Yellow Phragmites: Significance, Cause, and Remedies

Preliminary observations of chlorosis of the leaves of Phragmites australis growing in some aerobic treatment wetlands, including discussion of significance, cause and remedies.

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Abstract

Summary of observations of profound chlorosis of the leaves of Phragmites australis, deployed in treatment wetlands receiving high redox potential influent, including likely cause (lack of bio-available iron), reasons for cause (low ammonia, high redox potential), impact on growth and wetland performance, and possible remedies (e.g. use of alternative plant species or foliar application of iron solution).

Introduction

Although not widely broadcast before this meeting, within the discussion period following Clodagh Murphy's presentation concerning performance of forced aeration constructed wetlands, observations were verbally reported from many groups of profound yellowing of the leaves of Phragmites australis when used in particular treatment situations, characterised by well aerated sewage feeding the bed. Forced aeration beds and recirculated-effluent vertical down-flow systems were reported to be especially prone to chlorosis.

Importance

Generally regarded as a trivial or "cosmetic" issue, greater importance has arisen due to chronic susceptibility of the plants to diseases, such as fungal rusts, and insect infestation, as well as reduced biomass – occasionally catastrophic – allowing disproportionate weed intrusion. The combined effect can lead to an unhealthy and unacceptable appearance to owners and operators, requiring substantially increased maintenance labour in order to achieve an acceptable bed appearance.

Observations

General

Distinct yellowing, usually in combination with green & yellow longitudinal striation (Figure 1), of the majority of the leaves of the majority of Phragmites australis plants was reported to be typical, in:

- Free-draining vertical down-flow reed beds operated with effluent recirculation and/or receiving effluent of a rotating biological contactor

Main outcome of the discussion:

- Many academic and commercial groups verbally reported chlorosis of the leaves of Phragmites australis growing in either free-draining vertical flow (VF) treatment wetlands or forced aeration treatment wetlands
- Plants were reported with the majority of leaves predominantly yellow, and/or showing distinct green and yellow striation, over wide areas or throughout the entire bed
- Whilst producing an undesirable "unhealthy" appearance, more important consequences include reduced stem height and reduced biomass density allowing excessive weed intrusion, and susceptibility to disease and infestation, increasing undesirable bed appearance and increasing maintenance labour requirements
- Effluent treatment performance has not been reported to have been affected
- Informal interdisciplinary discussion during the course of the three day meeting has revealed the likely cause of Phragmites australis leaf chlorosis
- Low ammonia and high redox potential in the wastewater feeding the Phragmites is believed to result in the iron content taking the ferric form with insufficient solubility to meet the nutrient demands of the growing plants, resulting directly in leaf chlorosis (insufficient synthesis of chlorophyll) caused by lack of iron within the leaf
- Remedies include use of substitute plant species and foliar application of ferrous sulphate.

Table 1: RBC effluent concentrations feeding 2 compact VF treatment wetlands, operating conditions and leaf colour of reed.

Location	Growing season	Leaf colour	Recirculation	BOD_5 (mg/L) [1]	NH_4-N (mg/L)	NO_3-N (mg/L)
Bodiam Castle (UK)	1	G	x	22	64	26
	2-3	Y	+	8	8	15
Pont Abraham (UK)	1-4	Y	x	18	3	28
	5-6 [2]	G	x	146	85	9

[1] Leaf colour (G = green, Y = yellow) was established by June in each growing season. BOD_5, NH_4-N and NO_3-N figures are average inlet concentrations of monthly spot samples March-June

[2] RBC switched off, i.e. bed treating settled sewage

(RBC) or receiving first stage French vertical down-flow reed bed effluent; and in

- Forced aeration reed beds, both horizontal and vertical flow.

Table 1 shows the influent concentrations, and operational parameters from 2 CW systems in UK, i.e. Bodiam Castle (Figure 2) and Pont Abraham (Figure 3), as well as the leaf colour of reed in different growing seasons.

Second Stage "French System":

Of the many two stage vertical down-flow French systems in existence (first stage receives raw sewage; second stage receives effluent from first stage), a small proportion exhibit strong chlorosis of the second stage reeds (Figure 4) [JP], the most extreme resulting in almost complete disappearance of reed plants, replaced by terrestrial "weed" species (Figure 4d).

Forced Bed Aeration:

Langenreichenbach horizontal subsurface flow forced aeration reed bed (Figure 5), from early development, exhibited a striking plant morphology pattern, correlating with distance from the point of settled effluent entry to the bed: tall, green plants at the proximal end with progressively yellower and shorter plants along the bed.

Ferrous Sulphate Foliar Application

One-off foliar spray application of fresh ferrous sulphate (3.82g/l aqueous Fe2+SO42-) early in the growing season resulted in sustained green Phragmites australis plants that had grown chlorotically throughout the previous season(s) [CA, RK], in vertical down-flow beds treating settled effluent with partial recirculation to the pump chamber feeding the beds.

This approach was taken at Bodiam Castle, with iron application on 16 July 2013 (i.e. mid-growing season; following the Leipzig meeting). Close inspection of Figure 1a reveals droplets of FeSO4 solution on the leaf surface, suggesting poor Fe uptake into the leaves. However, surface droplet appearance is consistent with leaf iron uptake [CA]. Eight weeks after application, no discernible decrease in chlorosis was evident. However, their was an improvement in plant health, the leaves appearing more turgid than at the time of iron spraying.

Alternative Plant Species

Other aquatic plants species growing in the same bed as chlorotic Phragmites australis exhibited normal growth appearance, notably Phalaris arundinacea (Bodiam Castle) and Iris pseudacorus [RK].

Figure 1a: Chlorotic Phragmites australis leaves showing yellow & green striation (Bodiam Castle, 16Jul13); note droplets of FeSO4 on leaf surface, following spraying

Figure 1b: Chlorotic Phragmites australis leaves showing increased susceptibility to rust attack (Bodiam Castle, 16Jul13)

Figure 2a: Bodiam Castle reed bed, during first growing season, with no effluent recirculation, showing dense, green reeds throughout (12Sep11)

Figure 2b: Bodiam Castle reed bed, third season, with effluent recirculation, showing less dense, yellow reeds throughout (even following ferrous sulphate foliar spray on 16Jul13) (22Aug13)

Figure 3a: Pont Abraham reed bed, during first growing season, receiving well aerated RBC effluent (diluted with groundwater infiltration), showing yellow reeds throughout (13Aug08)

Figure 3b: Pont Abraham reed bed, fifth season, receiving settled sewage (undiluted), showing dense, green reeds throughout (21Aug12)

Figure 4a: Floirac first and second stage French system reed bed (left & right, respectively), showing yellowing of leaves in second stage, compared to vigorous green leaves in first stage (courtesy Joëlle Paing)

Figure 4b: Hauterive second stage French system reed bed, May 2011, receiving vertical down-flow reed bed effluent treating raw sewage, showing some yellowing throughout bed (courtesy Joëlle Paing)

Figure 4c: Hauterive second stage French system reed bed, July 2012, showing poor health and disappearance of reeds creating significant reed-free areas (courtesy Joëlle Paing)

Figure 4d: Hauterive second stage French system reed bed, May 2013, almost complete disappearance of reeds within three years of first yellowing, with replacement by "weeds" (courtesy Joëlle Paing)

Figure 5a: Langenreichenbach horizontal flow forced aeration reed bed, receiving settled effluent: tall, green, dense reeds near inlet; short, yellow reeds further from inlet (1Jul11)

Figure 5b: Langenreichenbach horizontal flow forced aeration reed bed, receiving settled effluent: progressively shorter, yellower reeds further from inlet (13Jun13)

Discussion

Cause of Chlorosis

The specific characteristics of the leaf appearance reported are typical of iron deficiency [BS, CF]. Lack of iron is a well documented prime cause of chlorosis.

The observations of chlorosis correlate with *Phragmites* supplied with well oxygenated sewage effluent, likely to be high in redox potential, pH 7 or slightly above, with a relatively low BOD and low ammonia content.

The same plants growing in seasons both before and after periods of chlorosis (Bodiam Castle & Pont Abraham compact vertical flow reed beds) but fed with poorly oxygenated sewage effluent, with low redox potential, and relatively high ammonia yielded "normal" chlorophyll levels and were green throughout.

Ferrous iron (Fe^{2+}) is the predominant form of Fe in low redox potential situations and is readily soluble in water. Fe^{2+}, is, therefore, invariably available for biological uptake – eg into plant roots or leaves. Ferric iron (Fe^{3+}) predominates in higher redox potential environments (eg as a result of oxidation of Fe^{2+}) and is relatively insoluble, when it is not available for take up into plant cells.

The presence of protons (H^+) – enhances Fe^{3+} solubility.

Nitrification results in a release of H+. Therefore, the presence of ammonia in oxygen-rich conditions, which allow nitrification, tends to increase the bioavailability of iron, even when the iron has been oxidised to Fe^{3+} in the aerobic conditions.

The observations of Langenreichenbach (Figure 5) can, therefore, be explained (BOD_5, NH_4-N, NO_3^--N & DO data from Tom Headley & Jaime Nivala, 2011, pers comm):

1. Settled effluent flows from one end of the bed to the other, at a depth of approx 1000mm
2. Aeration is provided evenly throughout the length of the bed (via subsurface compressed air supply)
3. Growing medium (ie sewage effluent) at the inflow end is relatively high in BOD_5 and NH_4-N, the microbial degradation of which sustains a relatively low DO and redox potential, despite the continuous oxygen supply, combined with H^+ release from nitrification – consistent with conserving Fe^{2+}, allowing sufficient iron uptake to ensure normal chlorophyll synthesis, and the observed green plants
4. As effluent proceeds along the bed, it becomes progressively lower in BOD_5 and NH_4-N, allowing a higher DO to pertain
5. In addition, NO^{3-}, produced from nitrification, is taken up by the *Phragmites* as a N source, with concomitant uptake of H^+
6. Therefore, passage along the bed results in the effluent iron being oxidised from Fe^{2+} to Fe^{3+}, which additionally encounters conditions of decreasing [H^+], so falling out of solution and depleting the Phragmites of an essential nutrient; hence chlorophyll synthesis becomes progressively less, correlating with decreased root iron uptake, resulting in the observed decreasing plant height and increased chlorosis with distance from sewage inlet.

Explanation of the observed growth pattern, during a site visit in 2011 (Figure 5a), favoured progressive N source depletion, with N removal by denitrification suspected in the proximal (green plant) zone. This explanation has now been superseded. The symptoms of N-limitation in *Phragmites* are green but shorter plants, rather than chlorosis [BS].

Avoiding Chlorotic Phragmites

Dissolved Oxygen Concentration in Influent

The higher the DO concentration of the influent water, the more likely that iron will be present in the insoluble ferric form. One approach to preventing chlorosis due to iron deprivation is, therefore, to minimise the DO concentration of the influent. However, this is often undesirable, the high oxygen content being prioritised as an essential ingredient for effective microbial sewage treatment; or unfeasible, without negating other more important benefits, such as nitrate return to achieve denitrification. For instance, part of the rationale for final effluent recirculation at Bodiam Castle was to introduce DO to an earlier stage, thereby eliminating foul odour as well as enhancing treatment, including increased TN removal. Nevertheless, optimisation of the recirculation ratio should take account of the risk of encouraging downstream iron deprivation.

Ammonia Influent Concentration in

Phragmites australis is able to utilise both NH_4-N and NO^{3-}-N as nitrogen sources for growth [BS]. However, the presence of some ammonia is important, as although Phragmites can survive on nitrate alone, the pH of environments devoid of NH_4-N can remain consistently too high to allow iron solubility, most of the iron occurring as insoluble $Fe^{3+}(OH)^{3-}$, leading to chlorosis [CF]. Because nitrification releases H^+, positively influencing iron solubility, the presence of some ammonia in the influent feeding an aerobic reed bed is likely to prevent iron-limited chlorosis. A ratio of NH_4-N/NO_3^--N of 2:1 is ideal, although 1:1 is adequate to prevent chlorosis through iron depletion [BS].

The Bodiam Castle and Pont Abraham data suggest that influent NH_4-N >60mg/l will prevent chlorosis in vertical down-flow reed beds; while NH_4-N <10mg/l tends to allow iron depletion and chlorosis.

However, this simple relationship does not apply in all situations because of the effects of other solutes contributing to the redox potential, which strongly influences which iron species dominates and iron solubility. For example, high ammonia, high redox potential conditions may still prevent iron remaining in solution, leading to chlorosis.

However, chlorosis has been observed when *Phragmites* was grown in recirculated (ie low ammonia) low DO influent (eg at Vesterskovej, <5% DO [CA]). Thus, the most influential factor on chlorosis in reed beds may be low influent ammonia concentration (and associated raised pH), rather than high DO, or high redox potential.

Alternative Plant Species

Although *Phragmites australis* naturally inhabits a wide range of ecological and geographical situations, the favoured rhizosphere condition is anoxic. Therefore, selection of a plant evolved to thrive in low redox potential environments is at odds with serving wastewater treatment needs in consistently high redox potential situations.

The growth characteristics of *Phragmites australis* are ideally suited to VF beds, their relatively thin, evenly spaced stems allowing easy flow of effluent across the bed surface during intermittent distribution pulses, while growing at sufficient density to out-compete terrestrial plants, which would otherwise thrive in such beds. Wind-blown stem movement at the stem-sand interface has also been observed to enhance effluent permeation into the bed.

Phragmites australis roots grow to relatively great depth, as part of the propensity to inhabit deep anoxic mud. However, this unique characteristic has not been conclusively demonstrated to be a decisive advantage in VF beds and, especially when fed with high redox potential effluent, it is difficult to ascribe a treatment benefit to deep roots. Moreover, the species' rhizome and root system is severely morphologically compromised when grown in forced aeration reed beds.

From the above emerges a strong argument for using alternative species of emergent macrophytes in place of Phragmites australis. This approach has already been followed by installers of forced aeration beds, where Phragmites is avoided, commonly being replaced with *Typha* spp. and *Phalaris arundinacea*, among others.

Phalaris arundinacea has been growing well alongside *Phragmites* at Bodiam Castle as has *Iris pseudacorus* in many Danish vertical flow reed beds [RK]. Under controlled nutrient feed in the lab, DO 6-7mg/l, Phragmites australis experienced chlorosis when Phalaris arundinacea grew normally [KW]. It seems that Phragmites has a comparatively greater requirement for iron to enable healthy growth than many other emergent aquatics.

Despite their greater tolerance of iron-depleted feed water, however, neither Phalaris arundinacea nor Iris pseudacorus are ideally suited to the physical requirements of a vertical flow treatment bed, both forming clumps of stems, prone to obstructing the surface flow of effluent during intermittent distribution.

Alternative species under investigation include *Glyceria* maxima and *Schoenoplectus lacustris* (both inter-planted at Bodiam Castle in July 2013). *Schoenoplectus tabernaemontani* has been successfully used in New Zealand vertical flow treatment beds for some years [BS].

Foliar Application of Ferrous Sulphate

For existing treatment beds, replacing Phragmites with one or more alternative species may be unfeasible or disproportionately costly. The reported successful application of ferrous sulphate early in the growing season [CA, RK], resulting in green plant colouration throughout that growing season, offers a remedy for chlorosis in cases where Phragmites will continue to be deployed in low ammonia, high redox potential conditions (although this solution requires annual repetition).

Further Studies needed

- Characterise NH_4-N concentration, DO and redox potentials of wastewaters that result in chlorosis due to iron deprivation in Phragmites australis
- Identify optimum plant species for low ammonia and high DO, high redox potential influent situations – especially for vertical down-flow beds
- Fully characterise method of foliar application of bio-available iron to Phragmites australis, particularly ensuring optimal leaf take-up.

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