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Research paper

Are advantages from the partial replacement of corn with second-generation energy crops undermined by climate change? A case study for *giant reed* in northern Italy

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ABSTRACT

Among non-food energy crops, giant reed (*Arundo donax* L.) represents a promising opportunity to reduce the fossil fuel dependency of Mediterranean countries. Nevertheless, the response of this crop to future climate projections is an open issue despite the crucial implications for mid-term planning policies. In this study, we present an exploratory analysis of the climate change impact on giant reed productivity in the Lombardy plain (northern Italy), an area that is currently characterized by intensive fodder corn-based cropping systems, but where corn is expected to be negatively affected by projected changes in thermal and pluviometric regimes. A dedicated simulation environment was developed, by coupling Arungro, a process-based model specific to giant reed, to a database including information on the presence of biogas plants, land use, crop management and distribution, in addition to weather scenarios for current climate and future projections. The baseline climate (1975–1994) was obtained from the European Commission MARS database; the Hadley3 and NCAR realizations of the IPCC AR4 emission scenarios A1B and B1 were used to generate 20-year climate projections centred on 2020 and 2050. Spatially distributed simulations were run at a sub-regional scale in areas selected according to their attractiveness for investments and low risk of competition between feed and no-feed crop destinations. The results indicate that an increased local suitability of giant reed in future climate projections is expected in terms of biomass production (+20% in 2020 for all scenarios and +30% in 2050 for Hadley-A1B) and the economic and environmental sustainability of related cropping systems.

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1. Introduction

Climate change threatens agricultural production worldwide because of rising temperatures, unfavourable rainfall distribution and increasing frequency of extreme weather events [1,2] in many regions. Although the extent of changes in crop productivity is still an open issue [3,4], corn is expected to be particularly affected in many regions [5–7]. This crop is one of the most important in the Lombardy plain (northern Italy), an area that is characterized by intensive agriculture and livestock farming. Future projections for corn in the region indicate a decrease in productivity mainly because of shortening the grain filling phase [7] and because of unfavourable rainfall distribution [8,9]. The latter would further reduce the extent of the few areas where corn is currently rainfed and, in general, would increase the frequency of irrigation events to avoid exposing the crop to water stress during crucial phenological phases (e.g., flowering and pollination) [10,11].

These projections are generating an increasing demand for mid-term analyses of the economic and social sustainability of current production systems; in this context, process-based biophysical models are the most suitable tools for estimating the potential impacts of climate change on the productivity of agricultural systems and to support local stakeholders and policy makers in defining effective and site-specific adaptation strategies [6,12].

Corn-based cropping systems will likely experience an increase in production costs, given the increased request of inputs, with water playing a key role [2,13] because of the exacerbation of the competition between countryside and urban areas for water use during the summer months. From this perspective, some farmers are testing alternative business models with a special focus on the agrofuel sector. Indeed, as established in the Renewable Energy Directive [14], Italy should increase, by up to 17%, the share of primary energy produced by renewable energy sources by 2020. Giant reed (*Arundo donax* L.) has recently been included in the list of renewable energy sources that are eligible for subsidies through the Ministerial Decree of 6 July 2012 [15]. As a result, alternative giant reed-based supply chains and technologies have been studied and tested at a regional level, in particular, focusing on (i) biogas production via anaerobic digestion, (ii) combustion targeting the production of electric and thermal energy, and (iii) production of ethanol and biodiesel from anaerobic fermentation. Moreover, this crop demonstrated a high potential for the extraction of compounds of interest for the chemical and pharmaceutical industries (i.e., cellulose, alkaloids) and for phytoremediation because of its ability to absorb nitrates, phosphates and other pollutants. Giant reed is a perennial invasive grass that showed a tolerance to a broad spectrum of soil types [16] and exceptional biomass accumulation rates even with low agronomic inputs [17,18]. These features make this species suitable for marginal areas where the cultivation of other species is not advantageous. Giant reed, therefore, can be considered to be a good solution to the ethical concerns dealing with competition for land between food (or feed) and energy crops. The evaluation of the potential productivity of giant reed in Italian environments [e.g., Refs. [19,20]] indicated the possibility of achieving values of attainable energy per hectare higher than those obtained with corn [21]; this is leading some of the farmers who are already growing energy crops in Lombardy to convert portions of their land from corn to giant reed. Concerning biogas production, giant reed is commonly ensiled by adopting the same techniques that are used for corn, which represents the main energy crop for bio-methane production in the region. The crop is harvested by chopping the stalks when the average dry matter of the aboveground biomass is within a range of 30–38%, and it does not require any fermentation-based pretreatment. The methane yield from giant reed anaerobic digestion ranges from 7.17 $dam^3\ ha^{-1}\ y^{-1}$ to 11.28 $dam^3\ ha^{-1}\ y^{-1}$ (all gas volumes measured at standard conditions of 298 K and 101.3 kPa), with double cutting leading to the highest biochemical methane potential and the most suitable digestion kinetics [21,22].

The aims of this study were (i) to estimate the impact of climate change on giant reed productivity in the Lombardy plain and (ii) to evaluate the opportunity of changes in land use from corn to giant reed by analysing related economic and environmental issues in the medium-long term.

2. Materials and methods

2.1. The study area

Lombardy is one of the most industrialised and intensively cultivated European regions, with a gross domestic product (GDP) equal to 21.1% of the Italian GDP and 2.6% of the European GDP. Agriculture plays a key role in the regional economy, and it is characterized by high productivity (a GDP/work unit is 30% higher than the EU-27 average), technology and quality of productions; such productions are responsible for 11.4% of the national agricultural value [9]. The regional utilized agricultural area (UAA) is mainly located in the watered Po plain (72,000 km^2 distributed between 44°50′N/8°40′E and 45°50′N/11°80′E) and is characterized by an overall temperate humid climate and by a pronounced heterogeneity in pedoclimatic conditions [23]. Most cropping systems target cereal and forage production (mainly corn, which covers approximately 30% of regional UAA, wheat, rice and alfalfa) to support the intensive livestock farming of pigs (4,639,000 heads), poultry (19,988,000 heads) and cattle (1,299,500 heads, of which 471,200 are dairy heads). In this context, livestock wastes represent the main substrate for bioenergy production in the region, which rely on 361 operating biogas plants accounting for 282 MW of total installed electric power. Fifty percent of the average digester diet is represented by liquid manure, whereas shares of 25%, 20% and 5% are a result of the use of (i) corn silage, (ii) industrial by-products (i.e., glycerine and vegetable oils) and organic urban waste and (iii) winter cereal silage, respectively [9]. Ninety-six percent of the total regional plants are characterized by a nominal power class up to 0.999 MW, corresponding to the maximum threshold for obtaining public funding for electricity production from renewable sources [24]. Given the strict European regulations for nitrogen loads, biogas plants also represent a solution for limiting the negative externalities from disposal of livestock manures, such as groundwater nitrate pollution [25].