting Retention:

The catchment slope is an important factor influencing the risk for soil erosion. For instance, Ekholm et al.,[42] has founded that concentrations of particles and total P in runoff increased when the slope of the fields increased. Risks for soil particle and particulate P losses depend on both the slope of catchments and the soil texture. The wetlands with high area specific particle retention described in Braskerud [43] were situated in streams draining fairly erosive areas as indicated by the high concentrations of suspended solids in some of the streams. Sovik and Klove [44] showed the kinetics of precipitation reactions are slower than the adsorption reactions, so retention times in the range of several days are necessary for them to occur. From above study its seem that slope of CWs and L: W ratio helps in Phosphorus retention. According to Persson and Wittgren [45] the hydraulic conditions depend mostly on aspect ratio (L: W), which determines both the effective volume ratio and the depth in wetlands. Wetland shape, i.e. L: W was completely related with P and particle retention. However, Johannesson et al., the results indicate that when the P and particle retention will decrease even if the L: W ratio is high [46]. Several studies have shown that in runoff from agricultural fields in clay and silt conquered areas the P is transported particulate P (PP) form [17, 18, 19]. However, periods of P release from constructed wetlands for example Braskerud [43] and Koskiaho et al., [47] during annual development of vegetation with re suspension occurring when seasons with decaying vegetation. Bratieres et al., [50] has reported that P removal in treatments evaluated for eight months can go beyond 90% at storm-water concentrations. Where as Ulen has showed that a majority of particles in the drain flow from a clay soil were colloids having theoretical settling velocity of 0.08 cm day−1[49]. Duff et al., [51] and Newman et al., [52] showed that Phosphorus accumulated in summer is highest which is related to air temperature and evapotranspiration. Johannesson, et al., [46] reported that agricultural catchments of clay retained P varied from 11 to 175 kg $ha^{-1}yr^{-1}$after two year.

4.1 Identifying the Condition that May Help in P Retention in Soil

Following Condition Helps In p Retention In Wetland Soil.

i. Retention of P is highly influenced by amorphous and poorly crystalline structure of the soil [30,31, 32].

ii. Kuhnel [36] showed that laterite has amouphous and Poorly crystlline structure.

iii. Laterite soil will fix more phosporous [56].

iv. Frolich [57]; Golterm [58]; Khalid et. al., [39] and Richardson [59] suggested that amount of P fixation in wetland will depend on Fe, Al oxides Ca and Carbon contents of the soil.

v. Khalid [39]also suggested that P retention is limited to top 5cm of soil only.

vi. As the quantity of $Fe(OH)_2$ and $Fe(OH)_3$ will increase the amount of P in the soil Huang and Violnate [60] will be increase in the soil.

vii. Organic Acids promote formation and stability of $Al\text{-}PO_4$ Complex Huang and Violnate [[58]].

viii. Addititional dissolved organic matter will increase P retention in soil [31].

ix. Dunnes et.al., [61] showed acidic soil adsorb more amount of P.

x. The high P fixing power of laterite soil is not only because of high content of Sesquioxides but also low content of organic matter [62].

4.2 NUTRIENT RETENTION/ REMOVAL RATE CALCULATIONS

Nutrient the percentage of nutrients removed from the water column based on both concentration and mass were calculated for each wetland site in a similar manner. Nutrient retention of Phosphorus was calculated using, Nutrient reduction (% by mass)

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where Q_{in} is the inflow flux of Nutrient in the incoming waste water and Q_{out} is the outflow flux of Nutrient from the wetlands [25, 26, 27].

5. IDENTIFICATION OF WETLAND PLANTS WHICH WILL RETAIN P IN THE SOIL:

Wetland plants play an important role in reducing the eutrophication of waterways, as plants take up and accumulate nutrients for growth, maintenance and reproduction during the growing season.Wetland plants have been reported to remove 16 to 75% of nitrogen (N) inputs [61, 62, 63]. A net release of nutrients often occurs in the fall and early spring as a result of decomposition and nutrient leaching of plant litter [56]. Since most problems associated with eutrophication occur during the growing season the contribution of plants to seasonal N and phosphorus (P) retention can be significant. Following listed plants help in P retention in soil.

1. **Typha:** less than18% of TP is retained in Soil Suggested by Mistch, et al., [69] whereas Borggaard et al., [53] showed 5-58% of TP retention by Typha plants.

2. **Pisitia**(Floaters): helps in P fixation in soil [70].

3. **Phragmities:** Helps in 4.8% in soil [71].

Typha (*latifolia Cattail*), Phragmites australis (*Reed*), Ocimum gratissimum (*Vana Tulsi)*, Poaceae (*Grass*), Althernanthera sessilis (*Elegator weed*), Eichhornia crassipes (*water hyacinth*), Nelumbo (*Lotus*), Colocasia esculenta (*Elephant-ear*) and Pistia stratoites (*Water lettuce*) are locally available wetlands plants in India. A few researches have to be done for effects of mixed culture above listed Indian plants in P retention in soil.

6.0 CONCLUSIONS:

Phosphorus retention in wetlands is regulated by a variety of biological, physicochemical factors. While evaluating wetlands P assimilation, one must consider both short-term storage assimilation into vegetation and long-term storage assimilation by soil. In wetlands P stored during active growth phase of vegetation was released into the water column during senescence and decay of the de-trital tissue. Wetland shape, i.e. L: W was positively related with P and particle retention. Reasonable forecasts of long-term P assimilation are based on the sediment accumulation rates and sediment P sorption capacity.

Phosphorus retention by stream systems is dominated by physical processes such as flow velocity, discharge and water depth. However, the same biological and chemical processes that regulate P retention in wetlands regulate P in streams. Abiotic processes controlling P retention in streams are dominated by sediment sorption reactions. However, biological uptake can account for the majority of dissolved P transformations in streams.

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