# PHYTOREMEDIATION POTENTIAL OF HEAVY METAL CONTAMINATED SOILS BY THE PERENNIAL ENERGY CROPS *MISCANTHUS* SPP. AND *ARUNDO DONAX* L. UNDER LOW IRRIGATION

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ABSTRACT: The increasing demand for biomass for the production of bioenergy is generating land-use conflicts which might be avoided through the establishment of dedicated energy crops on marginal land, e.g. heavy-metal contaminated land. But assessment of bioenergy from marginal land should take into account constraining factors, such as productivity and biomass quality, as well as environmental and social aspects. In this context, this research work aims to study the potentiality of two perennial grasses *Miscanthus* spp. and *Arundo donax*. in heavy metal contaminated soils. In a previous study, it was found that giant reed and *Miscanthus* spp. yields were negatively affected when grown in heavy-metal contaminated soil under full irrigation (950 mm) to overcome water stress. However, both crops can be considered interesting candidates for heavy metals phytoextraction, based on the metal accumulation observed and the high biomass produced. In this work, the yields and the biomass quality of these perennials were tested but under low irrigation (450 mm). Along two years, giant reed was tested on contaminated soils containing 450 and 900 mg Zn $kg^{-1}$, 300 and 600 mg Cr $kg^{-1}$ and 450 and 900 mg Pb $kg^{-1}$, while the *Miscanthus* genotypes: *M.* x *giganteus*, *M. sinensis* and *M. floridulus* were tested on 450 and 900 mg Zn $kg^{-1}$ contaminated soils. Giant reed biomass production was negatively affected by the Cr contamination, but not by the Zn or the Pb contamination. Zn contamination reduced significantly *M.* x *giganteus* production but not *M. sinensis* or *M. floridulus* yields. Yet, *M.* x *giganteus* was the most productive genotype. Biomass obtained in heavy metals contaminated soils presented higher ash content and higher Zn/Cr/Pb content then biomass from non-contaminated soils, thus showing phytoextraction and accumulation capacity. But, lowering the irrigation level reduced significantly the biomass production, causing lower accumulation of metals in the biomass. Even though, both crops still presented favorable potential for phytoextraction and showed to be well suited for phytostabilization of heavy metals contamination as these grasses prevented the leaching of heavy metals and groundwater contamination.
Keywords: perennial energy crops, *Arundo donax*, *Miscanthus*, heavy metals, phytoremediation, marginal soil

## 1 INTRODUCTION

*Miscanthus* and giant reed are lignocellulosic rhizomatous grasses. they are perennial plants, with an estimated productive lifetime of at least 10-15 years, and both the stems and leaves of the crop can be harvested annually [1]. They characterized by relatively high yields, high water and nitrogen efficiencies and an apparently low susceptibility to pests and diseases [2,3]. Both crops achieve high productivity under high summer temperatures, in the Mediterranean – and copes well with severe weather conditions such as flooding in autumn, winter or spring and dryness in summer [2,3]. Thei robustness and physiological characteristics as a deep, dense and extensive root system, allows it to easily adapt to different types of soils and ecological conditions, being indicated for reducing soil erosion, minimize nutrient leaching and sequester more C in soils [1,4].

However, the increasing demand for biomass for the production of bioenergy is generating land-use conflicts which might be avoided through the establishment of dedicated energy crops on marginal land, e.g. heavy-metal contaminated land. So, the cultivation of perennial grasses in polluted soils is being presented as an approach to restore or attenuate and stabilize contaminated sites while bringing additional revenue to owners [5,6]. Simultaneously, land use conflicts with food crops are avoided [7].

In a previous study, it was found that giant reed and *Miscanthus* spp. yields were negatively affected when grown in heavy-metal contaminated soil under full irrigation (950 mm) to overcome water stress [5]. But, water resources are scarce in the Mediterranean region and it seems unsustainable its use to irrigate energy crops in marginal soils. Therefore, in this work, the yields and the biomass quality of these perennials in contaminated soils were tested but under low irrigation (450 mm).

## 2 MATERIALS AND METHODS

The trials were established in April 2012 in pots, with three different *Miscanthus* genotypes, *M. sinensis*, *M. floridulus*, and a hybrid – *Miscanthus × giganteus*, and with local ecotypes of giant reed. *Miscanthus* rhizomes were provided by the University of Catania. In each pot (0,06154 $m^2$, 12kg of soil) 2 rhizomes were established (a pot for each grass and genotype with replicates). After the establishment of the rhizomes, pots were fertilized: 3 g $N/m^2$ (urea, 46% N); 3 g $N/m^2$ (nitrolusal, mixture of $NH_4NO_3+CaCO_3$, 27% N); 17 g $K_2O/m^2$ (potassium sulphate, 51% $K_2O$); 23 g $P_2O_5/m^2$ (superphosphate, 18% $P_2O_5$). In the *Miscanthus* pots, two concentrations of zinc in contaminated soils were tested (450 and 900 mg $Zn.kg^{-1}$ dry matter, respectively, $Zn_{450}$ and $Zn_{900}$). In the *Arundo donax* pots, two concentrations of zinc and lead in contaminated soils were tested (450 and 900 mg $Zn.kg^{-1}$ dry matter, respectively, $Zn_{450}$ and $Zn_{900}$ and 450 and 900 mg $Pb.kg^{-1}$ dry matter, respectively, $Pb_{450}$ and $Pb_{900}$).

Two concentrations of Cr were also tested (300 and 600 mg $Cr.kg^{-1}$ dry matter, respectively, $Cr_{300}$ and $Cr_{600}$). The low and high levels tested correspond to maximum allowable and to twice as maximum [8]. Water was applied at a rate of 475 mm. In all the experiments, control pots were also tested.

At the end of each growing season (January), the plants were harvested and the aerial productivity was monitored. To determinate the productivity of the biomass, the total aerial dry weight was determined along two consecutive growing seasons. The quality of the biomass (aerial fraction) was analysed taking in consideration the following parameters: ash content. The remediation of soil was analysed in terms of Zn, Cr and Pb accumulation in the biomass in comparison with the initial contamination. The chemical analyses were performed according to the following procedures: a) ash content: by calcination at 550ºC for two hours, in a muffler furnace; b) netals: by atomic absorption after digestion of the ashes with nitric acid.

## 3 RESULTS AND DISCUSSION

### 3.1 Biomass Productivity

Figure 1 presents the biomass productivity obtained in the trials at the 2nd harvest year. From the 1st to the 2nd year, the yields increased, on average, 150%. This pattern is typical from perennial crops showing that higher energy is used by the plant in the first year to establish its below ground biomass.

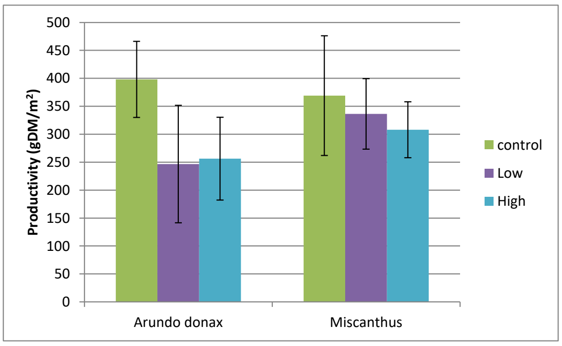


**Figure 1:** *Miscanthus* and *Arundo donax* productivity (dry matter) after two consecutive growing cycles in different contamination levels. Control pots represent pots without contamination; low and high contamination levels tested correspond to maximum allowable and to twice as maximum, according to [8]. In the case of *Miscanthus* for each contamination level, average results from different species; in the case of giant reed for each contamination level average results from different metals.

No significant effects were verified due to the metals contamination in the soil, although it was observed a reduction in the yields with soil contamination. Different patterns were observed for the different species of *Miscanthus* and for giant reed for the different metals.

Figure 2 presents the losses/gains in biomass productivity at the 2nd year for the different *Miscanthus* species and due to different levels of soil contamination compared to control pots.

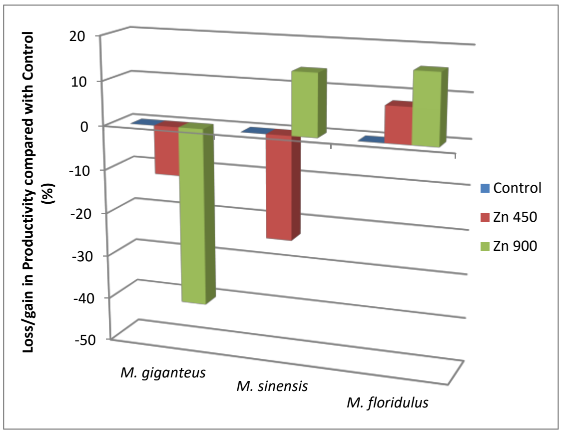


**Figure 2:** Loss/gain in biomass productivity at the 2nd year for the different *Miscanthus* species and due to different levels of soil contamination compared to control pots

According to the results obtained in the trials, *M.* x *giganteus* is the species that is more affected by Zn contamination, regarding yields. However, *M.* x *giganteus* was also the most productive genotype in terms of yields (Figure 3).

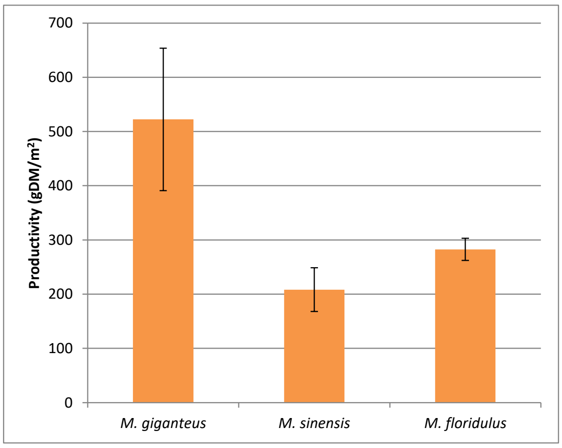


**Figure 3:** *Miscanthus* productivity (dry matter) after two consecutive growing cycles. For each genotype results presented are average results from different levels of contamination.

Figure 4 presents the losses/gains in biomass productivity at the 2nd year for giant reed due to different levels of soil contamination and different metals compared to control pots.

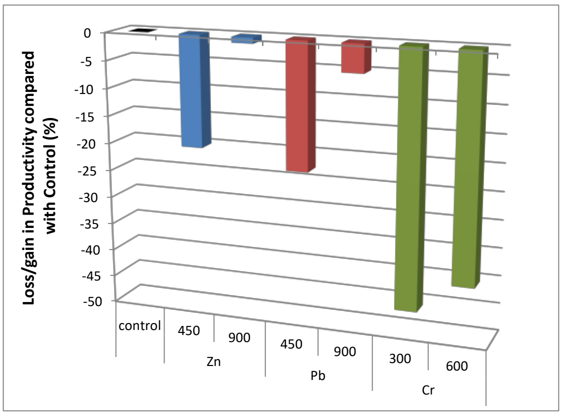


**Figure 4:** Loss/gain in biomass productivity at the 2nd year for giant reed due to different levels of soil contamination and different metals compared to control pots

According to the results obtained in the trials, giant reed is more affected by Cr contamination than Zn or Pb contamination, regarding yields.

When comparing giant reed yields with the most productive genotype (*M.* x *giganteus*), *Miscanthus* shows higher productivities (Figure 5).

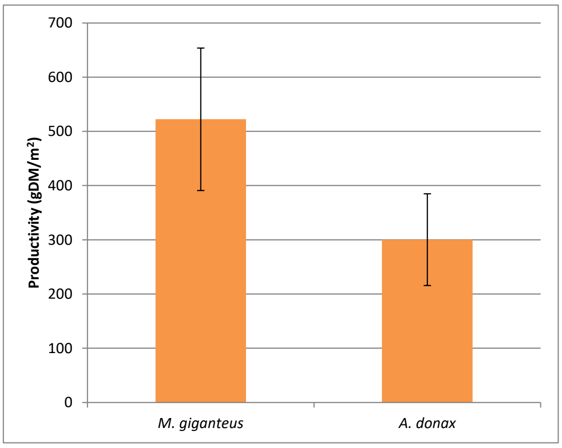


**Figure 5:** Comparison of *Miscanthus x giganteus* and giant reed productivities (dry matter) after two consecutive growing cycles. For each species results presented are average results from different levels of contamination.

3.2 Biomass quality

Considering that these perennial crops are usually used for bioenergy production in combustion furnaces, ash content of the biomass (stems) was assessed in order to evaluate the biomass quality. The increment in ash content of giant reed stems harvested from contaminated soils, compared to control soils is shown in Figure 6.

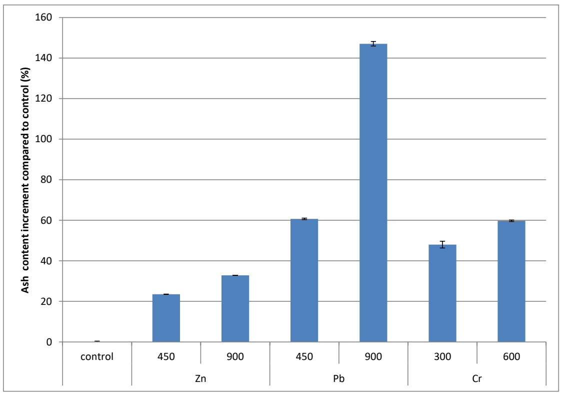


**Figure 6:** Ash content increment (%) of giant reed stems harvested from contaminated soils, compared to control soils.

According to results presented in Figure 6, metal contamination led to an increment in ash content of the stems of giant reed, especially in the Pb contaminated soils, followed by Cr contaminated soils. The lowest difference was obtained from soils contaminated with Zn. This can represent a constraint to the use of giant reed from contaminated soils when combusted.

The increment in ash content of *Miscanthus* stems harvested from contaminated soils, compared to control soils is shown in Figure 7.

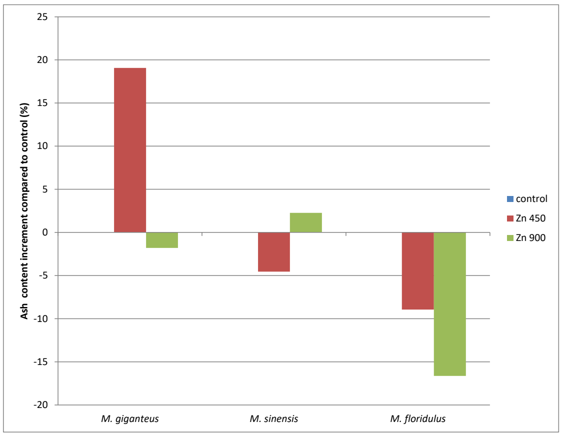


**Figure 7:** Ash content increment (%) of *Miscanthus* stems harvested from Zn contaminated soils, compared to control soils.

*M.* x *giganteus* is the genotype that presents the highest increment in ash content. Zinc contamination did not affect negatively the ash content of *M. floridulus* or *M. sinensis*. This means that the biomass quality of *Miscanthus* obtained from contaminated soils do not represent a constraint when used for combustion purposes, even the biomass from *M.* x *giganteus*.

3.3 Metal accumulation in the biomass

Figure 8 and 9 shows the metal content increment in the biomass of giant reed and *Miscanthus* harvested from control and contaminated soils, after 2 consecutive years.

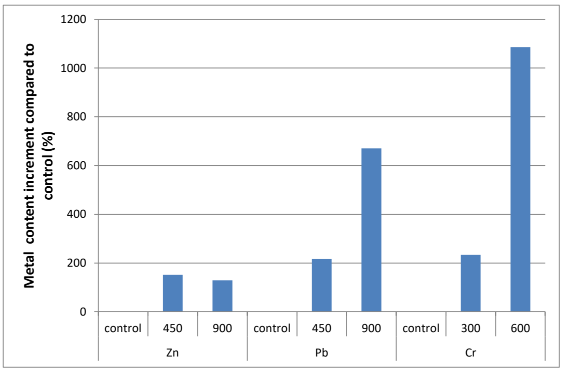


**Figure 8:** Metal content increment (%) of giant reed biomass harvested from contaminated soils, compared to control soils.

Figure 8 shows that the higher the level of contamination in the soil the higher the amount of metal that was accumulated in the aerial biomass. Highest increment in accumulation was observed with chromium contamination.

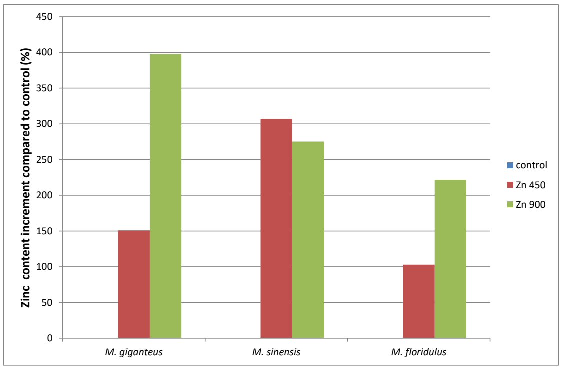


**Figure 9:** Zinc content increment (%) of *Miscanthus* biomass harvested from contaminated soils, compared to control soils.

Figure 9 shows that the higher the level of contamination in the soil the higher the amount of metal that was accumulated in the aerial biomass. Highest increment in accumulation was observed with *M.* x *giganteus* for the highest level of contamination.

## 4 CONCLUSIONS

The three studied *Miscanthus* genotypes showed zinc phytoextraction and accumulation capacity. Giant reed biomass also showed metal extraction from contaminated soils. Both crops presented favorable potential for phytoextraction and showed to be suited for growth in contaminated land at the levels tested.

After two years, the contamination with zinc or lead did not affect the production of giant reed but the yields were affected by Cr contamination. Regarding *Miscanthus* genotypes, zinc contamination affected affected *M.* x *giganteus* but not *M. floridulus* or *M. sinensis*. Among genotypes, *M.* x *giganteus* was the most productive, followed by *M. floridulus*. *M. sinensis* was the lesser productive genotype.

Ash content of giant reed stems, was affected by the level of contamination and this may represent a constraint to its use for energy by combustion. But *Miscanthus* spp. were not significantly influenced by the Zn contamination. This means that this biomass can be produced in Zn contaminated fields and that the quality of biomass is not significantly different from the one from non-contaminated land.

Further studies are needed to assess other parameters of the biomass quality with a view to its end use. The prospect of the valorisation of the perennial crops aerial biomass, for bioenergy or bio-products production purposes, could lessen the financial costs of soil remediation, compared to the traditional physical – chemical processes with the associated revenue of environmental benefits. Hence contributing to a more sustainable agriculture approach.

## 5 ACKNOWLEDGEMENTS

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