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Conclusions and Recommendations

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Abstract

Contamination of soil is a global concern. All inhabited parts of the world have land that is not being used productively because of past activities that have reduced soil quality. Improving the effectiveness and efficiency of phytotechnologies as well as reducing the costs of site restoration have value for society as better methods are used for revitalization of the contaminated sites. Great progress in developing phytotechnologies with biomass production has been reported. Miscanthus has been used with good results at many sites because the plant grows well in different marginal and contaminated soils. New knowledge has been developed on actions to take to increase biomass production at contaminated sites. The benefits of harvesting useful products and improving soil health during Miscanthus growth including those with adding amendments positively influenced the economics of land reclamation using phytotechnologies. Increased efforts to apply phytotechnologies with biomass production to improve contaminated sites and processing of harvested Miscanthus to different bioproducts are recommended.

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12.1 Conclusions

The applications of phytotechnologies depend on climate, local conditions including soil health, and plans for the site. The plans to address a contamination issue at a specific site should be developed based on available information on the site and on science and engineering knowledge. Miscanthus is one of many plants that have value for phytoremediation applications and has been investigated in several studies with positive results.

The contents of this book and in the references that have been included provide very useful information. Phytoremediation with biomass production has value as sustainability of land use is considered at specific sites that have contamination from past military and mining activities or other uses. Social value, environmental goals, and economic benefits enter into consideration as plans are developed. There has been very significant scientific progress during the last 30 years and many successful field applications have been carried out as reported in this book.

Chapters 2 and 3 review progress in developing phytotechnologies for addressing inorganic and organic soil contaminants, respectively. *Miscanthus* has been grown in many different environments with good results. Energy crops have been used in soils with trace elements contamination as well as at sites with organic contaminants. Phytostabilization with biomass production has been developed and applied at sites with inorganic contaminants such as lead and other trace elements. Methods to reduce the bioavailability of the trace elements are beneficial where biomass production is the primary objective and the uptake of trace elements into the biomass is intended to be small. There are many biomass products such as wood and paper where small quantities of trace elements in the finished product are acceptable with respect to health and safety. National and international regulations of course must be observed in this regard.

For soils with organic contaminants, the better options use strategies in which the contaminants are biodegraded or transformed by chemical processes. The goal is often to improve soil health such that the concentrations of any contaminants are reduced to levels so that they are no longer a concern, or are converted into less harmful products. Phytoremediation with biomass production can be implemented at many sites with organic contaminants where the biomass products are cellulosic fiber rather than food or feed products.

The economics associated with establishing and growing vegetation at contaminated sites can be improved if a trace element that has commercial value can be extracted from the soil by plants. Chapter 4 addresses to phytomining – the process of extracting a product such as nickel from soil using hyperaccumulator plants that are able to grow in the contaminated soil and accumulate a element product of value. Typically, after harvesting the plant biomass, drying it, and burning it for energy recovery, the ash can be processed to extract the element of interest.

The establishment of vegetation at some field sites requires a significant effort because of the physical state of the site, soil quality, and toxicity of the contaminants. Chapter 5 provides information on the science and technology for best practices when establishing vegetation at a contaminated site. Soil amendments, tilling, plant selection and production, water and weed management, harvest timing and nutrient optimization considerations are reviewed. Microbial ecology is altered by soil amendments and tilling, often in a positive way. Chapter 7 reviews biological options at contaminated sites

and the benefits of adding microbial populations. Plant–microbe associations act to improve the growth of vegetation, and overall soil health.

In applications of phytoremediation with biomass production, it is useful to have multiple approaches to reduce the effects of the contamination on soil health and to improve soil health and biomass productivity. Chapter 6 reviews processes to improve soil health and enhance ecosystem services. Soil amendments that add organic carbon and living organisms may help to improve soil health, plant growth, and nutrient cycling.

Plant-feeding insects and nematodes have the potential to impact *Miscanthus* growth and product yield. It is important to consider pest migration from one crop to another when fields are nearby. Chapter 8 provides information on important plant-feeding insects and nematodes that have been found in *Miscanthus* plantations and have been studied and reported in published literature, including *Miscanthus* mealybugs, aphids, May beetles, plant parasitic nematodes, armyworms, and rootworms.

A forward-looking approach in economic aspects of phytoremediation with biomass production is addressed in Chapter 9. This is followed by alternative ways to convert *Miscanthus* biomass to energy (Chapter 10) and to different bioproducts (Chapter 11). Economic aspects are introduced with full consideration of environmental, social, ecosystem, and economic benefits associated with the improvement of each contaminated site. A sustainable remediation approach is used along with options for increasing the value chain of *Miscanthus*. The benefits of soil remediation with biomass production include risk reduction, improvements in soil quality and soil health, biomass products, carbon sequestration, reduced soil erosion, community aesthetic benefits, and better habitat for birds and wild animals. The potential of *Miscanthus* to produce sustainable feedstock for energy, or to be converted to pulp, building materials and paper is characterized.

The NATO project field site at Fort Riley, Kansas, has been used to investigate the growth of *Miscanthus* in soil that contains lead from past military activities (Alasmay, 2020). *Miscanthus* establishment was successful, and the crop grew well in the lead-contaminated soil under the climatic conditions at the site. Tilling and soil amendments were beneficial to growth and crop yield. Lead uptake into the biomass was reduced by adding biosolids as an amendment; simultaneously, soil health was improved, based on microbial numbers and composition, and organic carbon increased with time. The soil health at Fort Riley field site was investigated by assessing the effects on the nematode community of growing *Miscanthus*, tilling, and adding soil amendments. Significant changes were observed in trophic group structure with *Miscanthus* compared to the soil with mixed plant cover. Tilling the soil prior to establishment of the *Miscanthus* and adding biosolids as an amendment affected the nematode community and important soil processes. Tilling and tilling plus adding biosolids affected the nematode community the most. The most conserved population of the trophic structure was the

bacterivores. There was also an increase in herbivores associated with the biosolids amendment (Alasmary et al., 2020).

The NATO project field site at Dolyna, Western Ukraine (former military site contaminated by various trace elements), has been used to ensure the successful cultivation of *Miscanthus* at the site and to investigate the impact of agricultural practices on *Miscanthus* biomass and phytoremediation parameters. These include incorporation of soil amendments, both mineral and organic, and/or treatment of rhizomes with Plant Growth Regulators (PGRs). Three and four years' cultivation of the crop at this military site showed good growth of *Miscanthus* with increasing biological parameters and harvest value (Chapter 5). Field experiments have shown the positive prospects for application of the *Miscanthus* phytotechnology with biomass production developed at contaminated military sites within NATO SPS MYP G4687 to other locations in Ukraine and Czech Republic where there is need to revitalize the postmilitary sites and to produce biomass for energy and bioproducts.

The NATO project research field established on marginal agricultural land at Tokarivka, Central Ukraine, illustrated the positive impact of different PGRs on *Miscanthus* development and harvest values on marginal land (Pidlisnyuk and Stefanovska, 2018). The successful reclamation of mined lands has been achieved by applying the best practices that are described in the book (Chapter 5).

One long-term phytotechnology option in the restoration of contaminated land is to develop it into a forest. Trees have been planted at many different sites, especially minelands, to address contamination and improve soil health. Some neglected sites eventually revert to forests if the climate is suitable. The Forest Service of the U.S. Department of Agriculture has developed the forestry reclamation approach, which has been used for successful reforestation of mined lands. A book with best management practices has been published by the U.S. Forest Service (Adams, 2017). *Miscanthus* has some specific advantages over woodlands when terrain permits its planting and harvest. First, it will yield useful product as quickly as even rapid-cycling poplars or willows, within 3–4 years. Because it is harvested annually, rather than on a longer rotation, it assures that biomass or income can be available every year. Second, it is far easier to remove if plans for the land are changed. This is a significant advantage on military or postmilitary lands that may be in transition. Third, *Miscanthus* is easily made into locally useful materials such as clean animal bedding or mulches, or used directly for combustion, and it will relatively rapidly decompose in situ without the need for chipping, unlike wood. This can more quickly and economically enhance soil tilth which is often an important component of the remediation of contaminated lands.

Economic issues are important and may limit choices at contaminated sites. Because of climate change, more decisions are being made based on sustainability and triple bottom line considerations. Adding organic carbon to the soil and improving soil health have value for society and may be included in making decisions. Since some benefits of phytoremediation such

as adding soil carbon have both soil benefits and global value because of climate benefits, there is a need to include all benefits in making decisions.

Taking a wide overview of the materials in the present volume, it is becoming clear that *Miscanthus* production is developed to the stage that it can be treated more like a commodity than a specialty crop. Technologies are well developed for reproduction of rhizome propagules, and micropropagation has become routine. There is a good understanding of the water and weed management needs for successful establishment of fields. Weather and climate change remain uncontrollable factors but genetic technologies are available to address both cold and heat injuries to plants. While there is legitimate concern for dangers of invasiveness in seed reproduction of crops, transformation of apical meristem tissues or somatic embryos (Kim et al., 2010), followed by regeneration of a single clone, should be feasible.

An additional tool in the kit of molecular biologists is the CRISPR-Cas system, the recently discovered, Nobel prize winning, DNA editing enzyme system, which can be used to edit in or out various gene sequences. No trace of the tool remains in the product, so that it behaves as if a random spontaneous mutation. This will allow one to edit out pollen function, for instance, to convert an optimal tetraploid *M. × giganteus* into a sterile hybrid. One might also alter the flowering locus C system (Ruelens et al., 2013) or its equivalent to delay flowering time, or fully disrupt flower development in a desirable CV, so that it fails to bloom either at most latitudes of interest, or entirely. This should significantly enhance biomass yields at lower latitudes, where early flowering seems to limit biomass, as discussed in Chapter 5. We recognize that in the European context some might raise objections to these technologies, although they introduce no foreign DNA by any means other than conventional hybridization. As a strictly nonfood crop, *Miscanthus* is exempt from such strictures in many countries. Time and necessity may also change minds.

12.2 Recommendations

Ideally all land should be used for beneficial purposes. Improving soil health and increasing organic carbon in soil should be high priorities because of both local and global benefits. Further research and development of phyto-technologies with biomass production is recommended, including additional research with *Miscanthus*. An important issue is how best to use *Miscanthus* biomass not only for energy production but also for conversion to different bioproducts. High yields with prominent content of lignocellulose, low requirement for nutrient inputs, and low susceptibility to pests and diseases make *Miscanthus* an excellent feedstock for producing fiber based materials such as construction or paper industry products. Future research and practice

should concentrate on looking into the full *Miscanthus* chain starting from production while ensuring sustainable land management, through ensuring optimal conditions for storing biomass, with development of proper technology for biomass processing into fibrous materials, pulp, and paper when *Miscanthus* has been harvested from marginal or contaminated soils. Some of the genetic techniques discussed above promise to enhance sustainable land management, allowing larger production of renewable energy and biomaterial without increasing land requirements. This is an essential component of a transition to a fully sustainable societal energy (and *Miscanthus*) cycle.

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