ENVIRONMENTAL AND SOCIO-ECONOMIC IMPACT ASSESSMENT OF THE PRODUCTION OF PERENNIAL CROPS WHEN IRRIGATED WITH TREATED WASTEWATERS

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Abstract

The production of energy crops has been presented as a promising alternative to partially replace fossil fuels. Perennial crops are promising because of their high productivity, resistance to low water regimes, and pests. Yet, the need to irrigate biomass during cultivation can cause the depletion of water resources, an environmental constraint in the Mediterranean region, due to water scarcity. In this context, the aim of this work was to evaluate the environmental and socio-economic impact of the production of perennial crops, when irrigated with wastewaters, in order to integrate them into a sustainable agriculture development. Studies conducted at FCT-Universidade Nova de Lisboa indicate that perennials show potential to simultaneously deliver high yields, restore soil properties and promote water quality improvement under wastewater irrigation. To determinate the environmental and socio-economic sustainability, different categories were studied: energy savings, reduction of greenhouse gases, carbon sequestration, emissions to soil, air and water, impact on water and mineral resources, costs savings, employment potential creation and consumers/producers acceptance. Overall results suggest that reuse of wastewater on the production of perennial crops have an advantage over traditional irrigation, namely regarding use of water and mineral resources and costs savings. No effects were observed in terms of energy savings, reduction of greenhouse gases, or carbon sequestration. But the reuse of wastewater still involves much controversy, and not always have social acceptance. In the study, several technical and economic barriers were also addressed, namely those related with the quantity and quality of biomass produced.

1- INTRODUCTION

The irrigation of energy crops with treated wastewaters in water-scarce regions is not new. This approach was developed as an additional stage to remove the wastewater nutrient loads prior to its disposal in the environment and also to save water resources in regions with low water availability. Because agriculture is a major consumer of water worldwide [1] the same technique is also used to irrigate drought tolerant crops that are very efficient in the removal of the constituents present in treated wastewaters. This can promote the creation of crop rotation systems more resilient, adding economic value and social benefits to water-scarce regions like the Mediterranean. The production of drought tolerance crops must be studied and evaluated in terms of environmental, economic and social impacts, in order to integrate them into a sustainable agriculture development. The reuse of treated wastewaters in their irrigation could be a strategy to minimize freshwater abstraction, field fertilization and also energy consumption in the treatment of these types of water. However, treated wastewater reuse for crops irrigation (even when used to irrigate non-food crops), are involved in much controversy and not always have social acceptance. Nevertheless, considering the high consumption of energy for treating wastewater [1], and also the quantity of treated wastewater daily available, and its high nutrient loads, research focus on more sustainable and cheapest methods of depuration of those waters is mandatory, especially in water-scarce regions. Furthermore, this source of water could constitute an economic valuable resource for these regions and not necessarily a negative externality.

From all the crops identified as suitable for combining high biomass production with wastewater treatment, *Arundo donax* and *Miscanthus* spp. are highlighted by several authors as two of the most promising cultures because they are both perennial and well adapted to water-scarce regions, presenting higher soil coverage and high resistant to diseases [2]. Considering *Arundo donax* and *Miscanthus x giganteus* ability for wastewater phytoremediation and nutrients removal, the aim of this work was to evaluate the environmental and socio-economic impact of its production when irrigated with wastewaters, in order to integrate them into a sustainable agriculture development in the Mediterranean region.

2- MATERIALS AND METHODS

In this study, it was assumed that only stems were used as solid fuel. Leaves must be left in the field as they produce large amounts of ash, contributing to field fertilization and carbon sequestration.

To estimate the environmental and socio-economic impact on the production of *Arundo donax* and *Miscanthus x giganteus* irrigated with wastewaters, results obtained in the work of Costa et al. [3] and Lino et al. [4] were the basis for the assessment. In this work, both crops, in pots, were irrigated with three water regimes: 950 mm, 475 mm and 238 mm of treated wastewater. Controls were irrigated with tap water and the same water regimes were used.

For the environmental impact assessment, the study focused on several categories, according to the methodology developed and applied by Biewinga and van der Bijl [5], and Fernando et al. [6]. Energy savings were calculated by subtracting the energy input to the potential energy produced by the combustion of the biomass stems being produced. Energy balance results obtained from the work of Cherubini et al. [7] were used to estimate energy savings. Carbon sequestration (Mg C/ha) was calculated assuming a carbon content of 48.7% for the whole plant [8] and the productivities in pilot fields in Italy [9]. Reduction of greenhouse gases emissions was estimated based on the work of Cherubini et al. [7]. Economic analysis was based in the work of Soldatos et al. [10]. Irrigation costs were assumed to be the same in the control and in wastewater irrigation.

3- RESULTS AND DISCUSSION

3.1- Crop productivity

Perennial crops yields were determined based on the results of Costa et al. [3] and Lino et al. [4]. Comparisons were made with 950 mm control. Results are presented in Figure 1.

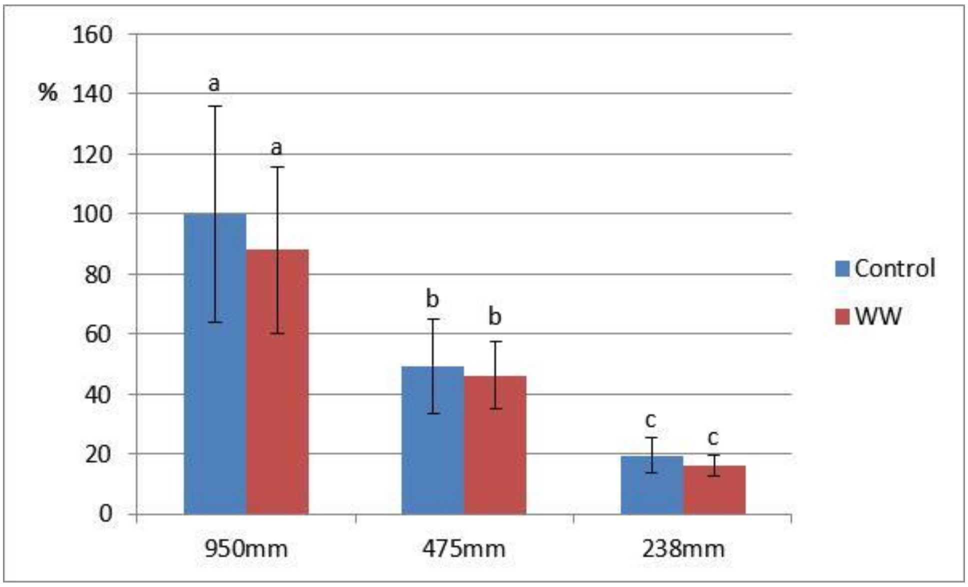

Figure 1: Yield of perennial grasses irrigated with wastewaters compared with the control (%).

According to the results in Figure 1, it is possible to observe that, for the crops in study, there are no statistical significant differences in yields between wastewater irrigation (WW) and tap water irrigation (Control) but yields are directly proportional to different water regimes, i.e., the lower the water provided the lower the yields.

3.2- Energy balance

The energy balance (GJ/ha) estimated for perennial crops irrigated with treated wastewaters is presented in Figure 2. Calculations were made assuming the combustion of stems to produce heat and the use of stems to produce electricity by cogeneration. According to these scenarios, it was estimated that crops obtained through wastewater irrigation can save the same amount of energy produced by crops irrigated with fresh water. Reduced energy savings are obtained when yields obtained are lower due to lower irrigation regimes provided, but still the overall energy balance is positive, indicating that fossil energy can be saved.

3.3- Carbon sequestration

Estimated carbon sequestration (Mg C/ha) is presented in Figure 3. For the estimation of this parameter it was only considered the carbon sequestered by the leaves. This fraction will remain in the soil, increasing organic matter content and improving its quality. The carbon sequestrated by the rhizomes and roots was not considered, meaning that the results presented are underestimated.

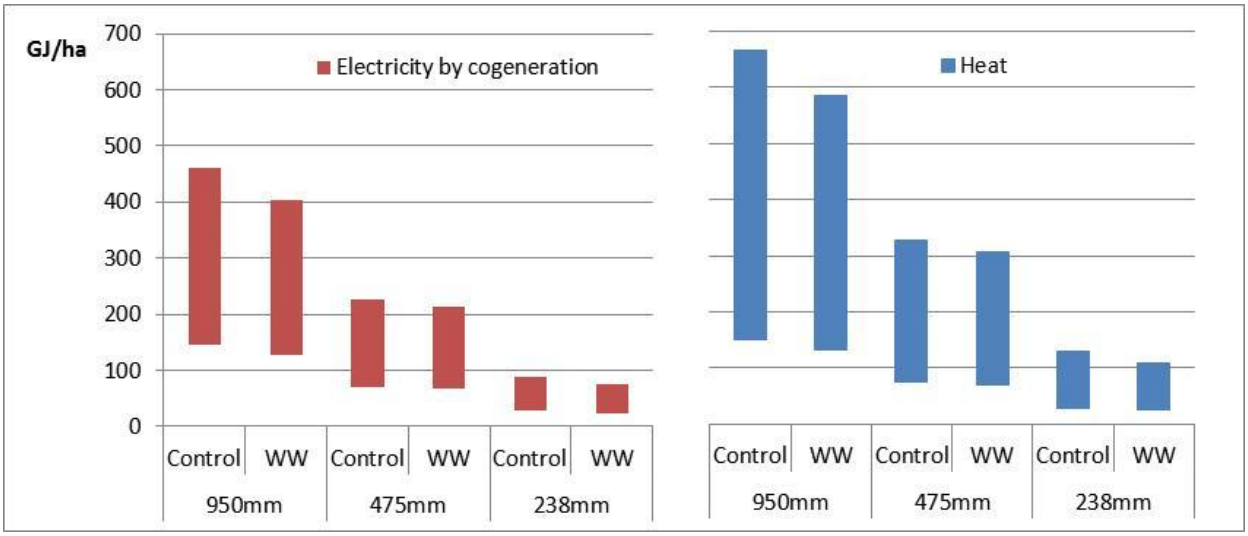

Figure 2: Estimated energy balance (GJ/ha) for perennials production and use.

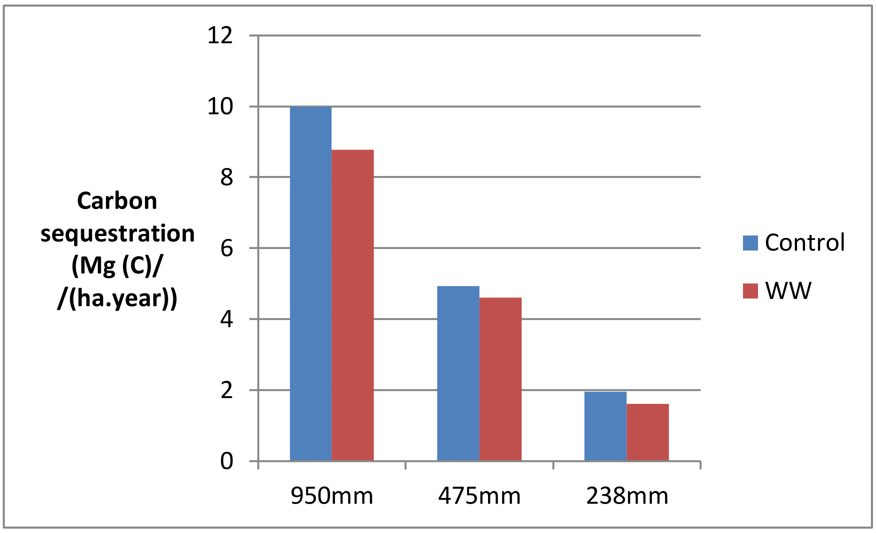

Figure 3: Carbon sequestration (Mg C/(ha.year)) by leaves of perennial grasses and by water regime.

Carbon sequestration in leaves, roots and rhizomes may also improve soil structure and soil aeration, factors that contribute to reduce soil erosion and to control desertification. Carbon sequestered by the stems was not considered because it will be released by combustion for energy production. Carbon sequestration results from Figure 3 are coincident with crops yields presented in Figure 1, which means the higher the yield, more carbon can be sequestered and stored in the soil. No significant differences were observed between fields irrigated with wastewaters and fresh waters, and the lower the amount of water provided the lower the yields and the carbon sequestered.

3.4- Emissions to soil, air and water

Reduction of greenhouse gases emissions (GHG) due to both crops production and use is presented in Figure 4. According to the estimated results, the use of stems as solid fuel is relevant to reduce GHG emissions as the released of CO_2 emissions is counterbalanced by the CO_2 sequestered by biomass in the photosynthetic process. Higher water regimes (and consequently higher yields) represent higher CO_2 savings. No differences were observed due to irrigation with wastewaters.

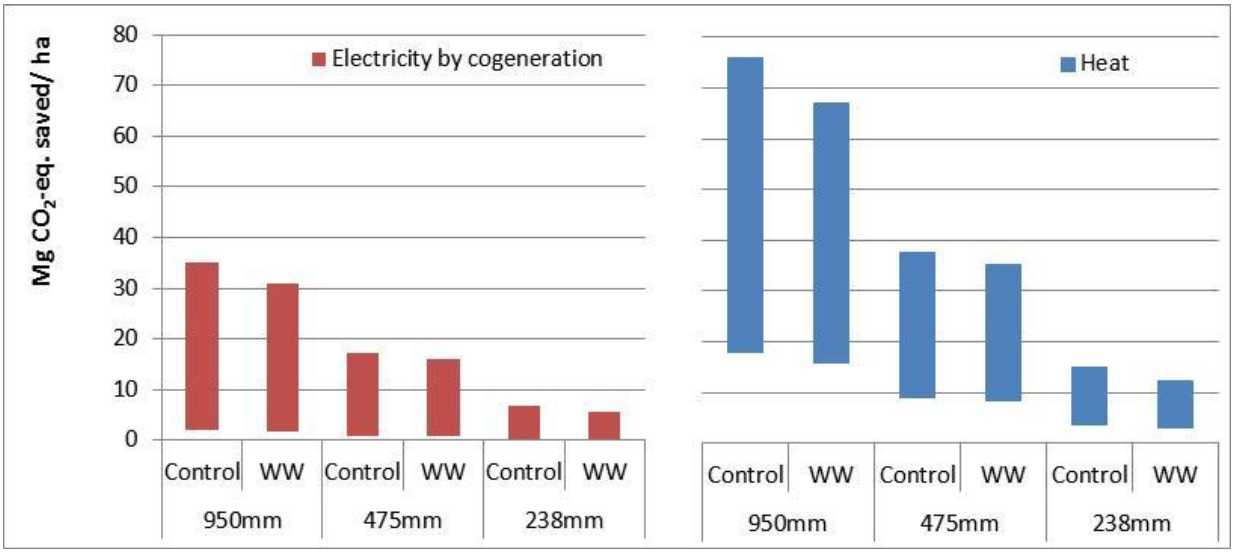

Figure 4: Estimated reduction of greenhouse gases emissions (Mg CO_2eq saved/ha per year) due to perennial grasses production and use.

Nitrogen applied to the soil can contribute to several environmental problems, which includes contribution to acidification, due to the volatilization of ammonia (NH_3) and N oxides (NO_x), contribution to greenhouse effect and ozone depletion, due to denitrification to nitrous oxide (N_2O) and ground and surface waters eutrophication, due to ammonium (NH_4^+) and nitrate (NO_3^-) leaching and runoff [6]. Excess of nitrate in drinking water can also be a threat to human health. NO_x are also emitted during the combustion of the stems [5] (Figure 5).

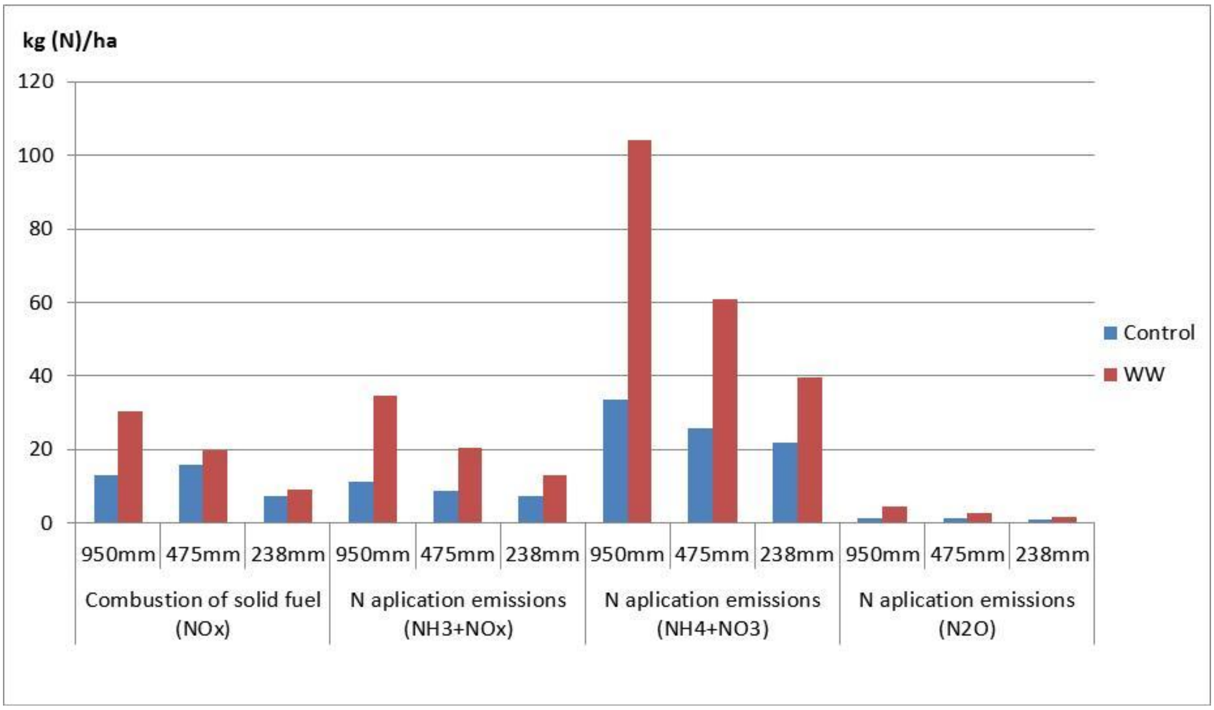

Figure 5: Estimated emissions to air, soil and water derived from N fertilizer and water/wastewater application and from biomass combustion.

Compared to control, wastewater irrigation presents higher N emissions due to higher N application (derived from a wastewater rich in ammonium and nitrate ions). The combustion of solid fuel also presents higher N emissions. This is because higher nitrogen is accumulated in the biomass due to the N richness of the wastewaters. These facts represent an environmental constraint for the irrigation of perennial crop fields with treated wastewaters. Yet, using wastewater in crops irrigation can decrease the amount of N-based nutrients artificially added to the soil, and it contributes to the pollutant load reduction once the soil-biomass system represents a depuration system. The highest share of N emissions are due to the NH_4 and NO_3 leaching and runoff from N application. N_2O emissions due to N application are not significant and represent the lowest share in N emissions. Lowering the amount of water used in the irrigation also reduces the nitrogen emissions pollutant load to air, soil and water.

3.5- Other environmental considerations

Irrigation with wastewaters enables the recycle of nutrients (N, P and K) from this water source, minimize fertilizers applications in soils, reduces the amount of energy and money spent in their extraction from mineral ore reserves and represent also a way to economize freshwater for more noble uses.

According to Costa et al. [3] and Lino et al. [4], 950 mm of freshwater resources can be saved if wastewaters are used in irrigation, contributing to recycling wastewater and its load. This practice is important also for combating the imbalance between the amount of water that falls by precipitation and losses by evapotranspiration (especially in water-scarce regions). It is also possible to save mineral resources, namely 230 kg P_2O_5/ha and 170 kg K_2O/ha [3], if no PK fertilization is added. Use of wastewater minimizes the energy utilized in the extraction, production and transportation of mineral ores as well as the depletion of those mineral resources.

3.6- Economic and social considerations

Profits per ha per year of perennial grasses production and use are presented in Figure 6. Irrigation with wastewaters is more valuable than control in all water regimes if no NPK fertilizers are added in fields irrigated with wastewaters. In fact, wastewater irrigation at 950 mm and at 450 mm is much more interesting than freshwater irrigation because it provides a higher and positive income. Concerning the use of only 238mm of water, the lower yields obtained do not allow to provide a positive income. Moreover, the use of wastewaters in the irrigation of energy crops may represent a viable environmental and economic opportunity as a tertiary treatment.

Energy crops Irrigation with wastewaters can also provide many social benefits to human communities. The reuse of wastewater for agriculture irrigation is still involved in much controversy, and not always have social acceptance, but simultaneously this approach involves new opportunities. Use of wastewaters in the irrigation of non-food crops, contributes to recycling of these liquid wastes, returning them back to environmental systems in a non-harmful way, and thus reducing human and environment exposure to pollutants. Also, the production of biomass for energy or for other applications, when irrigated with wastewaters, reduces the emissions of several pollutants and thus the human exposure to their effects on health and also the environment exposure.

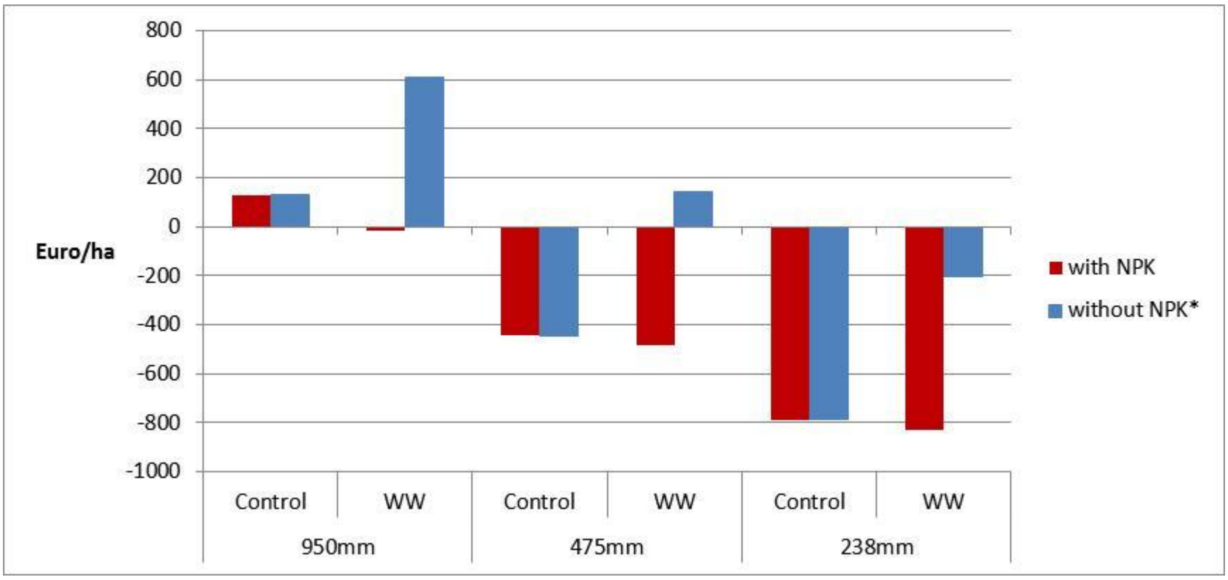

Figure 6: Perennial grasses production and use profit (€/ha, per year) under different types of irrigation. without NPK: control receives NPK but trials irrigated with wastewaters do not receive NPK.*

Energy crops production and use presents also a positive gain in terms of employment in small and medium-size enterprises and on rural areas. The positive influence on employment is also due to the contribution towards avoiding a rural exodus and to the contribution towards a more balanced rural development. Labour requirements per hectare for the production, in the farm, of giant reed is similar to the one showed for *Miscanthus* (9 hours per hectare per year) [5]. Irrigation with wastewaters doesn't represent an increase in agricultural activities but may increase indirect employment, mainly in transport or in the conversion sector when productivities higher than control can be obtained. But, labour requirements for conversion do not vary much, and so, no additional employment is expected with the yield increment.

4- CONCLUSIONS

Irrigation of perennial grasses with wastewaters could be a relevant tool to reduce water and mineral resources consumption and the associated environmental burdens arising from the combustion of fossil fuels. At the same time, it could constitute an opportunity to develop rural areas. This approach may display other environmental benefits, e.g. fossil energy savings, carbon sequestration, and it represent a viable economic opportunity and provide social benefits in Mediterranean regions. Combining wastewater irrigation with biomass production may also contribute to improve the effluents quality, with environmental, economic and social benefits.

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