Perennial crops in European farming systems and land use change: a model assessment

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Summary

The aim of this paper is to estimate the perennial crop potential regarding new uses like second generation biofuels. We focus on the introduction of a perennial yearly harvested crop, namely the miscanthus, in European agricultural short term supply model - AROPAj. Inserting this crop in the model requires the determination of two elements: a) the yield growth function which is calibrated and based on the few available data and adjusted to the yield of traditional crops, and b) the discounted cost, which is calculated through the "Faustmann" rule used in the case of a perennial yearly harvested crop. We estimate first the potential yield of miscanthus at the subregional level (i.e. the "farm group" level), and we parametrize the potential rate for simulations. The analysis covers a large part of the European Union and provides a land use change assessment estimated when the miscanthus yield potential varies. The model appears to be able to capture some complex land use change involving croplands and grasslands when a perennial competitive crop is introduced, beyond the usual competition between food crops and energy crops. The major result is summarized by the common evolution of substitution of croplands and grasslands by the perennial crop when its potential increases.

Keywords: Bio-economic model; mathematical linear programming; European Union; perennial bioenergy crops; grasslands; croplands, land use change.

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1 Introduction

Originating from energy crops, biofuels are increasingly being considered as a sustainable -but controversial- energy source when compared with the fossil carbon sources. Interrelated factors have led to an increased demand for this green energy. These factors include growing energy demand due to resource depletion and instability in oil producing regions, recent technological breakthroughs in agriculture and concerns over environmental impacts such as climate change [15]. Biofuel development is in addition driven by the rural development, the job creation [20], the seek of energy self-sufficiency and of competitiveness improvement [8, 9]. Two biofuel generations have been developed: the conventional biofuels which are produced from food crops (e.g. corn and soybeans), and the cellulosic biofuels that are made out of perennial grasses (e.g. Miscanthus, Switchgrass) and Short Rotation Coppice (SRC) (e.g. willow and poplar).

According to the EU's Renewable Energy Directive (2009/28), each member State is committed to reach a mandatory 10% target of energy from renewable sources in transport by 2020 [10]. To achieve this target, agricultural land should be allocated to crops devoted to bioenergy production, leading at the same time to direct and indirect land use changes at the global level. The land use consequences of such a policy have recently been the focal point of many debates and research studies. However most of these studies focused on the land use changes due to first generation biofuels (e.g. [4], [29],[11],[30]) and only few attempts have been made to estimate these changes for the second generation biofuels.

While the option of using "non-food" feedstocks has been touted as one of the advantages of cellulosic ethanol production, only the use of waste streams as a biomass source truly eliminates competition with food production. Cellulosic ethanol from many biomass sources will continue to compete with food and feed supply chains for agricultural land.

More recently, emissions assessments for alternative biofuels has been released by the United States Environmental Protection Agency (EPA). These assessments are concentrating on ethanol produced from corn stover and switchgrass [1]. Two partial equilibrium models FASOM and FARPRI were used to evaluate domestic and international land use impacts of the US cellulosic biofuel targets. 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.

Gurgel, Reilly and Paltsev [14] investigated the potential production and implications of a global 2^{nd} generation biofuels' industry. They developed alternative approaches aiming at introducing land as an economic factor input, in value and physical terms, into a computable general equilibrium (CGE) model, known as the MIT Emissions Prediction and Policy Analysis (EPPA) model. The authors modeled the land conversion from natural areas to agricultural use in two different ways: a) they introduced a land supply elasticity based on observed land supply responses, and b) they consider only the direct cost of conversion. These approaches do result in large differences in patterns of land use. Indeed, the version with the land supply elasticity allows much less conversion of land from natural areas, forcing intensification of production, especially on pasture and grazing land, whereas the pure conversion cost model led to significant deforestation.

Several studies have concluded that dedicated energy crops can be grown on marginal lands without imposing a major impact on cropland [11] [33]. These papers simply assume that these marginal lands have no opportunity costs. However, producing lignocellulosic crops for significant volumes of biofuels could increase the opportunity cost of land because that leads farmers to convert their marginal lands to produce these crops or produce them on their existing active croplands. This will alter the supply of agricultural commodities

which leads to a major changes in markets of animal feed, and livestock products.
In this paper, we discuss the interactions among the cultivation of a lignocellulosic biomass, i.e. miscanthus, and its joint implications on agricultural activities. Given the complexity of these impacts, we undertake the use of the AROPAj model to highlight them. The AROPAj model is a static mathematical programming model devoted to simulate the European agricultural supply. Regarding the introduction of perennial crop in a one-year period 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, whereas the average yield is correlated to a control plant yield. The second step is a computation step based on a Faustmann dynamic approach aiming at the estimation of the rotation duration, the average yield and the discounted annual costs. The paper is organized as follows. Section 2 describes the modeling 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 term of land use over the EU.

2 Methodology

In this section, we first describe the agricultural supply model used in our analysis. Then, we detail the different steps of 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 European Union by way of a large set of representative farm groups (see [12] for a description of the version used in this paper). It belongs to a class of models based on a micro-economic approach [2]. It describes the annual supply choices of the European farmers in terms of surface allocation, opportunity costs of land, vegetable and animal production, and on-farm consumption, among other numerous modeled activities. 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 the 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 AROPAj model has been used to study the successive reforms of the CAP [16], [12], including the 2003 Luxembourg reform in which many of the direct payments that were linked to production are decoupled and instead delivered in the form of an area payment. Different model versions were developed among them are the V_2 covering the European Union (EU) - 15, and V_3 version covering EU - 25. Results in this paper which are obtained from V_2 can be aggregated at regional, national and European scales (101 regions divided into 1074 representative farm groups). The model represents a large part of the used agricultural area devoted to "grandes cultures" (soft wheat,durum wheat, barley, corn, rice, oats, rye, other cereals, rapeseed,sunflower, soybeans, potatoes, sugar beet, peas, other proteins), fodders, grasslands, animal productions (bovine, goat and sheep herds, poultry and pigs), on farm consumption, purchased animal feed, and opportunity cost of land.

2.2 Steps of the introduction of Miscanthus into the AROPAj model

The lignocellulosic crops are considered as the future of the bioenergy industry. These crops belong mainly to perennial crop species. They require fewer inputs, produce more dry matter and consequently more energy, and reduce greenhouse gas emissions further 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 [24]. Among these second generation bioenergy crops, *Miscanthus x Giganteus* [1] has been chosen. 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 [13]. The remarkable adaptability of miscanthus to different environments [27] makes it suitable for establishment and distribution under a wide range of European and North American climatic conditions [21]. Physiologically, miscanthus, like maize, belongs to C_4 species, fixing carbon by multiple metabolic path-ways with a high water use efficiency [19, 26]. Miscanthus roots can reach 2-meter depth, which can provide a good protection against soil erosion. Even though its high biomass yield potential, this crop requires low input level and therefore involves decreasing risk of ground water pollution by pesticides and nitrates. Field trials have shown the high biomass yield potential, i.e. 15 to 20 tonnes dry matter per hectare, in comparison to other herbaceous crops [7, 17, 21].

For the introduction of miscanthus in the model, two main elements should be calculated, i.e. the average annual yield denoted hereafter by y^* and the discounted annual cost for each farm group.

2.2.1 Adjustment of the generic growth function

The miscanthus growth model is based on research conducted by Miguez et al. (2008) [25], Clifton-Brown et al. (2007) [6], and Christian et al. (2008) [5]. Let us denote the maximum biomass yield by a, the inflection point in which biomass yield reaches a half of the maximum biomass yield by b, the spreading parameter by c, and the attenuation coefficient by d. The model is given by the following equation describing the discrete annual yield $y(t)$ evolution inside one rotation :

$$y(t) = [a/(1 + \exp((b - t)/c) - a/(1 + \exp(b/c))] \exp(-d\ t) \tag{1}$$

In order to introduce miscanthus in the AROPAj model, we need estimates of its yield at the farm group level. However, miscanthus has been quite recently introduced in France, and information about the yield for the full rotation period (expectedly greater than 15 years) is partial (only for the early years inside one cycle) -or completely lacking. We assumed that miscanthus yield increases with the quality of the land, like wheat does as a traditional crop exist in the majority of AROPAj farm groups.Indeed, we adjust the average regional yield of miscanthus to the average regional yield of cereals (wheat and maize). Regional miscanthus yield data are provided by Beale et Long (1995) [3], Kahle et al (2001) [18], Lewandowski et al (2003) [22], Mantineo et al (2009) [23], Tayot et al (1995) [31], and Vleesshouwers (1998) [32]. Cereal yields are based on the European data provided by the Farm Accounting Data Network (FADN), on which the calibration of AROPAj model is based.

[1] Miscanthus x Giganteus is a sterile hybrid between *M. Sinensis* and *M.Sacchariflorus*.

2.2.2 The Net Present Value as intertemporal objective

We suppose that miscanthus plantations are typically grown as even-aged monoculture. We assume that long run production follows an infinite succession of T-year cycles, assuming T to be constant. Prices and costs are assumed to rise continuously upon time at a yearly rate of 1.5% (denoted by α). The discount rate δ is assumed to be 5%. Rotation cost (C_0) is paid off over each T cycle duration in an infinite sequence as established by the Faustmann's criterion (beginning at the year 1). Its present value is assumed to be 3000 €/ha, including activities or operations such as rhizome purchase, planting, cultivation, herbicides for a weed control. Annual production costs (c) appear at the end of the second year of the cycle and should be paid at each $T-1$ year. They correspond to variable costs and include expenses dedicated to fertilization, weed control, and harvest. The estimated value is 400 €/ha/year. All data are acquired from experts.

We consider that the crop is harvested annually. At year t, gross margin (GM) is obtained by multiplying the harvested miscanthus yield ($y(t)$) in tons of dry matter (tDM) corrected by an adjustment factor (ϵ), by the price (p) provided by *Bical Biomasse France (BBF)* at 70 € /tDM, minus the variable costs i.e., $GM(t) = p * \epsilon * y(t) - c$. The NPV of miscanthus production is obtained by maximizing the discounted profit in an infinite sequence, at time $t = 1$. Therefore, the discounted value of the net income is equal to

$$NPV(t) = [-C_0 + \sum_{t=2}^{T} GM(t) \ \exp(-(\alpha+\delta)\ t))] \ / \ (1 - \exp(-\delta \ T)) \qquad (2)$$

Realized for any farm group of AROPAj model, this computation allows us to deduce the average annual yield y^* and the discounted annual cost c^*.

2.3 Scenarios

The baseline scenario corresponds to the CAP post 2007 (i.e. the "Luxembourg reform") when miscanthus is not still introduced. The tested scenarios correspond to the introduction of miscanthus with 10 levels of yield potential. Indeed, a recorded level of 30 tDM/ha occurs in some areas, which is Highly optimistic. We proceed therefore to a homogeneous reduction of miscanthus yield from 0 to 100% by 10% step over all farm groups. The rate of reduced potential is denoted by $POTEN$.
We suppose that the part of the farm group UAA devoted to miscanthus does not exceed 20%.
The livestock adjustment is limited to the range $[-15, +15]$% of its initial level estimated thanks to FADN data.

3 Results

This section delivers estimates of the impacts due to the introduction of miscanthus in the AROPAj model. First we discuss the spatial distribution of miscanthus delivered at the regional level over Europe. Then we focus on land use changes and associated impacts.

3.1 The spatial distribution of miscanthus

Mapped examples of the different scenarios are presented on Figure 3, for 4 values of the reduced yield potential (30%, 40%, 70% and 80%).[2] We have to note that maps deliver information related to the part of the regional UAA considered in the AROPAj model, leading the regions to be colored' homogeneously. In all scenarios, miscanthus production is relatively strongly concentrated, because of the high interest for bio-transformation plans and growing biofuel industry. When its yield potential is low, miscanthus can be essentially planted in the North and in the center of Europe. When yields increase, miscanthus may attain 15 % of the UAA, and may even flood the south of some European countries such as England, Italy, France, Spain and Portugal. In the most favorable scenario among the four ones, high yield levels are mainly recorded in the North and Central European regions where large quantity of water is available.

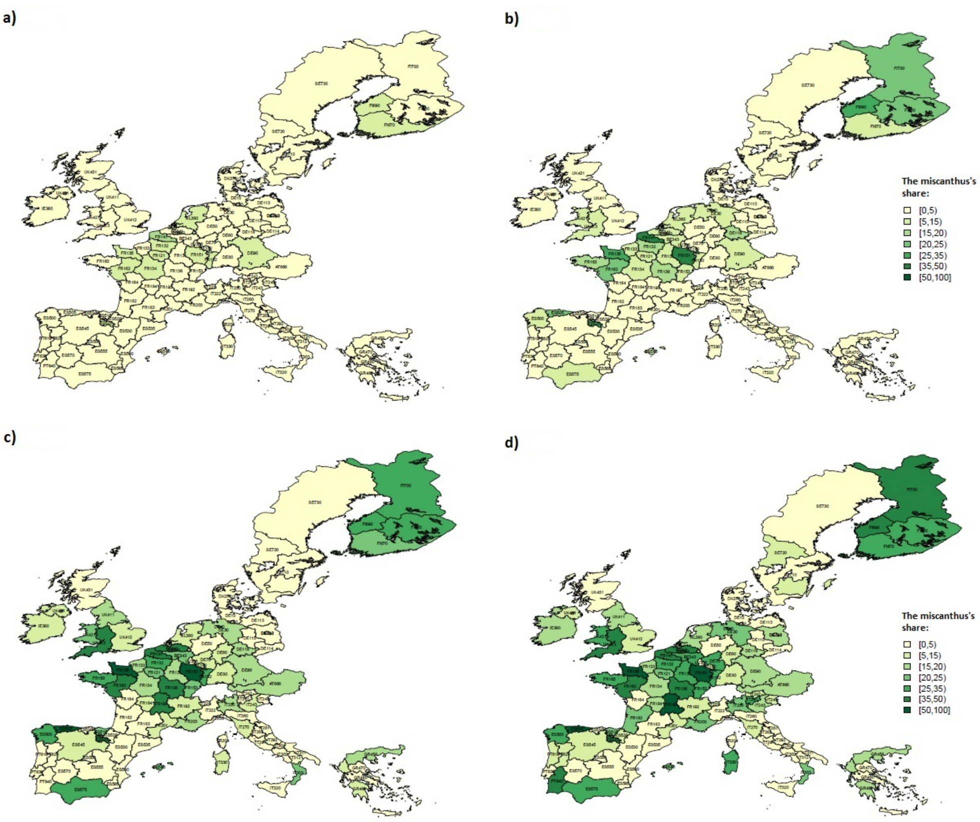

Figure 1: Estimated regional part of the UAA devoted for miscanthus over the EU-15 in the 4 following scenarios: a) $POTEN = 30\%$, b) $POTEN = 40\%$, c) $POTEN = 70\%$, d) $POTEN = 80\%$

[2] The 100% level appears to be more or less not realistic in terms of yields occuring in some regions.

3.2 Land use changes due to the insertion of miscanthus

Significant expansion of cellulosic biofuel production will require a significant part of land to be dedicated to the cultivation of energy crops. Actually, marginal areas and grasslands are considered as potential areas for biomass production, starting from the point of view that poor lands are eligible for new crops. But this point contradicts the fact that high crop potential usually exists on the most productive lands, and consequently the competition occurs on these lands. In the same time, grasslands can offer eligible lands for perennial crops when animal productions appear as less and less profitable.

As shown on Table 1, when the miscanthus is progressively introduced (with increasing yield potential), crops and grasslands are reduced at the same rate. Regarding the land use change among activities, their relative evolution is also interesting. When the average miscanthus yield is low (i.e. $POTEN = 30\%$), grasslands decrease by 0.3% (Figure 4). When the miscanthus potential increases, grasslands are slowly but continuously falling untill 10.7%; this is also the case for fallow lands (which are considered like abandoned areas in the AROPAj model), from 0.45% when the potential is low, untill 20.6% when it is high. When the yield of miscanthus increases, we notice a significant decrease in

	Without	With Miscanthus								
$POTEN =$	0	20%	30%	40%	50%	60%	70%	80%	90%	100%
Miscanthus	0	0.0	0.3	1.4	4.7	8.8	10.8	13.1	14.0	15.3
Cereals	38.7	38.7	38.6	38.1	36.6	34.7	33.8	32.7	32.4	31.8
Sugarbeet	3.0	3.0	3.0	3.0	3.0	2.8	2.8	2.8	2.7	2.7
Oilseeds&Proteins	6.0	6.0	6.0	5.9	5.7	5.3	5.1	5.0	4.9	4.9
Potatoes	3.6	3.6	3.6	3.6	3.5	3.4	3.3	3.3	3.2	3.1
Fodders	11.0	11.0	11.0	11.0	10.5	10.4	10.1	9.9	9.8	9.6
Fallows	10.2	10.2	10.2	9.7	9.5	8.8	8.5	8.3	8.2	8.1
Grassland	27.4	27.4	27.3	27.2	26.6	25.8	25.5	24.9	24.7	24.5

Table 1: Share of land among major groups of agricultural activities (% UAA) when miscanthus yield potential is increasing - estimates provided by the AROPAj model.

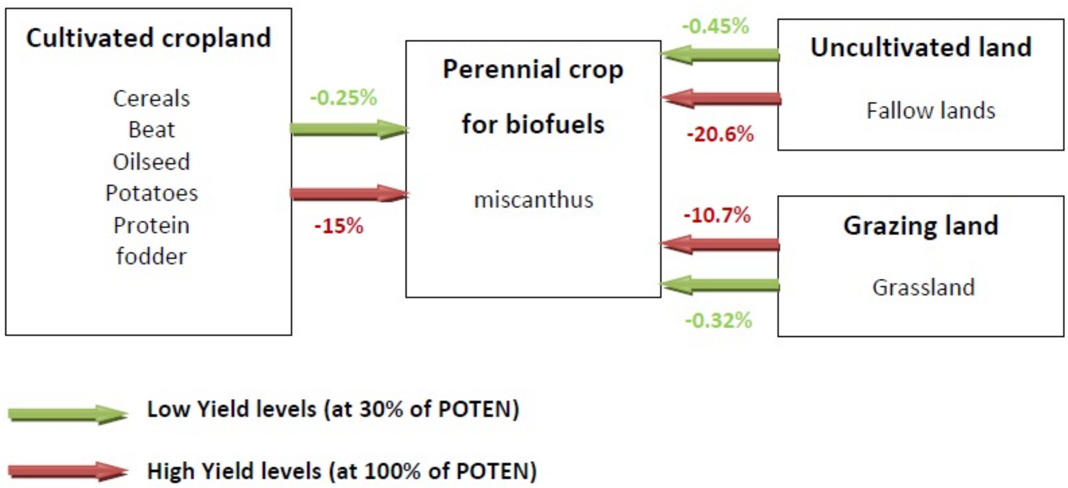

Figure 2: Global European land use change when miscanthus potential changes.

the cropland areas. For instance, when the average annual miscanthus yield reaches its full potential (as estimated by our method), areas devoted to oilseeds and cereals decrease sorely by 20% and 18%, respectively. In the same time, fodders and grasslands decrease by 12% and 11% respectively.

3.3 Impacts on animal activities

The decrease in cropland and grassland areas represents the replacement of animal and feed production by biomass energy production. As shown by Figure 3, high miscanthus yield leads grasslands significantly to decrease and that induces a reduction of livestock. The double change in land use and in livestock leads to dramatic change of feed. Figure 4 provides the change of on-farm cereals and purchased concentrates when the miscanthus potential is increasing. In spite of the livestock inertia, it is clear that high miscanthus potential could significantly affect the feed market.

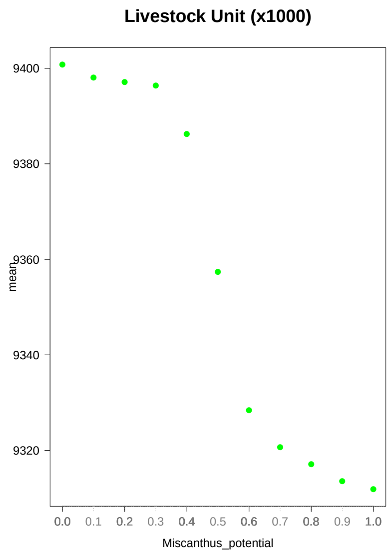

Figure 3: Livestock evolution as a consequence of the increasing in miscanthus potential - on-farm cereals and purchased concentrates (1000 LU).

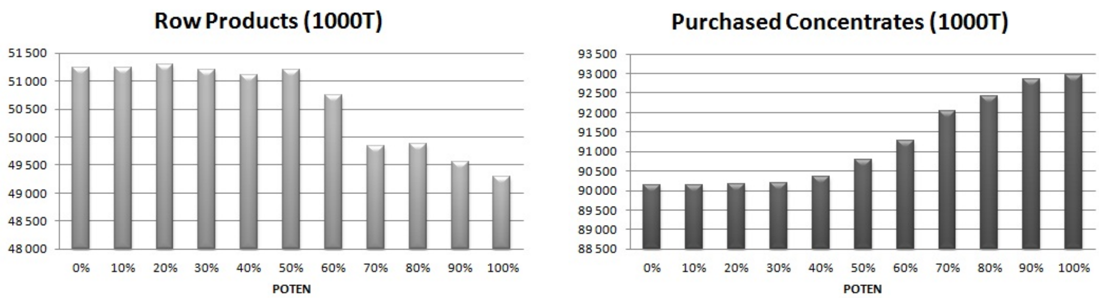

Figure 4: Animal feed evolution as a consequence of the increase in miscanthus potential.

3.4 Land Use Change Costs

The substitution of annual crops by perennial lignocellulosic plantations should be a subject for serious economic considerations. In other words, growing a well remunerated crop on an area where conventional crop could be grown has not only positive effects on farmers' net benefit, but also generates opportunity costs of using arable land to produce biomass for biofuel. More specifically, fig 5 shows that with a potential of 30 tDM, farmers gain 12% on net margin but loose an equivalent to 2% in terms of average land opportunity cost. Inserting miscanthus with a high yield potential has an insignificant impact on land opportunity cost in comparison to average net margin because adding some land to produce miscanthus in some neutral farm groups, in which land resource is totally used, is no more feasible. A regional analysis is therefore required in order to capture the possible interactions between land competition and opportunity cost.

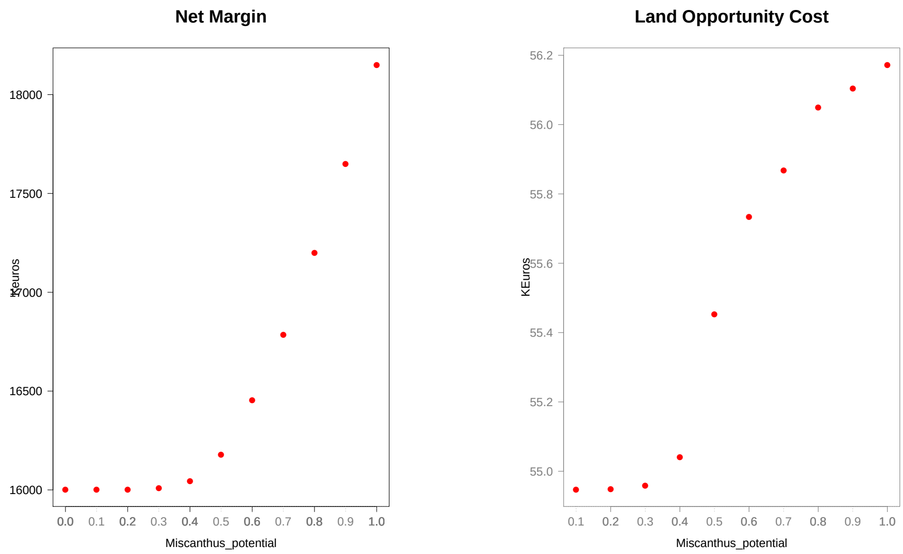

Figure 5: The evolution of average net margin and average opportunity cost of land as a consequence of the increasing in miscanthus potential.

Mapped illustrations of two different scenarios are presented on Fig 6 for 2 values of the reduced yield potential (40% and 70%). These maps confirm the result already found. More precisely, in some regions of Spain, France, United Kingdom and Germany, the major consequence of increasing miscanthus yield potential is to increase the competition between food and bioenergy crops. It becomes thus less and less interesting to produce miscanthus because it is increasingly expansive. In Finland and some other regions, the land share dedicated to the cultivation of miscanthus is already important and is at its maximum. Indeed, the increase in miscanthus yield potential does not have impact on land use anymore.

4 Discussion

In this study, we had to take into account the large range of food and animal productions which leads to a complex interactions in the farming system, like feed resources supplied by the farms (grain cereals, grasslands and fodders) and by the market (especially concentrates). We had to deal with the wide diversity of farming systems in terms of productivity

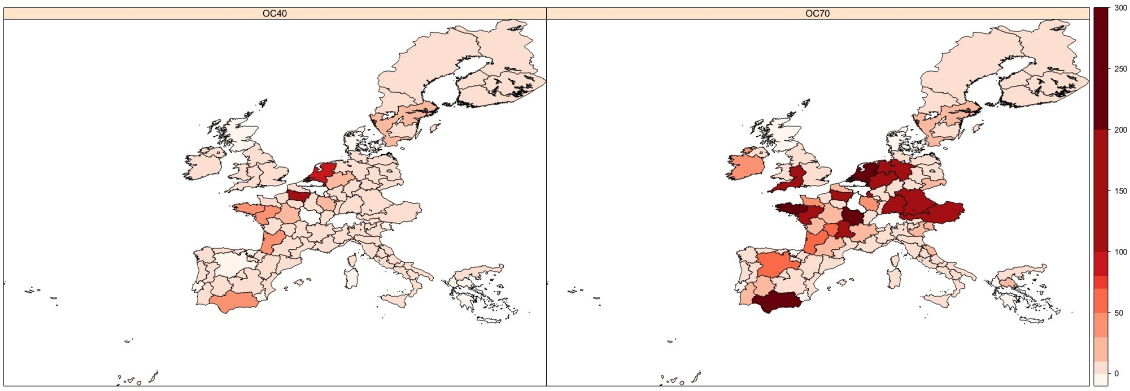

Figure 6: Regional distribution of land opportunity cost over the EU-15 in two scenarios a) OC40: $POTEN$= 40%, b) OC70: $POTEN$ = 70%.

related to traditional agricultural products and of pedo-climatic conditions which apply to the new crops like perennial ones.

Perennial crops are a crucial element in the future biofuel industry thanks to its theoretical high potential in term of dry matter yield and to technical progress in the biotransformation industry. Regarding the competition between food and non food agricultural outputs, these crops are usually claimed to be less in disfavor of food and feed destination.

The results show that agricultural system is complex. On one hand, the insertion of miscanthus in farming systems not only leads to a direct land use change due to cultivating miscanthus on uncultivated areas, but also to an indirect land use change when conventional activities required for food and feed production are displaced. This undoubtedly contributes to tightening food supplies and rising food prices.

On the other hand, the quantity of miscanthus produced in a region is not necessarily determined by the available cropland. It is, instead, determined by its expected yield and by the opportunity cost of displacing existing crops, combined with the region-specific water requirement. Requiring high level of water, miscanthus may compete with other uses for water and therefore contributes to rising water demands [28] which may leadsto an increase in shadow prices of irrigation water.

Being in an experimental stage, the 2^{nd} generation feedstock supply is still mainly in small-scale. Farmers may only be willing to consider lignocellulosic crops when a stable and sustained demand for 2^{nd} generation biomass is proven. Dealing with perennial and costly crops, farmers are required to fit their planning horizon and face high cost to convert conventional annual crops to perennial ones. Nonetheless, assuming good pedo-climatic conditions, it is economical and environmentally worthy to go through for a full rotation cycle once these crops are established.

5 Conclusion:

One of the major difficulty in this kind of analysis arises from the lack of data, even in terms of biophysical potential. This is enlarged by the economic problem of insertion in farming systems. We based our approach on the few data available for miscanthus, which is a perennial crop that is annually harvested. In order to insert this crop in European agricultural supply economic model, we provide "individual" estimates of yields and discounted annual costs (at the "farm group" level) thanks to a two-step procedure. First we correlate observed miscanthus yields to cereals yields at the regional level. That leads us to define a performance coefficient correlated to cereals. Secondly, after the assessment of the individual miscanthus potential (seen through our performance coefficient), we used a Faustmann-like approach providing optimal rotation, and consequently the average yield and the discounted costs at the individual farm group level.
The AROPAj model is then used for simulations, when the miscanthus potential is increased from 0 to 100% of the level previously assessed. When this potential is significantly reduced, crops and grasslands change (in terms of area) in close proportions. The part of cereals is relatively more affected when miscanthus reaches high level of performance. In the same time, in spite of inertia regarding livestock, there is significant change on this side mainly in terms of feed share between on-farm consumed cereals and marketed concentrates. Obviously this appears in complement of what happens for fodders and grasslands. To sum up, the perennial crop introduction clearly affects the cereals production, not only in terms of area but also in terms of destination. This more or less expected result, feeding the controversial point of food and non food competition, should be analyzed in a more global approach, including the fact that a great part of cereals are dedicated to feed animals (on-farm and concentrates through the feed industry). In the same time, grasslands and fodders are also affected at a quite significant level, firstly in terms of area. Even if a lot of phenomena are not taken into account in our approach, and first of them comes with price feedbacks (price are exogenous in our supply side model), our results show that the consequences of dedicated biofuel crops on the agricultural sector in a wide sense could be still more complex, well beyond the food - non food debate.

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