Phytoremediation and Phytomining: Status and Promise

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1. INTRODUCTION

1.1 What Is Phytoremediation?

Phytotechnology is a subset of Agronomy in which plants and soils are managed to solve environmental problems. Using cover crops to reduce soil erosion has been practiced for over a century. Even using plants plus soil amendments to revegetate metal-contaminated landscapes is relatively old with reports in the 1960s and earlier. As researchers began to use plants and soil microbes to biodegrade soil xenobiotic contaminants (complex organic compounds including polycyclic aromatic hydrocarbons), and the concept of phytoextraction was reported, the larger concept of 'phytotechnologies' was adopted by many researchers and environmental managers. Phytotechnologies or Phytoremediation include a number of separate

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technologies, each of which is being studied to develop or improve potential value of the technology. Research is being conducted on both metals and xenobiotics. Other reviews on phytoremediation and hyperaccumulator plants have summarized available knowledge from varied points of view (Assunção, Schat, & Aarts, 2003; Baker & Brooks, 1989; Baker, McGrath, Reeves, & Smith, 2000; Brooks, 1998; Cappa & Pilon-Smits, 2013; Chaney et al., 2007; Chaney, Broadhurst, & Centofanti, 2010, chap. 17; Chaney et al., 2000; Dickinson, Baker, Doronila, Laidlaw, & Reeves, 2009; Ernst, 2005; Hanikenne & Nouet, 2011; Jaffré, Pillon, Thomine, & Merlot, 2013; Koopmans et al., 2008; Koopmans, Römkens, Song, Temminghoff, & Japenga, 2007; Lombi, Zhao, Dunham, & McGrath, 2001; McGrath, Zhao, & Lombi, 2001; Pilon-Smits, 2005; Pollard, Powell, Harper, & Smith, 2002; Rascio & Navari-Izzo, 2011; Robinson, Anderson, & Dickinson, 2015; Robinson, Bañuelos, Conesa, Evangelou, & Schulin, 2009; Robinson et al., 2003; Tang et al., 2012; Van der Ent, Baker, van Balgooy, & Tjoa, 2013; Van der Ent et al., 2015; Van der Ent, Baker, Reeves, Pollard, & Schat, 2012; Van Nevel, Mertens, Oorts, & Verheyen, 2007; Vangronsveld et al., 2009).

For over 60 years, research has been developing to show use of metal-tolerant plants and soil amendments to restore vegetation on metal toxic soils where mine wastes were dispersed or surrounding metal smelters. It started with using Al-tolerant and Mn-tolerant plants plus soil amendments to raise soil pH and add nutrients to establish vegetation on strongly acidic barren coal mine wastes (Foy, Chaney, & White, 1978; Sopper, 1993). Essentially all soils may become Al or Mn phytotoxic if pH drops low enough; these are 'natural' soil metal phytotoxicities. When soil pH drops below 5.4, soil microbes which normally oxidize Mn^{2+} to Mn^{4+} (which precipitates as MnO_2) are mostly inactive so that Mn^{2+} can accumulate in the exchangeable ion pool to levels which are phytotoxic. When soil pH drops below 5.2, Al^{3+} is increasingly dissolved in soil solution and replaces Ca and Mg on the cation exchange complex and can be phytotoxic to most plant species. There are long-known naturally Mn-resistant and Al-resistant plants, and obvious soil amendments to raise soil pH to reverse Mn and Al phytotoxicity. Much research has been conducted in the last few decades to understand the fundamental processes in Al phytotoxicity and to develop natural or genetically modified crop plants resistant to the Al^{3+} in soil solution of acidic soils (Kochian, Pineros, & Hoekenga, 2005). Al phytotoxic soils are extensive; enough limestone to prevent these toxicities can be expensive and limit choices in developing countries. When cultivars of