ADVANCES IN AGRONOMY

DONALD L. SPARKS

VOLUME 138

VOLUME ONE HUNDRED AND THIRTY EIGHT

ADVANCES IN AGRONOMY

Edited by

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Academic Press is an imprint of Elsevier

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125 London Wall, London EC2Y 5AS, United Kingdom
525 B Street, Suite 1800, San Diego, CA 92101-4495, United States
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK

First Edition 2016

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ISBN: 978-0-12-804774-3
ISSN: 0065-2113

For information on all Academic Press publications visit our website at https://www.elsevier.com/

Publisher: Zoe Kruze
Acquisition Editor: Mary Ann Zimmerman
Editorial Project Manager: Helene Kabes
Production Project Manager: Magesh Kumar Mahalingam
Designer: Maria Ines Cruz

Typeset by Thomson Digital

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PREFACE

Volume 138 contains four excellent and timely reviews on topics in the crop, soil, and environmental sciences. Chapter 1 deals with the role of iron plaques that occur on the surfaces of aquatic plants, nutrient and contaminant retention, and mobility. Chapter 2 covers the use of biowaste for mine spoil rehabilitation. Regulations are discussed, as well as the effect of biowaste addition on mine spoils. Chapter 3 discusses the exposure, toxicity, health impacts, and bioavailability of heavy metal mixtures. Chapter 4 deals with integrated farming systems and impacts on small and marginal farmers in India and other developing countries.

I appreciate the authors' excellent contributions.

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CONTENTS

CHAPTER ONE

Root Iron Plaque on Wetland Plants as a Dynamic Pool of Nutrients and Contaminants

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Advances in Agronomy, Volume 138
ISSN 0065-2113
http://dx.doi.org/10.1016/bs.agron.2016.04.002

Abstract

Loading of nutrients and contaminants is increasing in wetlands due to anthropogenic activities. The scope of this paper is to (1) provide an overview of natural, cultivated, and constructed wetlands and hydrophytes, (2) characterize root iron plaque of hydrophytes, (3) show roles played by root iron plaque as a source and sink for nutrients and contaminants for hydrophytes, (4) present toxicity tolerance mechanisms employed by hydrophytes, and (5) offer implications of the findings about iron plaque, and (6) to suggest future research. Iron plaque deposits on hydrophyte root surfaces are a result of oxidation of ferrous iron in the oxic rhizosphere under waterlogged conditions in wetlands. The iron plaques mainly consists of amorphous and crystalline iron oxyhydroxides. They, therefore, can sequester nutrients and contaminants that can bind to iron oxides. Recently advanced spectroscopic techniques, such as synchrotron radiation techniques, have been used to identify and characterize iron plaque components. Sequestration and plant uptake of these materials mainly depend on the available nutrients and contaminants, oxygen diffusion capability of hydrophyte roots, and bio-physico-chemical properties of the rhizosphere. Root iron plaque plays a vital role in controlling the sequestration of excess loads of nutrients and contaminants in wetlands.

1. INTRODUCTION

Excess nutrients and contaminants can harm ecosystems adversely impacting on biodiversity. But wetland ecosystems are considered to be natural recyclers of inputs of excess nutrients and contaminants. Hence, the concept of constructed wetlands gained popularity as a low cost treatment system for high volumes of nutrient-rich and contaminated wastewater (Horne, 2000). Wetlands efficiently remediate contaminated wastewater influents without external energy input, thereby keeping investment and operating costs low (Sheoran and Sheoran, 2006). Hydrophytes play important roles in the processing of nutrients and immobilization of contaminants in wetlands. Root iron plaque (root plaque), commonly formed on the surface of roots of hydrophytes, may undergo various interactions with nutrients and contaminants, thereby affecting their cycles. Due to the miscellany of wetlands, sediments, hydrophytes, microorganisms, nutrients, and contaminants, these interactions are diverse. A large number of studies have been conducted in recent years on the dynamics of nutrients and contaminants in wetlands, particularly involving paddy rice. The scope of this review is (1) provide an overview of natural, cultivated, and constructed wetlands and hydrophytes, (2) characterize root iron plaque of hydrophytes, (3) show roles played by root iron plaque as a source and sink for nutrients and contaminants for hydrophytes, (4) present toxicity tolerance mechanisms employed by hydrophytes, (5) offer implications of the findings about iron plaque, and (6) to suggest future research. This information will be useful for the development of constructed wetlands to treat contaminated effluent and for the management of cultivated wetlands containing toxic sediment.

2. WETLANDS AND HYDROPHYTES

Wetlands are transition zones between terrestrial land and aquatic systems, such as rivers, and receive nutrient, energy, plant, and animal inputs from neighboring ecosystems (Hammer and Bastian, 1988). The nutrients support the wetland macro- and microscopic-vegetation, which is consumed by animals and humans. Wetlands may receive excessive amounts of nutrients such as N, P and S, with entry of wastewater and agricultural runoff that may lead to eutrophication (Lamers et al., 1998; Mitsch et al., 2005; Sánchez-Carrillo and Álvarez-Cobelas, 2001). Wetlands may receive high amounts of metal(loid)s, such as As, Cu, Pb, and Zn, from local coal and metal mines and mills (Banks et al., 1997; Deng et al., 2004, 2006; Sheoran and Sheoran, 2006; Taggart et al., 2009). Cultivated fields like paddy soils may accumulate As due to irrigation with contaminated shallow groundwater (Panaullah et al., 2009). The metal (loid) contamination may adversely affect biota in wetlands resulting in the reduction of vegetative cover that eventually subjects the soils to wind erosion during dry seasons and water erosion during wet seasons.

Wetlands possess at least three conditions (1) hydric soils, (2) hydrophytes, and (3) wetland hydrology (Federal Interagency Committee for Wetland Delineation, 1989). "Swamps" possess shallow-water or saturated areas dominated by woody plants and trees; "marshes" are dominated by soft-stemmed plants and trees, and "bogs" contain mosses (Hammer and Bastian, 1988). Wetland ecosystems are under temporary or permanent inundation. Submergence of wetlands causes anoxic conditions that change the physico-chemical (Faulkner and Richardson, 1989) and rhizospheric microbial activities (Faulwetter et al., 2009).

Wetlands play a range of important roles such as nutrient recycling, increasing dissolved O_2 in the rhizosphere, stabilization of water currents, protection of water shores, recharging of aquifers, improvement of water quality, remediation of contaminated water (such as removal of iron, manganese, and other metals from acid drainage), and provision of habitat for native and migrating fauna (Hammer and Bastian, 1988). Hydrophytes have the capacity to enhance water quality through mobilization and uptake of nutrients and contaminants (Allen et al., 2002; Deng et al., 2004). Wetland (hydrophytes) may also attenuate the leaching of toxic metal(loid)s during periods of high groundwater levels or flooding (Voegelin et al., 2007). Fig. 1A shows a diagram of key roles and processes in wetlands.

2.1 Fresh, Marine, Cultivated, and Constructed Wetlands

Freshwater wetlands are differentiated from aerobic soils of nonwetlands and uplands by abundance of water and accumulation of organic matter (Faulkner and Richardson, 1989). Freshwater wetland hydrophytes are water-tolerant, while marine wetland plants are saltwater-tolerant (Hammer and Bastian, 1988). "Mangrove wetlands" are marine swamps dominated by salt-tolerant woody plants, and "salt marshes" are dominated by salt-tolerant herbaceous plants (Hammer and Bastian, 1988). Wetlands that are in use for cropping are called cultivated wetlands. Paddy soils and jute fields are common examples of cultivated wetlands. In fact, paddy soils make up the largest cultivated wetlands on earth (Kögel-Knabner et al., 2010). *Corchorus capsularis* (jute) is a major crop of the Bengal basin (Bhattacharya et al., 2014). Artificial ecosystems mainly are designed to treat wastewater. The principal components of a constructed wetland are the following: substrate with various rates of hydraulic conductivity, hydrophytes suitable for an anoxic substrate, aerobic and anaerobic microorganisms, invertebrates and vertebrates, and a flowing water column

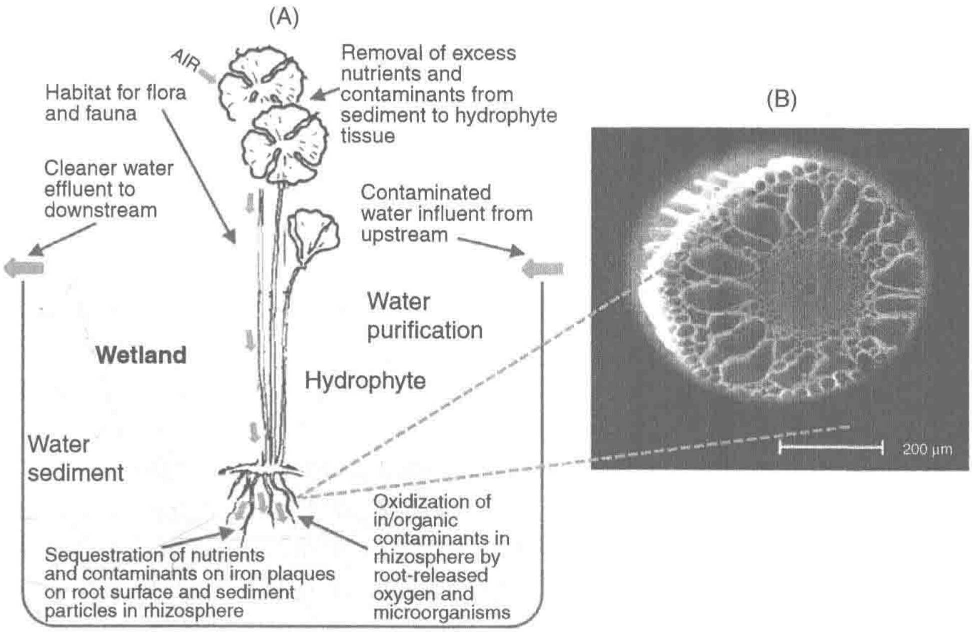

Figure 1 (A) Key roles and processes in wetlands. (B) Aerenchyma in root tissues of hydrophytes: cross-sectional scanning electron micrographs of the root (5 cm behind root tip) showing aerenchyma in *Beckmannia syzigachne. Reprinted (adapted) from Deng et al. (2009), Copyright (2009), with permission from Elsevier.*

(Hammer and Bastian, 1988). The combination of hydrophytes, algae, and bacteria turns constructed wetlands into highly effective treatment ecosystems for detoxification and for the control of eutrophication (Horne, 2000). However, metals accumulated over long periods may surpass toxic levels that may have detrimental effects on bioaccumulation and/or biotransport (Hammer and Bastian, 1988).

2.2 Radial Oxygen Loss and its Effects

Flood tolerance is the ability of a plant to produce biomass under anoxic conditions (Kercher and Zedler, 2004). Radial oxygen loss (ROL) is the mechanism employed by hydrophytes (Mendelssohn et al., 1995) to survive under anoxic conditions (Hammer and Bastian, 1988). Radial oxygen loss changes the bio-physico-chemical properties of the rhizosphere that eventually make the hydrophyte tolerant to flooding and also enable to deal with sediment toxicity. Radial oxygen loss and its impacts are described later in detail.

Under aerobic conditions, plant roots obtain O_2 for respiration directly from the soil pore air. Under submergence the soil O_2 becomes severely depleted, except for surface water where algae may oxygenate it, giving rise to