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Competition between food, feed, and (bio)fuel: A supply-side model based assessment at the European scale

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ABSTRACT

This paper aims at estimating the perennial crop potential regarding uses like bio-fuels instead of food or feed ones. A perennial yearly harvested crop, namely the miscanthus, is integrated in the European agricultural supply AROPAj model. That requires the knowledge of its yield growth function, with a yield potential over time statistically adjusted to the yield of traditional crops. This allows us to estimate the cycle length, the average yearly yield and the discounted cost through the Faustmann rule adapted to the case of a perennial yearly harvested crop. The analysis covers a large part of the European Union and provides a land use change assessment estimated when the miscanthus yield potential varies. We show that the cellulosic biofuels compete with food and feed production as well, by the way of complex interactions and trades-off between marketed concentrates and on-farm consumed crops related to animal breeding. The "food, feed and fuels" analysis is widened by a spatial downscaling analysis applied to a series of French regions which differ in terms of farming systems. At the European scale, cereals and oilseeds areas are relatively more affected when miscanthus reaches high levels of performance. In spite of livestock inertia, there is a significant change in terms of feed share between on-farm consumed cereals and marketed concentrates. Regarding greenhouse gas emissions, an increasing miscanthus yield potential leads to a considerable decrease in N_2O losses and to a slight abatement of CH_4 emissions.

1. Introduction

Biofuels are increasingly being considered as a sustainable but controversial energy source when compared with the fossil carbon sources. Relying on food crops such as wheat, maize, rapeseed or corn, the first generation (1G) biofuel has the potential to compete with food production for arable land. Several studies have already shown the expected direct and indirect land use changes (LUC and ILUC) caused by the implementation of biofuel policies in the European Union (EU) (Gabrielle et al., 2014; Beckman et al., 2011; Taheripour et al., 2011; Rosegrant et al., 2008; Searchinger et al., 2008).

A heated "food vs. fuel" debate has therefore emerged, in particularly after the food crisis of 2007 and 2008, creating the fear of an enormous and use competition led by the enhancement of the 1G biofuel production. In parallel, other studies show that there are considerable non-food cellulosic resources available for an expansion of biomass production in Europe without significantly affecting the supply of food crops. Such a second generation (2G) feedstock could have less environmental impact (low fertilizer consumption) and higher per hectare yield than food crops. Although 2G resources are expected not to compete with food production when provided by forestry, agriculture may supply biomass such as herbaceous grasses (e.g., miscanthus, switchgrass) or wood from short rotation (SR) plantations (e.g., willow and poplar). Cellulosic biofuels from these sources will certainly continue to compete with food and feed supply chains for agricultural land.

The land use consequences of energy crop production have recently been the focal point of many debates and research studies. Only few attempts have been made to estimate these changes for the 2G feedstocks. Several studies have concluded that dedicated 2G energy crops can be grown on marginal lands without imposing a major impact on cropland (Taheripour et al., 2011; Cai et al., 2011). These papers simply assume that these marginal lands have low opportunity costs. Domestic and international land use (LU) impacts of the US cellulosic biofuel production have been evaluated by the US Environmental Protection Agency (EPA). For this purpose, two partial equilibrium models FASOM and FAPRI were used. The results show that producing ethanol from switchgrass will increase global cropland areas and will curb acreages of US soybeans, wheat, hay, and other crops, and reduce the direct emissions related to decreasing traditional crop areas.

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Gurgel et al. (2008) investigated the potential production and implications of a global 2G biofuels industry by using the MIT Emissions Prediction and Policy Analysis (EPPA) model. The authors showed that the development of such industry leads to a potential intensification of production, especially on pasture and grassland. In a preliminary work, Taheripour et al. (2011) used an economy-wide CGE model based on a modelling framework for Global Trade Analysis Project (GTAP) to assess the land use consequences of producing biofuels from miscanthus and switchgrass. Their results suggest that cultivating these perennial crops competes with cropland and pasture. Khanna et al. (2011) studied the competition for land among perennial crops, i.e., miscanthus and switchgrass, food/feed and livestock production in the US, by using a dynamic, multimarket equilibrium, nonlinear mathematical programming model. They found that miscanthus would be the most important bioenergy source in terms of both production and land allocation.

More recently, Stürmer et al. (2012) assessed the bio-physical and economic production potentials of 2G energy crops and explore the trade-off between food, feed and energy crop production on arable lands in Austria. Their results indicated that the accession of SR poplar plantations can displace several food and feed crops, mainly corn, wheat and grasses. Supporting 2G feedstock may increase the LUC between poplar and grasslands, which decreases the feed production.

The impacts of producing cellulosic biofuels from dedicated energy crops go beyond agricultural activities and influence environmental outputs at local, regional and national scales. In this article, we make an attempt to assess the trade-offs between food, feed and (bio)fuel production at the European scale, by emphasizing the interactions among the cultivation of a lignocellulosic biomass, i.e. miscanthus, and its joint implications on agricultural activities and environmental outputs. More precisely, we analyze the spatial distribution of the marginal value of land over Europe, considering that farm agricultural land is limited. Based on a linear mathematical approach, we identify the areas that are likely to be converted into miscanthus.

By taking into account the likely LUC, we point up the changes in terms of feed share between on-farm consumed cereals and marketed concentrates. Finally, we estimate the relationship between cultivating miscanthus and the abatement of CH_4 and nitrous oxide N_2O. Viewed at different scales, our analysis focuses on the controversy of LUC, extending the food vs. fuel competition to the feed side. Given the complexity of these impacts, we use the AROPAj model to highlight them. AROPAj is a static (single-year period) mathematical programming model that simulates European agricultural supply. Regarding the introduction of a perennial crop in this model, we develop a two-step procedure to feed the model with the appropriate information. The first step is devoted to the selection of a continuous time–yield function, which is correlated to a control plant yield. The second step is based on a Faustmann dynamic approach aiming at the estimation of the rotation duration, the average yield and the discounted annual costs of the perennial crop. The paper is organized as follows. Section 2 describes the modelling chain, focusing on the introduction of a perennial activity in the static short term model. Section 3 presents impacts emerging from the increasing miscanthus potential in terms of land use over the EU.

2. The modelling framework

In this section, we first describe the agricultural supply model used in our analysis. Then, we explain the introduction of a perennial crop (miscanthus) in a one year period model.

2.1. The agricultural supply side model

The AROPAj model, which is a one-year period mathematical programming model, covers the EU by way of a large set of representative farm groups (see Galko and Jayet, 2011; for a description of the model version used in this paper). Based on a micro-economic approach (Arfini, 2001), the model describes the annual supply choices of the European farmers in terms of surface allocation, crop, vegetable and animal production, and on-farm consumption, among other numerous modeled activities. AROPAj is a supply side model, and farmers are considered to be price takers. Farmers are clustered into farm groups according to the techno-economic orientations within each region, the economic size and the altitude class. Each farm group which is statistically representative of the different production systems is assumed to select the supply level and input demand in order to maximize its total gross margin. The feasible production set is limited by several constraints: land endowment, animal demography, livestock limit, animal feeding, and Common Agricultural Policy (CAP) requisites including milk and sugar quotas. The model covers the EU-15 by dividing it into 101 regions and 1074 representative farm groups. The model's results can be aggregated at the regional, national, and European scales. The farm groups are derived from a version of the model that allows for their spatial distribution at a fine level. (i.e., the V2 version, Jayet et al., 2015).

The model represents a large part of agricultural activities: crop production (cereals, oilseeds, potatoes, sugar beet and fodders), grasslands, fallow land, animal production (bovine, goat and sheep herds, poultry and pigs), on farm consumption, purchased animal feed and joint production and pollution such as CH_4 and N_2O emissions (see De Cara et al., 2005; for more description). All these outputs are geographically distributed at fine scale. The spatialization process is based on spatial econometric method developed by by Chakir (2009). It consists in linking cropping activities to pedoclimatic characteristics at a very fine geographical resolution level. An application is presented by Cantelaube et al. (2012), aiming at calculating the probabilistic contribution of any AROPAj farm group to the agricultural activities at any spatial unit cell. That allows us to distribute AROPAj outputs across geographical areas at a fine resolution level.

2.2. Introduction of miscanthus into the AROPAj model

The lignocellulosic crops are considered as alternatives to first generation resources in the bioenergy sector. These crops belong mainly to perennial crop species. They require less fertilizers and produce more dry matter and consequently more energy, and reduce greenhouse gas emissions more than annual cropping system devoted to first generation biofuels. The cellulose in these perennial crops represents a vast and renewable source of biomass feedstock for conversion into the second generation biofuel (McLaughlin et al., 2002). Among these second generation bioenergy crops, *Miscanthus* × *Giganteus* is emblematic. It is a perennial rhizomatous grass which has its origins in the tropics and subtropics, but different species are found throughout a wide climatic range in East Asia (Greef and Deuter, 1993). The remarkable adaptability of miscanthus to different environments (Numata, 1974) makes it suitable for establishment and distribution under a wide range of European and North American climatic conditions (Lewandowski et al., 2000). Physiologically, miscanthus, like maize, belongs to C_4 species, fixing carbon by multiple metabolic pathways with a high water use efficiency. Miscanthus roots can reach 2-m depth, which can provide a good protection against soil erosion. It therefore involves decreasing risk of ground water pollution by pesticides and nitrates.