CARBON SEQUESTRATION POTENTIAL OF CONSTRUCTED WETLANDS USED FOR WASTEWATER TREATMENT
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Abstract
Wetlands present an important opportunity for carbon sequestration and greenhouse gas offsets by virtue of their potential for restoration using known and innovative land management methods, because inherently they are highly productive and accumulate large below-ground stocks of organic carbon. Wetlands are major carbon sinks. While vegetation traps atmospheric CO₂ in wetlands and other ecosystems alike, the net-sink of wetlands is attributed to low decomposition rates in anaerobic soils. Carbon fluxes and pool sizes vary widely in different wetlands. Recently, artificially created constructed wetlands used to treat wastewater has been in common usage in Europe, USA and developed Asian countries for ecosystem-based eco-technology. Thus, waste water treatment and protecting these wetland bodies clearly represent an immediate and large opportunity for enhancing terrestrial carbon sequestration too. Experiments were conducted to measure the rate of photosynthesis in the key planted macrophytic plant species of the constructed wetland: the Phragmites karka (Reed grass, the local plant species) using the Li-Cor 6400. The uptake of carbon-dioxide by the plants could be measured at different CO₂ levels in the atmosphere. It was found that the reed grass shows maximum photosynthesis at levels as high as 500 ppm of CO₂. Thus, it can prove ideal for plantation at industrial sites emitting higher concentration of CO₂, capable of treating the wastewater, thus purifying water as well as fixing CO₂ and thus purifying ambient air in the industrial campus. Further it was found that the constructed wetlands have a good capacity to maintain the organic stocks in its medium as well at the anchoring gravel medium and the floor. Present study focused on the ‘subsurface flow constructed wetlands’ that have a smaller water column around the anchoring gravel bed as compared to the natural systems. Hence they have a greater carbon sequestration potential when compared to the natural systems. Constructed wetlands are a wise option to treat industrial waste waters efficiently when compared to the energy intensive conventional (engineering-based) treatment plants. Moreover they not only help to develop green belt around the industry but also serve to absorb the atmospheric carbon in a beneficial manner. The present study focuses on the carbon sequestration potential of two constructed wetlands.
Keywords- Constructed wetlands, Organic carbon, sequestration, wastewater, treatment plants, photosynthesis

I. INTRODUCTION

Historical changes in the quasi–steady state of the carbon system are clearly reflected in ice core and isotopic records, which also record the unprecedented changes caused by anthropogenic CO₂ emissions (Raynaud et al. 1993). The globally averaged atmospheric CO₂ mole fraction is now over 365 µmol/mol (or parts per million, ppm) — higher than it has been for hundreds of thousands of years. Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming.

In brief, a constructed wetland is a water treatment facility. Duplicating the processes occurring in natural wetlands, constructed wetlands are complex, integrated systems in which water, plants,
animals, microorganisms and the environment--sun, soil, air--interact to improve water quality. Whereas geology, hydrology and biology create natural wetlands, constructed wetlands are the result of human skill and technology. Humans design, build and operate constructed wetlands to treat wastewater. By utilizing, and even attempting to optimize the physical, chemical and biological processes of the natural wetland ecosystem, constructed wetlands also are, to various extents, natural environments.

Constructsed wetlands are functional systems, hence they serve as sinks of atmospheric carbon rather than emitting GHGs. Subsurface flow constructed wetlands have a smaller water column when compared to the natural systems which has stagnant water and larger sediments. Hence they have a greater carbon sequestration potential when compared to the natural systems. Moreover they not only help to develop green belt around the industry but also serve to absorb the atmospheric carbon in a beneficial manner. Wetlands as ecology are more productive in biomass production than any other environment except the rain forests. Since one of the treatment goals is to remove carbon from wastewater, passive treatment technologies such as constructed wetlands should be considered because they offer significant savings in atmospheric carbon. Conventional, energy intensive, wastewater treatment plants discharge four pounds of carbon into the air, generating the electricity to remove one pound of carbon from the wastewater.

Carbon Sequestration is defined as either the net removal of CO$_2$ from the atmosphere or the prevention of CO$_2$ net emissions from the terrestrial ecosystems into the atmosphere. There are two fundamental approaches to sequestering carbon in terrestrial ecosystems: (1) protection of ecosystems that store carbon so that carbon stores can be maintained or increased; and (2) manipulation of ecosystems to increase carbon sequestration beyond current conditions.

II. METHODS

In the present study, two sites of following Constructed wetlands were selected to study the carbon dynamics. Both the sites are geographically located in Ujjain city (23° 11´ N latitude and 75° 43´ E longitude)

A. Subsurface flow constructed wetland in Ravindranagar (8 year old)
1. Location: Ravindra Nagar, Ujjain
2. Area: 30 m length x 10 m width=300 m$^2$
3. Gravel Depth: 0.85 m
4. Gravel Size: 0.8 - 2.5 cm
5. Treatment capacity: 40 m$^3$/Day
6. Water Retention capacity: 120 m$^3$
7. Retention period: 3 days

B. Subsurface flow constructed wetland on the Nala near Harijan thana (2-yr old Reed bed)
1. Location: wastewater channel near the M.R.–11 road of Mahakal Commercial Area, Ujjain
2. Dimension: (Length: 70m, Width: 15m, Depth: 0.60m, Effective surface area: 1050 m$^2$)
3. Retention Capacity: 221 m$^3$
4. Lean treatment capacity: 75 m$^3$/day
5. Retention time : Approx 3 Days
6. Bed Lined with 0.05 mm LDPE
7. Gravel Bed Depth: 0.60 m
8. Treated water collection: via PVC pipe (Dia 20 CM)
9. Plantation : 2 Plants per m$^2$

The Constructed wetlands are grown with *Phragmites karka* (Reed grass), which is a perennial grass used to treat the wastewater entering the two Wetland sites, planted on the gravel bed. Besides, common reed roots reach deeper than any other hydrophyte (root depth up to 3 m) what helps the plant to take up water and first of all wetland nutrients (Kohzu et al., 2003). Field studies were carried out during December 2007 to December 2009.
C. Evaluation of the parameters

Seasonal measurements of leaf gas exchange parameters were conducted between January 2008 and December 2009. All measurements were made on clear sunny days. Diurnal measurements were made for every two hour intervals between 6am to 6pm. Leaf gas exchange rates were measured using an open gas exchange Portable Photosynthesis System (Li-6400, Li-COR, Lincoln, NE, USA) with independent CO$_2$ control, using a 6 cm$^2$ clamp-on leaf cuvette. All measurements were carried out at ambient air temperature, CO$_2$ and at 950 micro mol/m$^2$/s Photon Flux Density (PPFD) on the fully expanded healthy leaves.

To assess the response of leaf photosynthesis to different CO$_2$ concentrations in the well-established plants, CO$_2$ response curves were studied using portable photosynthesis system (Li-6400, Li-COR, Lincoln, NE, USA). The Li-6400 has a controllable CO$_2$ injection system to manipulate CO$_2$ concentration in the cuvette. A/Ci measurements were made for the randomly selected healthy plants in the constructed wetland ecosystem at regular intervals. The data for Net Photosynthesis (A) and Intercellular carbon (Ci) were computed approximately every 50ppm. Before making measurements, leaves were acclimatized in the chamber for more than 30 mins at ambient temperature and CO$_2$ concentration (360 micro mol/m$^3$/s) and PPFD (950 micro mol/m$^3$/s), a value at which photosynthesis is at least 90% saturated. For production of A/Ci curves, the CO$_2$ concentration in the leaf chamber was raised to 1000 micro mol. While exposed to constant and saturating sunlight. Leaves were allowed to equilibrate for around 6-8 mins before logging the data. The CO$_2$ concentration was then lowered and the procedure was repeated. The CO$_2$ concentrations used to generate the A/Ci curves were increased in a stepwise fashion to 50, 100, 200, 300, 400, 500, 600, 700 micro mol/m$^3$/s with at least 6-8 minutes acclimatization at each CO$_2$ step. At each point, the next step did not occur until steady-state gas properties were measured. Each measurement of A/Ci required approximately 45-55 minutes. All the measurements were carried out in three leaves per plant and in three replicate plants in a completely randomized statistical design. Data were subjected to two-way analysis of variance.

III. RESULTS AND DISCUSSION

A. Carbon content in the constructed wetlands (CW)

Both the CWs were sinks of carbon measured in terms of total organic carbon, organic matter, total carbon, plant biomass carbon, microbial biomass carbon, biological oxygen demand, chemical oxygen demand and inorganic carbon measured in terms of photosynthesis or carbon assimilation. The values of the above mentioned parameters were evaluated experimentally at the inlet and outlet locations of each CW site regularly for two consecutive years (i.e. 2008-2009). The seasonal averages and percentage efficiencies were calculated and reported.

B. Rate of CO$_2$ assimilation by Phragmites Karka - A/Ci measurements

The ambient CO$_2$ measured in the atmosphere was 386 µ mol/m$^3$/sec. A/Ci measurements were made by computing the CO$_2$ concentration every 50 ppm using the controllable CO$_2$ injection system in the instrument. The CO$_2$ concentration used to generate the A/Ci curves were increased in a stepwise fashion to 50, 100, 200, 300, 400, 500, 600, 700 µ mol/m$^3$/sec.

C. Intercellular carbon concentration (Ci)

The intercellular C concentration (Ci) varied significantly depending upon the amount of CO$_2$ injected. Initially the intercellular C concentration in the leaf did not rise for the first two readings. The Ci was observed to gradually increase latter on. The Ci ranged from 21.5 µ mol/m$^3$/sec at 50 ppm CO$_2$ to 830 µ mol/m$^3$/sec at 1200 ppm CO$_2$ in the month of May (Fig 18a). The Ci ranged from 15.6 µ mol/m$^3$/sec at 100 ppm CO$_2$ to 225 µ mol/m$^3$/sec at 800 ppm CO$_2$ measured in the month of January.

D. A/Ci response curve

The net photosynthesis (A) was found to increase as the CO$_2$ concentration increased. In the month of May the value of A was 19.4 µ mol/m$^3$/sec at 383 ppm of ambient CO$_2$. It was found to further increase as the CO$_2$ increased. Net photosynthesis value increased up to a value of 22.3 µ mol/m$^3$/sec at 700.82 ppm CO$_2$ with an intercellular concentration of CO$_2$ to be 380 µ mol/m$^2$/sec.
Thereafter as the ambient CO₂ was gradually increased, it resulted in gradual decrease in net photosynthesis rate. The value of A was recorded to be 21.00 µ mol/m²/sec at 1000 ppm CO₂ (Table 19) and further to 21.2 µ mol/m²/sec at 1200 ppm CO₂. Maximum photosynthesis rate was observed at 700.82 µ mol/m²/sec CO₂. Whereas in normal conditions in terrestrial plants the optimum rate of photosynthesis is usually recorded in the range of 12-13 µ mol/m²/sec at ambient level of CO₂ in the atmosphere (386 ppm).

In the wetland plants where water and nutrients are available in plenty the plants are capable of C assimilation in a remarkable manner. Rate of photosynthesis was recorded at three points in a single healthy leaf and three such leaves were sampled. There was a slight variation in the rate of photosynthesis in the 3 leaves depending on the light received. There was only marginal difference in accordance with light response, stomatal conductance, leaf temperature and the rate of transpiration. There was a steep increase in the net photosynthesis rate till the CO₂ level reached 700 ppm; thereafter a slight declining trend was noticed as the CO₂ concentration further increased.

In the month of January the rate of carbon assimilation was slightly lower than during the month of May. The mean CO₂ assimilation rate attained the maximum value of 20.5 µ mol/m²/sec at 801.265 µ mol/m²/sec of CO₂, the intercellular CO₂ being 225.5 µ mol/m²/sec The value of net photosynthesis was as low as 4.55 µmol/m²/sec at CO₂ concentration of 100. µ mol/m²/sec when the ambient CO₂ was 100 ppm the intercellular CO₂ was 15.6 µmol/m²/sec. As the CO₂ was increased there is a steep increasing trend observed in the rate of photosynthesis. At the atmospheric ambient concentration of CO₂ (386 µ mol/m²/sec) the net photosynthesis reached a value of 16.525 µ mol/m²/sec with an intercellular CO₂ concentration (Ci) of 67.2 µ mol/m²/sec The value increased at 400 ppm CO₂ to A of 18.4 µ mol/m²/sec This value was observed to increase gradually as the CO₂ concentration was increased.

The normal photosynthesis reading indicated net photosynthesis value of 13.01 µ mol/m²/sec at an ambient CO₂ concentration of 385 µ mol/m²/sec whereas the net photosynthesis or the CO₂ assimilation in the Phragmites karka species, the value was observed to be much greater. It was 16.525 µ mol/m²/sec at the same concentration of CO₂ (386 ppm) in the month of January and even greater in the month of May (19.4 µ mol/m²/sec.)

The exhibited trends of the A/Ci curve were almost similar in the month of May and that of January indicating that the Reed grass is quiet efficient in CO₂ assimilation as the concentration of CO₂ is increased in the atmosphere. The increase in the rate of photosynthesis was highly significant (p≤ 0.01). In the month of may when the weather was sunny with no clouds the photosynthesis rate increased with an increase in Ci concentration. There was a significant positive correlation between net photosynthesis and increasing ambient CO₂ concentration (p≤ 0.01)

E. Modelling Carbon Fluxes in Constructed Wetland

CW treatment systems effectively treat organic matter and pathogens. Water plants (macrophytes) have several relevant properties, the most important being their physical effects (Brix,1997, Kadlec et al., 2000). The amount of nutrients, removed by plant harvesting, is generally insignificant compared to yearly loadings with wastewater. If plants are not harvested, the nutrients will be returned to the water during plant decomposition (Brix, 1997; Tanner, 2002). In general, the use of CWs provides a relatively simple, inexpensive, and robust solution for treatment. As natural treatment systems, CWs require a larger specific surface area compared to technical solutions such as activated sludge. However, CWs usually have lower operation and maintenance expenses and other additional benefits, including tolerance against fluctuations of flow and pollution load, ease of water reuse and recycling, provision of habitat for many wetland organisms, and a more aesthetic appearance than technical treatment options (Kadlec et al., 2000; Haberl et al., 2003).

Wetlands of several typ
highest at the wetland site largely due to slower decomposition rates of C in the upper layers of medium. Increases in light levels and nutrient availability result in an increase in the biomass production of reed-grass. The thick mats of reed-grass are beneficial in controlling soil erosion, contributing large amounts of soil organic matter to the site and excluding other competitive species. Daily carbon uptake rates increased from morning, attained peak around mid-day and declined towards the end of the day. It has been found that high rates of carbon assimilation is attained when the moisture is adequate.

F. Constructed wetlands act as green belts

A net increase in photosynthesis rate is noticed at increasing CO₂ concentration in this study (Fig. 1 & 2). Only whole-system approaches, such as eddy-covariance flux measurements, can potentially provide a measure of the net balance for these ecosystems. The prevailing view is that wetlands worldwide still constitute a significant net sink for carbon dioxide (Roulet 2000; Roehm 2009). Although most of this excess carbon fixation will likely be buried, a portion will be exported downstream as dissolved organic carbon (DOC) where it may eventually support some heterotrophic respiration in lakes and rivers. However, because CO₂ uptake in these land-water transitional systems is largely done by the emergent part of the vegetation, it is more akin in function to that of a forest. Thus, in the model of carbon flow, (Roulet 2000; Roehm 2009) wetland gas flux is considered a component of the terrestrial influx of carbon from the atmosphere and is not separately quantified. Carbon sequestration can be enhanced through application of proven engineered wetlands technology.

Constructed Wetlands are major carbon sinks. While vegetation traps atmospheric CO₂ in wetlands and other ecosystems alike, the net-sink of wetlands is attributed to low decomposition rates in anaerobic soils. Enhancing carbon reserves in constructed wetlands, in the context of climate change, is consistent with reducing GHG emissions from the wetlands and restoring their carbon reserves. Protecting and creating treatment wetlands is a practical way of retaining the existing carbon reserves and thus avoiding emission of CO₂ and GHGs.

![A/CO2 graph](image1)

*Figure 1. Increasing rate of photosynthesis (A) at increasing CO₂ concentration*

![A/Ci graph](image2)

*Figure 2. Increasing rate of Photosynthesis (A) at increasing intercellular CO₂ (Ci) concentration*
IV. CONCLUSION

Both the CWs have been found to be potential sinks of Carbon in terms of organic and inorganic carbon. We face several significant questions regarding the potential for carbon sequestration in wetlands. The Constructed wetlands can be managed as net carbon sinks over time. In the two years of the study it was found that the net carbon gain and the biomass was comparatively higher in the Constructed wetland system at the Nala than at Ravindra nagar. Though the Total Carbon value at the CW at Ravindra nagar was higher than that at the Nala. Tropical warm weather in Ujjain (Central India) is particularly beneficial for the growth of Phragmites karka (emergent macrophyte). Both aboveground and belowground portion could serve as carbon sink by primary production. Photosynthesis rate is found to increase at high concentrations of carbon dioxide (800ppm) sequestering more carbon into the biomass. CWs can be used to treat the waste water from an industry or community development and also provide an additional benefit as green belts around the industries or the community development. By adopting these Biological CW treatment systems, we can not only achieve our plan of carbon emission reduction but also generate huge amount of savings and earn carbon credits too to ensure a Clean Development Mechanism.

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Abbreviation

C: carbon
Ci: intercellular carbon concentration
Cm: centimeter
°C: Degree celcius
CO₂: carbon dioxide
gs: stomatal conductance
g: gram
max: maximum
NPP: net primary productivity
NEP: net ecosystem production
Pn: net photosynthesis
Pt: plant
µ: micro
CWs: constructed wetlands
WW: wastewater
WWTP: waste water treatment plant
Wl: wet land
CO₂R: ambient carbon dioxide concentration
A: net photosynthesis
Ppm: parts per million
ETP: Effluent Treatment Plant