Ecological Engineering 91 (2016) 65–73

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Impact of aeration on macrophyte establishment in sub-surface constructed wetlands used for tertiary treatment of sewage

Eleanor Butterworth[a], Andrew Richards[b], Mark Jones[b], Hans Brix[c], Gabriela Dotro[a,*], Bruce Jefferson[a]

[a] Cranfield University, Cranfield, UK
[b] Severn Trent Water, Coventry, UK
[c] Department of Bioscience, Aarhus University, Aarhus, Denmark

ARTICLE INFO

Article history:
Received 26 June 2014
Received in revised form 30 October 2015
Accepted 26 January 2016

Keywords:
Aeration
Plant development
Reed beds
Nutrients
Biomass
Wastewater

ABSTRACT

The effect of artificial aeration on plant growth in constructed wetlands in terms of above and below ground biomass and nutrient uptake of two macrophyte species *Phragmites australis* and *Typha latifolia* was carried out to provide quantitative, mechanistic evidence to support any differences between the plant species establishment. Pilot scale systems were built and supplied with different intensities of aeration and corresponding controls, with supporting evidence from two full scale operational sites. Results show *T. latifolia* was more impacted by aeration than *P. australis* when comparing against their respective non-aerated controls, evidenced in reduced height, growth rate and leaf length. However, the impact was less visible due to *T. latifolia*'s faster growth rate compared to *P. australis*. Micro and macronutrient uptake by each species had no discernible pattern, preventing the identification of a definitive mechanism to explain the retarded growth. However, results suggest a synergy between iron and manganese may be at play.

1. Introduction

Constructed wetlands (CWs) by definition contain vegetation adapted to waterlogged conditions (Mitsch and Gosselink, 2000). The specific function of this vegetation in CWs has been much discussed in the literature (Brix, 1997; Stottmeister et al., 2003; Langergraber, 2005) with their importance primarily being attributed to seasonal storage of nutrients; extra surfaces for microbial growth (although this is small in comparison to the surface area of the gravel); insulation in cold and temperate climates, blocking wind and shading out algae that can lower re-aeration; carbon content of plant litter supplying energy for heterotrophic denitrifiers; promotion of wildlife/biodiversity; aesthetics and prevention of unwanted species colonizing the bed (Brix, 1997; Kadlec and Wallace, 2009). In screened sewage treatment systems in France, the reeds also contribute to keeping the beds aerated by breaking up the surface sludge layer in the first stage bed through wind-rock action (Knowles et al., 2011).

A recent innovation in horizontal sub-surface flow (HSSF) CWs has been the inclusion of forced aeration to promote aerobic conditions and ammonia removal (Ouellet-Plamondon et al., 2006; Zhang et al., 2010). This has proved successful in the US (Kadlec and Wallace, 2009) and testing is producing successful results in the UK (Butterworth et al., 2013) and Europe (Nivala, 2012). However, poor/non-establishment of *Phragmites australis* has been reported at highly aerobic sites. For instance, during full scale trials of aerated horizontal sub-surface flow (HSSF) CWs, poor establishment of *P. australis* was observed in an artificially aerated HSSF CW compared to excellent growth in an identical non-aerated control (Butterworth et al., 2013). Additionally, poor growth/non-establishment of *P. australis* has been reported in the first growing season in the second half of a pilot aerated CW in Germany (Nivala, 2012). Similar issues with either yellowing of the leaves (chlorosis) and/or poor establishment of *P. australis* has been reported in second stage vertical flow (VF) wetlands both in the UK and France (Weedon, 2014).

Consequent literature searches revealed a gap in the knowledge with respect to the response of the plants to forced aeration. Wetland plants have been adapted to grow in typically oxygen limited, slow flow conditions (Mitsch and Gosselink, 2000). Artificially aerating the environments, either by forced aeration or by

* Corresponding author.
E-mail address: g.c.dotro@cranfield.ac.uk (G. Dotro).

http://dx.doi.org/10.1016/j.ecoleng.2016.01.017

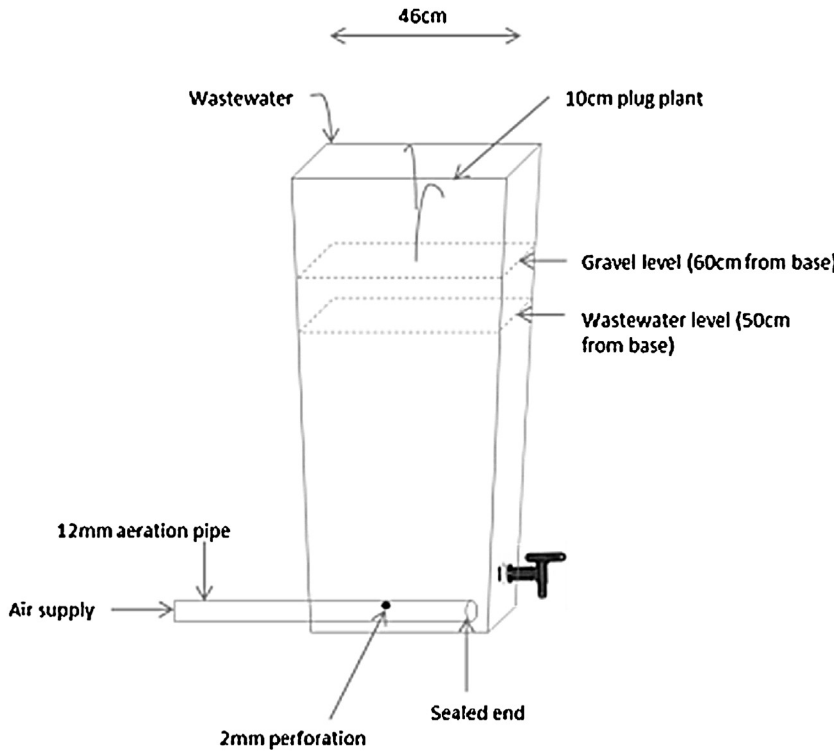

Fig. 1. Pilot reactors.

rapid and strong pulses of flow injection (by pumps or siphons) as employed in VF systems, changes those conditions radically. The main changes could be grouped into biogeochemical, i.e., macro or micro nutrient deficiency caused by the aerobic environments leading to changes in redox states that can affect their bio-availability (Weedon, 2014); or mechanical, i.e., flow turbulence causing root destabilisation resulting in stress induced growth inhibition and/or water ingress into the aerenchyma preventing effective oxygen transfer to the roots. Additionally, it was discussed that the problem is possibly species specific, as species other than *P. australis* have been able to colonise the aerated environment. It was further noted that the species *Typha latifolia* is commonly used in the US due to its competitive and aggressive nature; ability to colonise inert substrates and adapt to diverse and not always optimal climate conditions (Jesperson et al., 1998).

To date, discussion has been largely qualitative such that to the authors' knowledge a paucity of direct experimental evidence exists to help populate the discussion, limiting the potential to define mitigation strategies going forward. Accordingly, the aim of the current investigation was to provide an experimental assessment of the impact of aeration on plant health in terms of above and below ground biomass and nutrient uptake of two macrophyte species *P. australis* and *T. latifolia*. The main hypothesis were that aeration intensity reduces nutrient uptake and causes physical destabilisation of the root zone, both resulting in reduced plant establishment in aerated wetlands.

2. Materials and methods

2.1. Pilot studies

Individual test microcosms were constructed utilising water butts (height 83 cm, width 46 cm, depth 45 cm—gardens4less.co.uk) fitted with an aeration pipe of 12 mm diameter irrigation pipe with a single 2 mm diameter orifice connected to the mains air supply to imitate conditions found in the aerated bed (Fig. 1). The columns were filled 0.6 m deep with gravel of 6–12 mm diameter, and planted with a single plug plant (Reeds from Seeds, Denbighshire, UK; 10 cm pot size), as per standard Severn Trent Water reed bed design, and fed with partially treated wastewater (12.1–20.9 mgNH_4^+–N/L and 184–300 mgO_2/L for ammonium and chemical oxygen demand, COD, respectively) to 0.1 m below the gravel surface. A tap fitted to the bottom of the water butt allowed drainage and re-filling which took place every other day for the duration of the experiment. The composition of the wastewater on the feed and effluent of each reactor was tested three times throughout the study for NH_4^+-N, nitrate (NO_3^-–N) and nitrite (NO_2–N) and COD with Hach–Lange test kits. The reactors were placed outside and were operated for the period May to August 2013. The temperatures during this period averaged 16 °C (min 3 °C, max 30 °C) with 40.5% cloud cover recorded (records obtained from www.wunderground.com).

Two aeration rates were investigated. The first represented the equivalent rate used on an operational site (Site 2) defined as 150 m^3/h of air delivered per 100 m^2 of bed, corresponding to 2.3 L/min per hole [defined as *high*]. The second was based on a separate study that determined the required air delivery rate to maintain aerobic environments as the operational rates above had been observed to exceed those actually required (Butterworth et al, in prep.). The reduced rate was 0.8 L/min per hole [defined as *low*] and thus provided insight into whether optimised aeration could mitigate any observed impacts. Tests were carried out in triplicate and include a non-aerated control for each plant species (Fig. 2).

Direct observations were recorded during the growing period including plant height (measured from gravel level to the tip of the tallest stem); number of stems, leaf length (measured from the base to the tip) and leaf width (measured at the widest part). Harvesting took place four months after planting, at the end of the growing season. The plants were removed from the butts and any loose soil washed away. Visual differences were recorded in the roots and rhizomes including the presence of primary and lateral fine side roots, their number, diameter and length. In addition,