Valentina Pidlisnyuk*, Larry Erickson, Tatyana Stefanovska***, Iryna Pidlisnyuk*, Lawrence Davis****

* Jan Evangelista Purkyne University, Czech Republic
** Kansas State University, USA
*** National University of Life and the Environmental Science

e-mails: Valentyna.Pidlisniuk@ujep.cz; lerick@ksu.edu; tstefanovska@nubip.edu.ua; ira.pidlisnyuk@gmail.com ldavis@ksu.edu

PHYTOTECHNOLOGIES WITH BIOMASS PRODUCTION AS A SUSTAINABLE SOLUTION FOR MILITARY LAND REVITALIZATION

FITOTECHNOLOGIA Z PRODUKCJĄ BIOMASY JAKO ZRÓWNOWAŻONE ROZWIĄZANIE POZWALAJĄCE NA REWITALIZACJĘ ZANIECZYSZCZONYCH TERENÓW WOJSKOWYCH

DOI: 10.15611/br.2017.1.08

Summary: The military sites polluted by heavy metals, oil and degraded organic products constantly pose health risks and negatively affect soil, water resources and biodiversity. The prospective approach for sustainable land management of these localities is a green technology based on phytoremediation combined with the production of biomass that allows to restore marginal land to the agricultural or urban land bank and to obtain profits from processed bioproducts. The main goal of this paper is to present the results on using the second generation biofuel crop *Miscanthusxgiganteus* for the revitalization of the former military sites in Ukraine, the Czech Republic and the US using such an approach. The results of laboratory experiments and two years' field research proved the prospects of the phytotechnology and calls for further investigation related to economic value chain and behaviour aspects.

Keywords: contaminated military sites, miscanthus, biomass production, proved phytotechnology, behavior economics.

Streszczenie: Tereny wojskowe zanieczyszczone metalami ciężkimi, olejami i produktami prowadzącymi do ekologicznej degradacji stale stanowią zagrożenie dla zdrowia i negatywnie wpływają na glebę, zasoby wodne i różnorodność biologiczną. Perspektywicznym podejściem do zrównoważonego zarządzania gruntami w tych miejscach jest fitotechnologia z produkcją biomasy miscanthus, która pozwala na przywrócenie gruntów brzegowych do puli terenów rolniczych lub miejskich, a jednocześnie na zaspokojenie zapotrzebowania na alternatywne źródła energii. Wyniki trwających dwa lata badań nad wykorzystaniem miscanthusa do przywrócenia do użytku byłych terenów wojskowych na Ukrainie, w Czechach i Stanach Zjednoczonych potwierdziły przyszłe perspektywy dla tej technologii i nakłoniły do dalszych badań nad wartościami ekonomicznymi i zastosowaniem zasad ekonomii behawioralnej.

Słowa kluczowe: zanieczyszczone tereny wojskowe, niewykorzystane grunty, miscanthus, produkcja biomasy, ekonomiczna wartość, studia behawioralne.

1. Introduction

In accordance with the European Commission report [Remediated Sites and Brownfields 2015] there are 250.000 contaminated sites within the European Union including military ones which require urgent attention. In the US the number of Superfund sites is estimated as 1289 in accordance with the National Priorities List and the number of brownfield sites is about 450.000 [EPA 2017]. In Ukraine the intensively and medium contaminated sites are widespread and most of them are located at the industrially developed East [Ministry of Ecology and Natural Resources of Ukraine 2012]. The contaminated sites constantly pose health risks to humans and negatively affect soil, water resources and biodiversity.

Using conventional remediation technologies such as excavation and land filling, physico-chemical treatment (washing), biological treatment and thermal desorption is estimated to cost up to 129 $ /m^3 in Europe, and up to 252 $ /m^3 in the US [Witters et al. 2012] and can be used preferentially only for strongly contaminated sites. Current waste management strategy underlines that not all existing toxic substances have to be removed, but only those posing a harmful impact on human health and the environment while in the soil and after remediation as well [Van-Camp et al. 2004]. It is evident that the remediation activities undertaken have to be in line with sustainability [Haemers 2009]. The sustainable management of contaminated and unused lands is based on two main pillars: selection of the most appropriate technology and using sustainability principles [Vegter 2001; Pidlisnyuk et al. 2013]. This request is formulated in guideline documents for the implementation of green remediation technologies [Rock 2003].

Public acceptance of phytoremediation is based on the belief that green technologies are more widely accepted in a community that the alternative involving unsightly excavations and heavy equipment, nevertheless this acceptance requires an assessment of the risks to human health and the environment, as well as the dissemination of reliable information and education. The practical use of the crops for the revitalization of contaminated sites looks promising in terms of the relatively cheap cost of the technology and the real chances of acceptance by the public in comparison with using expensive conventional remediation accompanied by constant lack of financial support at regional or state levels for remediation measures as is thought in particular in the countries of Eastern Europe and Central Asia.

The prospective union of two processes: phytoremediation and production of biomass is evident for a number of reasons: the possibility to restore the marginal land and put it back to the land pool [Pidlisnyuk et al. 2014a], the increasing demand for biomass production as alternative energy sources [Rosillo-Calle et al. 2006]. According to the Europe 2020 program [Europe 2020], an alternative energy sector including biomass plays an important role in the strategic energy planning process in the EU [Biomass Action Plan 2005; Green Paper 2006]. An innovation trend on using phytotechnology biomass for bioproducts – fibers and building materials was reported recently [Wagner et al. 2017]. The overall scheme for using phytotechnology with biomass production for ensuring profitable outputs is presented below [Conesa et al. 2012].

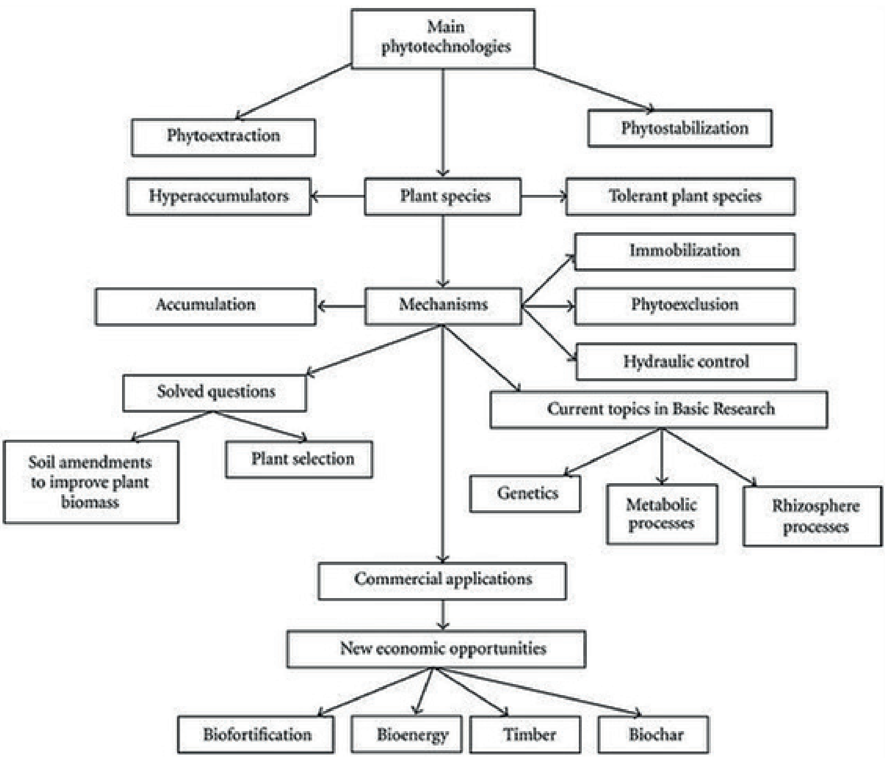

Figure 1. Scheme for using phytotechnology with biomass production for ensuring profitable outputs

Source: [Conesa et al. 2012].

The main goal of this paper is to introduce the green technology based on phytoremediation in combination with the production of biomass to be processed for bioproducts and to present the results of the practical application of phytotechnology for the revitalization of the former military sites when the key plant is *Miscanthus x giganteus*.

2. Results and discussion

M. x giganteus, native to Southern Asia, has a good adaptive potential in European Union countries and the USA, high harvest yields and can be grown at the relatively poor soils [Kocon, Matyka 2012; Techer et al. 2012]. The utilization of the miscanthus biomass obtained for energy and commercial products is attractive [Dornburg, Faaij 2005] and can turn the phytoremediation into a profit making operation [Marmiroli, McCutcheon 2003]. The first results are reported regarding using miscanthus for phytoremediation of land contaminated by radionuclides in Ukraine [Los et al 2011], and metals in Slovakia [Pidlisnyuk et al. 2016] and France [Nsanganwimana et al. 2014; Soubi et al. 2017].

There are very significant amounts of land that are not presently used for agriculture because the soil quality is poor and the land is not sufficiently productive. Miscanthus has the potential to be an important agricultural crop for use on that marginal site as well [Pidlisnyuk et al. 2014a]. The crop belongs to the second generation crop with a net calorific value, on a dry basis, of 17 MJ/kg and it is recognized as a very promising crop for alternative energy production. The energy value of 20 t of dry *M. x giganteus* would be equivalent to that of 8 t of coal [Brosse et al. 2012]. Growing it as a fuel is very energy efficient. The plant can be used for a range of end-users: from co-firing in coal power stations, to large-scale electricity power stations and for small scale heat production. Existing straw burning technology can be used to meet farm heat requirements [Daraban et al. 2015].

At the same time miscanthus has a good environmental profile with the potential to increase soil carbon, soil fertility and biodiversity and to reduce nutrient run-off and leaching. Despite these benefits, the plant cultivation and the utilization of biomass are still not widespread in Europe- currently about 38.300 ha in Europe. One of the reasons is competition with other energy and agricultural crops for the agricultural land bank.

The literature review [Pidlisnyuk et al. 2014a] showed that the crop can grow productively on metal-contaminated soils. Improvement of the soil and increasing each year the yield of miscanthus will have great value to society [Kalinina et al. 2016].

We initiated investigations on using *M. x giganteus* for the revitalization of former military sites located in the Czech Republic, the US and Ukraine. The research sites are diverse and included: an airport of the former Soviet Union Air Force (Mimon, the Czech Republic), former shooting training range (Ft.Riley, USA), former military training ground (Dolyna, Ukraine), and the recently available site following the military operations in East Ukraine (Kurakhovo). The main contaminants at the research sites are different metals and spilled jet fuel (kerosene). The locations are classified as contaminated and damaged by the local environmental authorities in the corresponding countries and require revitalization. The results of two years' laboratory experiments with growing miscanthus on these diverse soils confirmed the ability of the plant to grow with good quality biomass [Nurzhanova et al. 2015; Pidlisnyuk et al. 2016; Erickson et al. 2017]. The field plots were established at the abandoned military locations in Fort Riley, USA, Mimon, the Czech Republic, Dolyna and Kurakhovo, Ukraine. The biomass growing during two seasons at the plots at Ft. Riley, USA and one season in Dolyna and Kurachovo, Ukraine showed a good production [Hettiarachchi et al. 2017; Erickson et al. 2017]. The current results have proved the suitability of *M. x giganteus* for the simultaneous revitalization of the former military sites soil and the production of energy biomass which may be processed for direct burning or for pellets, and transformed to biofuels or industrial products [Kharchenko et al. 2017].

The commercial success of phytotechnologies depends on the generation of valuable biomass on the contaminated land, rather than a pure remediation technique that may not compare favorably with the costs of inaction or alternative technologies [Conesa et al. 2012]. Additional research is needed to commercialize the production of miscanthus at the peripheral and contaminated military sites and to estimate the most applicable economic value depending of the land varieties and technique used. In particular, research has to be focused on the production of biomass with the necessary energy efficiency indicators allowing the use of biomass commercially for direct burning and/or transformation to biofuel. According to Lewandowski et al. [2006], the quantification of land use functions in biophysical terms requires site-specific information on the landscape, site conditions, or plant species. Target groups have been also identified which may benefit from phytotechnologies (farmers, authorities, industries etc.). This implies that evaluation costs are site-specific and, therefore, that general economic assumptions or yield rates cannot be estimated without site-specific studies.

As an initial step in the economic evaluation of phytomanagement projects, some scenarios have to be established in the decision-making process. The direction of supplemented research has to be focused at the aspects of behavioral economics [Guidelines for Behavioral Change Programmers 2009] for developing mechanisms of implementation the proposed phytotechnlogy at local levels.

3. Conclusion

The application of the proposed union phytotechnology with miscanthus biomass production for the revitalization of contaminated military sites and unused agricultural land is classified as sustainable and offers considerable potential for the further development of abandoned military land. The regeneration of such sites has a positive social and economic impact on the given area, even though their preparation is time-consuming. Further research has to be focused on commercializing the production of miscanthus on the peripheral and contaminated military land and to estimate the most applicable economic value chain of the phytotechnology using the approach of behavioral economics.

Research is supported by NATO SPS MYP G4687.

References

Biomass Action Plan, 2005, COM 628.

Brosse N., Dufour A., Meng X.Z., Sun Q.N., Ragauskas A., 2012, *Miscanthus: A fast-growing crop for biofuels and chemicals production*, Biofuels Bioproducts & Biorefining-Biofpr, vol. 6(5), pp. 580-598.

Conesa H.M., Evangelou M.W.H., Robinson B.H., Schulin R., 2012, *A critical view of current state of phytotechnologies to remediate soils: still a promising tool?,* Scientific World Journal, 173829.

Daraban A.E., Jurcoane S., Viocea L., Voicu G., 2015, *Miscanthus giganteus biomass for sustainable energy in small scale heating systems*, Agriculture and Agricultural Science Procedia, vol. 6, pp. 538-544.

Dornburg V., Faaij A.P.C., 2005, *Cost and CO2 – emission reduction of biomass cascading: methodological aspects and case study of SRF poplar*, Climate Change, vol. 71, pp. 373-408.

Erickson L., Pidlisnyuk V., Trögl J., Shapoval P., Popelka J., Davis L., Stefanovska T., Hettiarachchi G., 2017, *Perennial phytotechnology with biomass production for abandoned military site in Sliač*, Slovakia. Proc. of International conference " Chemical technology and engineering ", Lviv, Ukraine, Published by: Lvivska Politekhnika, pp. 282-283.

Europe 2020: A European Strategy for smart, sustainable and inclusive growth, 2012, COM (2010).

Green Paper. A European Strategy for Sustainable, Competitive and Secure Energy, 2006, COM, 105.

Guidelines for Behavioral Change Programmers, 2009, *Changing energy behavior*, edited by IDEA, Published by: Instituti para la Deversificacion y Ahorro de la Energia, Spain, 96.

Haemers J., 2009, *Sustainable remediation: how to compare the technologies*?, Green Remediation Conference, Copenhagen, Denmark, pp. 7-9.

Hettiarachchi G., Alasmary Z., Roozeboom K., Davis L., Erickson L., Pidlisnyuk V., Stefanovska T., Nurzhnova A., Trogl J., 2017, *Field–based investigations on phytostablization of a contaminated military site using biofuel crop growth assisted with soil amendments*, Proc. of 14th International Phytotehnologies Conference. Phytotechnologies: New Sustainable Solution for Environmental Challenges, Montreal, Canada.

Kalinina O., Thumm U., Lewandowski I., 2016, Miscanthus-complemented Grassland in Europe: Additional Source of Biomass for Bioenergy, [in:] *Perennial Biomas Crop for a Resources Constrained World*, eds. S. Barth, D. Murphy-Bokern, O. Kalinina, G. Taylor, M. Jones, Springer Nature Switzerland AG, pp. 51-63.

Kharchenko M., Pidlisnyuk V., Stefanovska T., *Production of Miscanthusxgiganteus biomass at the abandoned industrial soil for further use at the paper industry*, Studia Biologica, vol. 11/3-4, pp. 98-99.

Kocon A., Matyka M., 2012, *Phytoextractive potential of Miscanthus giganteus and Sida hermaphrodita growing under moderate pollution of soil with Zn and Pb*, Journal of Food, Agriculture & Environment, vol. 10, pp. 1253-1256.

Lewandowski I., Schmidt U., Londo M., Faaij A., 2006, *The economic value of the phytoremediation function—assessed by the example of cadmium remediation by willow (Salix ssp*), Agricultural Systems, vol.89(1), pp. 68-89.

Los L.V., Zinchenko L.V., Zajvoronovskyi V.P., 2011, *Growing and gasification of biofuels as effective direction for solving energetic and ecological problems: case of Miscanthus gigantheus*, Release of Zytomir National Agroecological University, vol. 29, part 1, pp. 46-57 (in Ukrainian).

Marmiroli N., McCutcheon S.C., 2003, *Making Phytoremediation a Successful Technology*, [in:] *Phytoremediation. Transformation and Control of Contaminats*, eds S. C.McCutcheon, J.L. Scxhnoor, published by: Wiley-Interscience.A John Wiley&Sons, Inc. Publication, pp. 85-119.

Ministry of Ecology and Natural Resources of Ukraine, 2012, Enriched five-years report regarding land desertification and erosion, www.menr.gov.ua/Zvit5rokOpus2013.doc (in Ukrainian).

Nsanganwimana F., Pourrut B., Mench M., Douay F., 2014, *Suitability of miscanthus species for managing inorganic and organic contaminated land and restoring ecosystem services. A review*, Journal of Environmental Management, vol. 143, pp. 123-134.

Nurzhanova A., Pidlisnyuk V., Kalugin S., Stefanovska T., Drimal M., 2015, *Miscanthusxgiganteus as a new highly efficient phytoremediation agent for improving soils contaminated by pesticides residues and supplemented contaminants*, Communications in Agricultural and Applied Biological Sciences, 80(3), pp. 361-366.

Pidlisnyuk V., Erickson L., Kharchenko S., Stefanovska T., 2014b, *Sustainable Land Management: Growing miscanthus in soils contaminated with heavy metals*, Journal of Environmental Protection, Special Issue in Environmental Remediation, vol. 5, pp. 723-730.

Pidlisnyuk V., Stefanovska T., Lewis E., Erickson L., Davis L., 2014a, *Miscanthus as a productive biofuel crop for Phytoremediation*, Critical Review on Plant Science, vol. 32(1), pp. 1-16.

Pidlisnyuk V., Stefanovska T., Shapoval P., 2016, *Developing perennial phytotechnology for contaminated military site: case of Kamenetz-Podilsky*, Ukraine, Proc. of the International Conference Contaminated Sites, Bratislava, Slovakia, pp. 124-132.

Pidlisnyuk V., Zagirnyak M., Jilkova J., 2013, *Strategy of Sustainable Development and Climate Change*, Zsherbatux Publishing, Kremenchug, Ukraine (in Ukrainian).

Remediated Sites and Brownfields, 2015, *A report of the European Information and observation Network's National Reference Centers for Soil (Eionet NRC Soil),* eds. A. Perez, S. Sanchez, M. Liedekerke. Published by IRC.

Rock S.A., 2003, *Field Evaluation of Phytotechnologies*, [in:] *Phytoremediation. Transformation and Control of Contaminants*, eds S. C. McCutcheon, J.L. Scxhnoor, Wiley-Interscience. A John Wiley&Sons, Inc. Publication, pp. 905-924.

Rosillo-Calle F., de Groot P., Hemstock S.L., Woods A. (eds), 2006, *The Biomass Assessment Handbook: Bioenergy for a Sustainable Environment,* J. Earth Scan Publications Ltd., London.

Soubi A., Louvel B., Douay F., Porrut B., 2017, *Assessment of Miscanthus x giganteus capacity to restore the functionality of metal-contaminated soils: Ex situ experiment*, Applied Soil Ecology, vol. 7.

Techer D., Martinez-Chois C., Laval-Gilly P., Henry S., Bennasroune A., D'Innocenzo M., Falla J., 2012, *Assessment of Miscanthus x gigantheus for rhizoremediation of long term PAH contaminated soils*, Applied Soil Ecology, vol. 62, pp. 42-49.

Van-Camp L., Bujarrabal B., Gentile A.-R., Jones R.J.A., Montanarella L., Olazabal C., 2004, *Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection*, [in:] *Contaminated Land Management*, vol. 4, European Commission, Luxembourg .

Vegter J.J., 2001, *Sustainable contaminated land management approach*, Land Contamination and Reclamation, vol. 9, pp. 95-100.

Wagner M., Kiesel A., Hastings A., Iqbal Y., Lewandowski I., 2017, *Novel Miscanthus germplasm-based value chains: a life cycle assessment*, Frontiers in Plant Science.

Witters N., Mendelsohn R.O., Van Slycken S., Weyens N., Schreurs E., Meers E., Tack F., Carleer R., Vangronsveld J., 2012, *Phytoremediation, a sustainable remediation technology? Conclusions from a case study. I: Energy production and carbon dioxide abatement*, Biomass and Bioenergy, vol. 39, pp. 454-469.

www.epa.gov/superfunds/sites/npl/index.htm,2017 and https://www.epa.gov/brownfields.