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Miscanthus x Giganteus: Contribution to a Sustainable Agriculture of a Future/Present - Oriented Biomaterial

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Abstract. The main purpose of this work was to study the phytoremediation capacity of *Miscanthus* x *giganteus* to soils contaminated with heavy metals and also to evaluate the environmental risks due to its utilisation as a biomaterial. Indeed, the concentration of metals in the aerial part of the plant might represent a question of its future use. Four levels of contamination were studied: P_0 = 0 t; P_{50} = 50 t; P_{100} = 100 t; P_{200} = 200 t domestic sludge.ha^{-1}. The results obtained permit to conclude that in terms of the productivity there are significant differences among the plants obtained with different levels of contamination. P_{50} and P_{100} presented significantly higher values. In relation to the ash, nitrogen and phosphorous contents, the results showed an increase in mineral matter and an accumulation in nitrogen and phosphorous, in the plants, with the increase of the level of contaminants. But this increase was not significant. No significant differences were observed in the plants among the different levels of sludge, for most of the metals studied. This fact leads to the conclusion that the utilisation of the biomass, obtained in those contaminated fields, is possible, as a biomaterial. Thus, contributing not only to increase its economical value but also to a sustainable agriculture.

Introduction

Miscanthus x giganteus is a hardy perennial grass originated in South-East Asia and related to sugarcane. *Miscanthus* was originally introduced to Europe as an ornamental garden grass. The field production in Portugal gives high yields, with plants up to 3.5 m tall [1]. It achieves high productivity under high summer temperatures – and copes well with severe weather conditions such as flooding in autumn, winter or spring and dryness in summer. In the Southern Portugal conditions, *Miscanthus* typically yields 25 – 30 t.ha^{-1} dry matter [1]. *Miscanthus* is a multi-use crop whose potential is now fully realised. The most current use is as a renewable energy crop. However, its very high yields, high lignin and lignocellulose fibre contents and capacity of growing without pesticides and fertilisers, make it also an attractive material for many other uses such as thatching, animal bedding, high quality paper pulp, fibreboards and inclusion in composites [2,3].

But the main interest of this kind of crop lies on the possibility to make use of set aside land, limiting erosion risks and on the remediation of contaminated land, thus contributing to a sustainable agriculture. In fact, phytoremediation is, for example, a not very expensive strategy, using vegetation *in situ* for the decontamination of polluted soils and sediments [4]. Advantages of phytoremediation include its relatively low cost, aesthetic benefits and non-obtrusive nature [5]. The establishment of a vegetative cover on derelict land can also be beneficial to reduce aerial dispersion and runoff, to function as a supply cover for wildlife and to allow economically viable cultivation [5].

In this context, the main purpose of this work was to study the potentialities of the production of *Miscanthus* x *giganteus* in a soil treated with domestic sludge, and to evaluate the environmental risks due to its utilization as a biomaterial. The utilization of domestic sludge in agriculture, presents the advantage of contributing to an increase in organic matter and nutrients in the soil,

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making it more fertile and improving its structure. It contributes, simultaneously, for the reuse and reforward of those residual materials. Nevertheless, the application of domestic sludge in the soil can also contribute to increase heavy metals and xenobiotics, with possible negative effects at the level of the soil fertility.

Materials and Methods

In 1994, experimental plots, each one with an area of 6x4m^2 were established by spacing rhizome pieces and plantlets of *Miscanthus* x *giganteus* at a distance of 50 cm. In 1998, the density of the plants was 88 plants.m^{-2} and those experimental fields were prepared for the experiment, using as a source of contamination, domestic sludge obtained from a waste treatment plant in the outskirts of Lisbon (S. João da Talha). Four levels of contamination were studied, in a replicated trial (x2): P_0 = 0 t, P_{50} = 50 t, P_{100} = 100 t and P_{200} = 200 t sludge ha^{-1}. The sludge used had 25% dry matter. Fertilization was applied in all the fields when the plants had about 70 cm high. 60 kg N ha^{-1}, 140 kg K ha^{-1} and 100 kg P ha^{-1} were used (P was applied only in the year of the establishment of the plants and in 1998). Between the months of June and October, irrigation was applied daily, in order to compensate the water deficit of the soil and to prevent water stress.

The productivity of the fields (the total aerial dry weight) was determined at the end of the growing season. To assess the effect of contamination on the quality of the biomass, ash, nitrogen, phosphorous and some metals contents (Cd, Cu, Ni, Pb, Zn, Cr and Hg) were determined in the aerial fraction of the plants, at harvest time. The following methodologies were applied: ash content, by incineration at 550 ± 50 ºC for 2 hours in a muffler furnace; nitrogen content, by the Kjeldahl method; phosphorous content, by the ascorbic acid method, after digestion of the sample; metals, by atomic absorption spectroscopy, after digestion of the ashes with nitric acid, and, in the case of Hg, with potassium dichromate. To assess the quality of biomass for energy and paper pulp production, were determined in the aerial fraction of the plants, at harvest, the calorific value, determined with an adiabatic calorimeter, and the total cellulose content, determined by the Belluci method.

Results and Discussion

Characterization of the domestic sludge. Selection of the sludge quantity to be applied in the fields. Table 1 presents the physical and chemical characterization of the domestic sludge obtained from the waste treatment plant of S. João da Talha.

Table 1. Physical and chemical characterization of the domestic sludge applied on the experimental fields [6] (dm – dry matter).

pH	6.8 ± 0.2
Moisture [%]	75.7 ± 0.2
Ash [% dm]	64.5 ± 0.4
Organic matter [% dm]	35.5 ± 0.4
Azoto total [% N dm]	2.00 ± 0.07
Fósforo total [% P dm]	0.69 ± 0.02
Cd [mg.kg^{-1} dm]	0.7 ± 0.1
Cu [mg.kg^{-1} dm]	134 ± 3
Ni [mg.kg^{-1} dm]	24.8 ± 0.4
Pb [mg.kg^{-1} dm]	94 ± 2
Zn [mg.kg^{-1} dm]	940 ± 20
Hg [mg.kg^{-1} dm]	5.4 ± 0.2
Cr [mg.kg^{-1} dm]	55 ± 2

According to the results in Table 1, the domestic sludge presents a neutral pH and high levels of organic matter, nitrogen and phosphorous. So, application of this material on soils might contribute to the correction of the physical characteristics of those soils and/or improve the level of fertility. The several heavy metals concentration are below the limit values established in the 176/96 Public

Law [7], related to the use of domestic sludge in agriculture. Zn is the metal that presents the lowest and more restricted limit-value/sludge-value ratio, followed by the Cu and the Pb values ratio. According with the same document, and using the zinc concentration value (the most restricted metal) as a criterion basis, four levels of sludge application were selected: P_{200} equivalent to the maximum allowable deposition plus half of this quantity, in order to study possible phytotoxic effects; P_{100} and P_{50}, equivalent, respectively, to a half and a quarter of P_{200}; and P_0, as testimony.

Biomass Production. Table 2 and Figure 1 present the productivity observed in all the experimental fields, for the different levels of contamination, at the end of the growing season. All the data presented are average results obtained for 1998/99, 1999/2000 and 2000/2001 crops. The results obtained leads to the conclusion that there are significant differences among the fields according to the different levels of contamination, in what concerns the productivity. The presence of the domestic sludge in the fields affected positively this parameter. P_{50} and P_{100} fields presented the highest productivities. P_{200} fields presented lower values than P_{50} and P_{100}, but higher than P_0.

Table 1. Productivity of *Miscanthus* x *giganteus*, for the different levels of contamination, at harvest.

	P_0	P_{50}	P_{100}	P_{200}
Productivity [t.ha^{-1}]	19 ± 1	32 ± 3	29 ± 2	24 ± 1

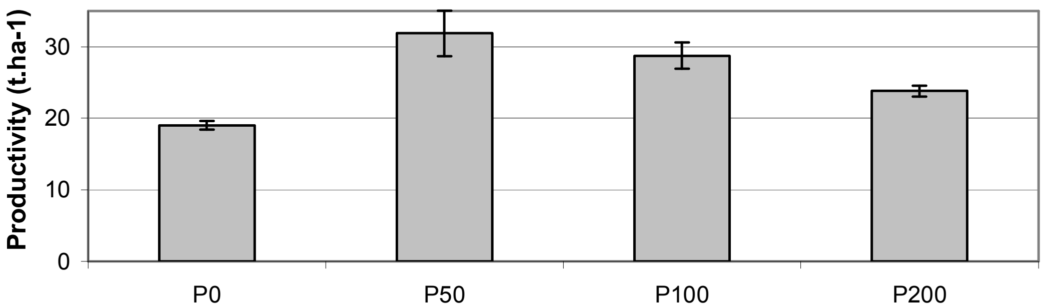

Fig. 1. Productivity of *Miscanthus* x *giganteus*, for the different levels of contamination, at the end of the growing season.

Chemical characterization of the Biomass. Tables 3 summarises the results of biomass chemical composition, except the heavy metals analysis, and energy content which were determined at harvest time. The data presented in Table 3 are average results obtained for 1998/99, 1999/2000 and 2000/2001 crops.

Table 3. Chemical analysis of the biomass at harvest (on a dry matter basis).

	P_0	P_{50}	P_{100}	P_{200}
Ash [%]	3.1 ± 0.8	3.0 ± 0.6	3.4 ± 0.7	3.5 ± 0.5
Nitrogen [%]	0.10 ± 0.01	0.11 ± 0.01	0.10 ± 0.01	0.15 ± 0.02
Phosphorous [%]	0.03 ± 0.01	0.02 ± 0.01	0.03 ± 0.02	0.06 ± 0.03
Cellulose [%]	51 ± 1	50 ± 5	52 ± 4	51 ± 4
Calorific Value [KJ.g^{-1}]	18 ± 1	17 ± 1	18 ± 1	16 ± 2

According to the results presented at Table 3, no significant differences were observed for the biomass harvested in all the fields. So, considering the economic exploration of this biomaterial, *Miscanthus* obtained in contaminated fields could be processed and utilized. Thus, the reuse of contaminated land could be seen as an opportunity for the reduction of production costs, as this land has, usually, lower overheads and rental prices. However, the results showed an increase in mineral matter and a higher accumulation of nitrogen and phosphorous, in the plants, with the increase of the level of contamination, for the ash content, particularly in the P_{100} and P_{200} level, and in the P_{200}

level, for the nitrogen and phosphorous content. This is particularly evident, knowing that domestic sludge is rich in N, P and in several minerals, thus contributing for the fertilization of the fields, and explaining the increase of the uptake of those nutrients by the plants.

Considering the economic valorisation of the biomass, in terms of outputs, P_{50} and P_{100}, presented the best results, due to their higher productivity (Table 4). Effectively, the amount of cellulose and energy produced, in those fields, per ha, is higher than in P_0 and in P_{200}. Although more ash material and consequently, more residual material should be produced, in those fields. If the production of energy or paper pulp is not the major target, but reuse of domestic sludge and/or, extrapolating, reuse of contaminated land, then P_{200} fields are these that should be considered.

Table 4. Biomass outputs at harvest (on a dry matter basis).

	P_0	P_{50}	P_{100}	P_{200}
Ash [$t.ha^{-1}$]	0.59	0.97	0.97	0.85
Nitrogen [$kg.ha^{-1}$]	19	34	29	36
Phosphorous [$kg.ha^{-1}$]	5.6	7.8	8.1	13.8
Cellulose [$t.ha^{-1}$]	10	16	15	12
Energy output [$GJ.ha^{-1}$]	335	539	512	391

Table 5 shows the heavy metals analysis of the biomass obtained, at harvest, in all the experimental fields, along the three experimental years.

Table 5. Heavy metals content of the biomass at harvest (on a dry matter basis).

	1998/1999				1999/2000				2000/2001			
	P_0	P_{50}	P_{100}	P_{200}	P_0	P_{50}	P_{100}	P_{200}	P_0	P_{50}	P_{100}	P_{200}
Cd [$mg.kg^{-1}$]	0.015	0.036	0.018	0.037	0.004	0.011	0.001	0.003	<0.001	<0.001	<0.001	<0.001
Cu [$mg.kg^{-1}$]	4.13	5.56	4.26	6.24	1.30	1.24	0.94	2.05	0.97	1.48	1.36	1.81
Ni [$mg.kg^{-1}$]	1.24	0.36	1.74	1.18	0.46	0.17	0.14	0.34	0.47	0.33	0.28	0.30
Pb [$mg.kg^{-1}$]	0.54	0.37	0.50	1.01	0.91	0.33	0.14	0.18	0.13	0.05	0.04	0.09
Zn [$mg.kg^{-1}$]	37.8	24.2	42.9	35.9	12.3	12.1	11.1	54.6	24.0	15.8	14.5	17.0
Cr [$mg.kg^{-1}$]	2.10	1.21	2.60	1.59	0.27	0.23	0.08	0.20	0.41	0.34	0.22	0.32

Hg was also determined. Nevertheless this element is not detectable in the digested samples. Results obtained in the first year (1998/99) are significantly higher then on subsequent years. But, no significant differences were observed among the different levels of contamination, for the three experimental years. Table 5 also shows that biomass accumulates more zinc than any other metal, for the several levels of contamination.

Considering the results obtained in this experiment, as there are no significant differences, in several metals content analysed, among the different levels of contamination, the aerial biomass obtained at harvest, could possibly be economically valorised (for example, in the production of energy). Nevertheless, before taking the option of using this type of biomass for energetic purposes (or other), it is necessary to safeguard the environmental interests.

Conclusions

The results obtained leads to the conclusion that application of domestic sludge presents a positive effect, in terms of the productivity. Plants obtained in contaminated fields presented significantly higher productivities than plants cultivated in the fields do not receiving sludge. P_{50} and P_{100} presented significantly higher values.

In relation to the ash, nitrogen and phosphorous contents, results present an increase in mineral matter and a higher accumulation in nitrogen and phosphorous, following the increase in sludge input. But, this increase was not significant. Concerning the different metals determined on aerial biomass, no significant differences were verified among the different levels of contamination. Environmentally, P_{50} and P_{100} are the levels that presented a better behaviour, in terms of the metals contents in the ashes. Biomass obtained in P_{200} fields presented a somewhat higher accumulation in some metals, than plants obtained in less contaminated fields. Thus, is possible the utilisation of the biomass, obtained in those contaminated fields, for example as a biomaterial, not only contributing to an increase in its economical value but also in terms of a sustainable agriculture strategy.

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