INNOVATIVE LIGNOCELLULOSIC CROPPING SYSTEMS IN EUROPE: COMBINING KNOWLEDGE FROM SEVERAL EU-PROJECTS

Conference Paper · August 2019

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INNOVATIVE LIGNOCELLULOSIC CROPPING SYSTEMS IN EUROPE: COMBINING KNOWLEDGE FROM SEVERAL EU-PROJECTS

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ABSTRACT: The biomass demand for the use as both renewable energy source and raw material for the biotechnology industry is increasing. Simultaneously, the supply of biomass is requested to become more cost-competitive. Innovative solutions for cost-effective biomass production should also avoid indirect land use changes and direct negative environmental effects. The main aim of this study is to identify the most promising innovative lignocellulosic cropping systems regarding environmental sustainability as well as social acceptance for different cost scenarios and different regions in Europe. To gather innovative cropping knowledge from around Europe ADVANCEFUEL organized a workshop. Participating Horizon 2020 projects presenting innovative approaches on lignocellulosic cropping systems included: FORBIO, MAGIC, BECOOL, LIBBIO, GRACE, and SEEMLA. Data was collected from field studies of the participating projects prior to the workshop and later presented in an aggregated way as a basis for discussions. This approach incorporates the knowledge gained in over 60 study cases conducted in 12 different countries. Under these study cases, 16 different lignocellulosic crops were covered. This field based knowledge can be used to validate spatial assessments of sustainable biomass production potentials in Europe.
Keywords: feedstock, biomass, costs, sustainability, stakeholders, innovative concepts.

1 INTRODUCTION

ADVANCEFUEL aims to increase the share of renewable energy in the future energy mix by increasing the share of sustainable advanced biofuels and renewable alternative fuels in the final EU transport energy consumption. A key barrier for increasing the share of advanced biofuels is the feedstock cost [1]. Cost reduction potentials for biomass production might be achieved by innovative cropping systems, while avoiding greenhouse gas (GHG) emissions by indirect land-use change (ILUC) and other negative environmental impact. Such innovations need to be accepted by farmers for implementation and by the public after implementation.

Several ideas are emerging on how biomass cropping for biofuel or industrial use can be innovated. The question is "what are the most promising innovative cropping systems for different regions in Europe?". Next to the profitability of innovative cropping systems, the best innovations should be associated with positive or neutral environmental impacts on the global and local scale. These different innovations have been studied in several projects all over Europe. But we are unaware of any systematic comparison of the different ideas and respective study cases.

The aim of this study is, therefore, to formulate fields of innovations for lignocellulosic cropping and give examples for each field. The innovations are then evaluated from different perspectives: biomass production costs, environmental impact, and innovation acceptance by farmers and the public. We conclude with specific recommendations for future work on this topic.

2 METHODOLOGY

The starting point for the identification of fields of innovation for lignocellulosic cropping was a report published by the European Commission in 2017 on innovation potentials for feedstock production for biomass from agriculture, forestry, waste and aquatic biomass [2]. Our study focused only on feedstocks from dedicated cropping, since these are expected to make the largest share of feedstock for advanced fuels [3]. Fields of innovations were restricted to improved biomass cultivation and harvesting, but excluded other steps of the supply chain.

For each field of innovation, we searched for examples in order to describe details. The approach to summarize existing study cases was twofold. First, a workshop was organized that brought together and discussed different study cases of innovative cropping in Europe – mainly on marginal land. Participating Horizon 2020 projects presenting innovative study cases on lignocellulosic cropping systems included: FORBIO, MAGIC, BECOOL, LIBBIO, GRACE, and SEEMLA. In an interactive session, the study cases were discussed and evaluated regarding major impacts on biomass production costs, environmental impact and innovation acceptance by farmers and the public.

Second, a literature review was performed in order to add details to the previously identified fields of innovations. In addition, new fields of innovation were added to those first mentioned by Baker et al. [2] if needed. Here we only summarize the findings. Details about the workshop design and results as well as results from the literature review can be found in ADVANCEFUEL deliverable D2.2 [4].

3 FIELDS OF INNOVATION

The innovations in lignocellulosic cropping were grouped in eight fields of innovation. For each field of innovations the scope of innovative ideas and their economic and environmental implications were described in detail in ADVANCEFUEL deliverable D2.2 [4] and are summarized here.

3.1 Agricultural management

One example of the improvement of agricultural management is the optimization of the planting density. The threefold increase in miscanthus planting density for an experimental site in Poland doubled yields [5]. While some studies state, that fertilization is only needed during crop establishment, other studies report repeated fertilization during the plantation lifespan [6], [7]. The reduction of synthetic fertilizer usage or the substitution with of organic fertilizer or sewage sludge have the potential to reduce biomass production costs and GHG emissions. While some studies state, that fertilization is only needed during crop establishment, other studies report repeated fertilization during the plantation lifespan [6], [7]. Lessons learned from study cases regarding fertilization in lignocellulosic cropping need to be complied and discussed, but most respective articles do not report information on fertilization [8].

3.2 Breeding

Breeding aims among others at increasing yields and quality or in improving plant propagation. One of the largest threats to sustainable energy crop production are yield losses by pests or diseases [9]. Therefore another objective of breeding is to increase the resistance of energy crops in order to achieve the maximum possible annual yields. Also the resistance to abiotic stresses such as water limitation is a very important breeding target in order to reduce senescing, losing leaf area, and avoid mortality. Increasing the resistance of energy crops can also lead to the expansion of energy crop production onto marginal land, as more resistant plants are able to grow in less suitable conditions [2]. The last major focus of breeding concerns the improvement of plant propagation.

The cheapest way of propagation is direct sowing by seed. As common clones are sterile, miscanthus is commonly propagated by vegetative reproduction using rhizomes.

3.3 Crop selection

Crop selection might focus on cultivar selection of already used species and hybrid species or on the selection of new species. The precondition of hybrid selection is that some time and effort has been spent before on breeding. For instance, for a former mining area in Spain Castaño-Díaz et al. [10] found that willow biomass yield can range from 1.3 to 8.6 tonnes DM/ha between genotypes. The water and nutrient use efficiency also varies between genotypes [11], [12]. For instance, yield, nitrogen-use efficiency and nitrogen export rate varied widely between 56 poplar genotypes [12], which has implications for the need of fertilization.

Crop selection includes the selection of endemic species that are not yet commonly used as feedstock. An example is the suggestion to grow birch in short rotation coppices on marginal land in Belgium, as after 4 years of growth birch was found to be well adapted to grow on marginal land compared to poplar and willow [13]. While yields from birch are lower than for poplar and willow, birch plantations are established by sowing instead of planting and rotation cycles are longer. This leads to lower costs over the plantation lifespan, but the cost effectiveness has not been assessed yet [13].

The introduction of new exotic species in Europe, in contrast, is more complex. Beside the agronomic and economic feasibility, new species need to be registered to the plant variety catalogue as a precondition for the certification of seeds and the Nagoya protocol needs to be implemented. An example is the use of Andes Lupine in Europe for biomass production, as studied in the Horizon 2020 project LIBBIO.

3.4 Crop rotation

Annual lignocellulosic energy crops as sorghum, hemp, kenaf, and sun hemp can be used in crop rotations. Traditional food crops that are used as dedicated energy crops fit well in conventional crop rotations, but little knowledge exists on the management of new lignocellulosic energy crops as mentioned above [14].

Crop rotation might lead to yield decreases of the main crop if the duration of cultivation of this crop is reduced, but total biomass production on the field is increased if a second crop is cultivated in addition to the main crop [15]. Crop rotation can reduce soil erosion and improve soil quality and it has the potential to reduce external input through nutrient recycling, maintain productivity, avoid pest accumulation associated with monoculture as summarized by Zegada-Lizarazu and Monti [14]. Another positive environmental effect of crop rotation is that it can increase the belowground microbial diversity with positive effects on soil organic matter and soil fertility [16].

3.5 Intercropping

The main impacts of intercropping documented in the literature include the reduction of negative environmental effects (erosion, leaching) and, the reduction of synthetic nitrogen fertilizer usage in order to decrease the global warming potential, but biomass yield increases were not always observed. For instance, intercropping of poplar SRC with a legume had no effect on yield compared to poplar monoculture, but the intercropping plantation had higher soil nitrate content due to the legume and higher soil water content as the mulch of cut cover crops decreased evaporation from soil [17]. Another study compared intercropping of sorghum and Andes lupine with sorghum monocropping [18]. While under optimal conditions concerning water and nutrient supply the monocropping resulted in better yields, deficiency of water, P and N supply resulted in no significant yield differences between treatments. Therefore intercropping might be a promising option to reduce synthetic fertilizer usage and, hence, decrease GHG emissions as well as to increase soil quality when cropping on marginal land.

3.6 Multi-purpose cropping

Multi-purpose cropping can refer to the use of different parts of one crop for different purposes or it can point to the production of a crop and at the same time avoid negative or generate positive environmental effects.

Orr et al. [19] suggested that dual-purpose sorghum (food and energy) provides a promising alternative to continuous maize cropping with respect to soil health indicators. It has been shown that growing willow SRC on wastewater irrigated fields in Estonia could reduce N and P concentrations efficiently [20]. At the same time the irrigation with wastewater increased wood yield by

41%. In practice, however, the use of wastewater has environmental and social concerns due to harmful substances, which need to be addressed when designing and managing such a systems [21].

3.7 Cropping on marginal land

In ADVANCEFUEL marginal land is defined as: “Land on which cost-effective food and feed production is not possible under given site conditions and cultivation techniques [22]”. There is no standardized and generally accepted definition of marginal land in the EU, which hampers the comparison of general findings between different studies performed on marginal land. In addition, the reasons for marginality can be very diverse: land unsuitable for food production; ambiguous lower quality land; or economically marginal land [23]. Wagner et al. [24] assessed the economic feasibility of miscanthus cultivation on marginal land for biogas production and comes to the conclusion that profitability can indeed be achieved depending on the individual case. But, the authors identified the biomass yield as the limiting factor of the economic attractiveness of cultivating miscanthus on marginal land, which is in line with previous studies [25]–[27]. Yields of at least 11 tonnes DM/ha are necessary to be economically competitive to maize silage. Biomass production costs per tonne depend very much on the achieved yields per hectare, which depends on the reason for marginality. Yields from some relative fertile marginal land can equal that of agricultural land.

This was, for example, the case for willow SRC on abandoned farmland in Canada [28] or for grass on very dry sites or sites prone to flooding compared to the control site in Ireland [29]. But in general yields are lower on poor-quality marginal land compared to agricultural land [26].

Positive environmental effects of biomass cropping on marginal land are associated in relation to soil organic carbon (SOC), biodiversity, soil erosion, or soil hydrologic characteristics. Even though several studies mention the possibility to increase SOC by growing lignocellulosic energy crops, only few studies have assessed the effect in the field. Walter et al. [30] sampled 21 SRCs in Europe and found that there is no general pattern of carbon sequestration in the soil. The SOC change rather depends on the initial SOC and the clay content of soil – aspects that are not always reported in the literature.

3.8 Harvesting technology

Energy crops can be harvested by machinery for grain harvest and straw collection that are commonly part of farmer machinery pools. Depending on the machinery, this requires two to three passes for mulching, windrowing and baling. Substantial expansion of the area cropped with lignocellulosic energy crops and shared use of the machinery by neighbouring farmers will promote the production and use of specialized harvesting machinery as suggested for single-pass harvesting of giant reed and switchgrass (Martelli, Bentini, & Monti, 2015). The use of such machinery will reduce costs and GHG emissions due to reduced fuel consumption. Taking values of CO_2 eq. emissions of miscanthus production [6], the difference of single pass to double pass leads to differences of less than 1% of total emissions and fuel consumption during 16 years including all field establishment and management activities.

4 WORKSHOP EXAMPLES

Some of the study cases presented and discussed during the workshop could be related to several innovation fields, in particular to “cropping on marginal land” as this was the focus of the workshop. Their insights, however, also contributed to other fields of innovations as described below.

4.1 SEEMLA project

This project discussed the study case of cropping black locust in short rotation coppice on marginal land in Lusatia/Germany and Thrace/Greece. Black locust (robinia pseudoacacia) was grown on 2 different types of marginal land: post-mining and abandoned land (grassland) in Germany and Greece, respectively.

4.2 FORBIO project

The discussed study case during the workshop was willow SRC cropping on degraded former agricultural land in the Ivankiv region of Ukraine. Soil degradation was due to intensification of agriculture in this area after withdrawal of large areas from agricultural production after the Chernobyl disaster. The land was abandoned 15 years before the SRC establishment because of unsatisfying soil conditions and bad economic conditions in the region. The study fields were part of an industrial production of biomass.

4.3 LIBBIO project

This workshop example suggested Andes lupine cropping in Europe as a new species with multiple potential uses. Study sites were established in different European countries. No particular country was selected for the study case discussion during the workshop.

4.4 BECOOL project

This project was only running for one year as the workshop took place and no final results were available yet. The project established rotational cropping study sites with lignocellulosic crops (sunn hemp, hemp, kenaf, and fiber sorghum) after maize on agricultural land in Italy, Spain and Greece. The case studies discussed during the workshop were sorghum and hemp grown in rotation with maize or wheat in Italy.

4.5 MAGIC & GRACE projects

The projects MAGIC and GRACE had only completed the first year of their project duration and, hence, documented results were still not available at the time of the workshop. Both projects have study cases on miscanthus cropping on marginal land in altogether seven European countries. Part of this study cases were performed on degraded land.

5 RESULTS AND DISCUSSION

5.1 Biomass production costs

For all discussed study cases, the range of impact on costs by land rental, pesticides and herbicides was low to average, but capacity development had average to high impact (Fig. 1). Irrigation, if needed, also had a high impact. Other features were, however, were very case dependent. For example, the planting material for miscanthus establishment has a high impact on costs, while seeds for willow or for crops in rotational cropping have rather low impact on total costs.

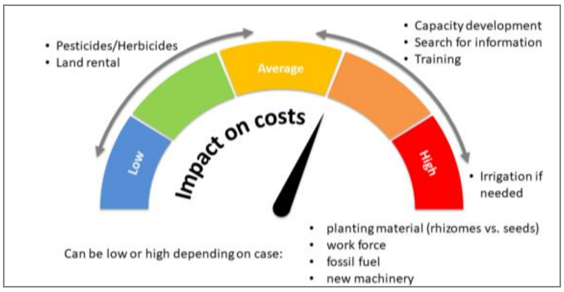

Figure 1: Summary of workshop results for the 5 study cases on the level of impact on biomass production costs by selected features. Arrows show the range of impact for different study cases

But what changes in biomass production cost can we expect in future? Only little info can be found in the literature. Here we summarize a few cost reduction potentials are from literature and from own calculations based on published costs for some innovations; details can be found in the ADVANCEFUEL deliverable D2.2 [4]. A potential to reduce biomass production cost was calculated to be around 10% for changes of the miscanthus propagation method which includes breeding and 7% to management aspects as the planting density or the application of sewage sludge to SRC. In contrast, cropping on marginal land can increase biomass production cost up to 44%.

Beside cropping innovations, there are also other effects that influence biomass production costs. Upscaling the cropping area and learning effects were estimated to decrease costs by 10% and 25% for willow SRC, respectively [31]. The learning effects had the highest potential to decrease costs as it can include several innovations at once. The learning effect for example composed of the establishment and selection of new genotypes as well as improved agricultural management and logistics.

Biomass production costs per tonne of biomass are directly linked to yields. Changes of biomass yield can also be positive or negative depending on the innovation. Yields can be reduced up to 70%, but in general are rather around 30-40% when cropping on marginal land compared to agricultural land. This might, however, be outbalanced partly by breeding that increases the crops drought resistance or nutrient use efficiency. Most of the field studies are done on the plot scale. But due to edge-effects and more intensive management, yield can be 40 to 80% higher on small plots compared to large fields.

Therefore it is very important to report study details as field size, which is not always done. Also for yield data it was found that the learning effect had the highest potential to increase yields and, hence, reduce biomass production costs.

5.2 Environmental impact

The environmental impact of study cases was expected to be rather positive for soil quality, but negative for water availability and quality (Fig. 2). Other features as biodiversity, nutrient retention and GHG emissions depended very much on the specific case. But this is probably also true for soil quality features as SOC.

To illustrate this, Figure 3 provides an example of SOC in the topsoil of several short rotation coppices established on cropland as assessed by Walter et al. [30].

The SOC change after several years of SRC depends on the initial SOC before land-use change and the clay content of the topsoil. Low initial SOC and high clay content lead to a higher probability that SOC will be stored in the soil by SRC, but high SOC and low clay content rather lead to SOC release which translates into GHG-emissions instead of sequestration. Therefore it is very important to assess and document certain features of study cases on lignocellulosic cropping.

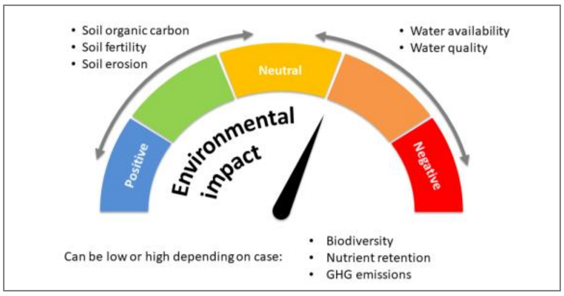

Figure 2: Summary of workshop results for the 5 study cases on positive, neutral or negative environmental impact by selected features. Arrows show the range of impact for different study cases

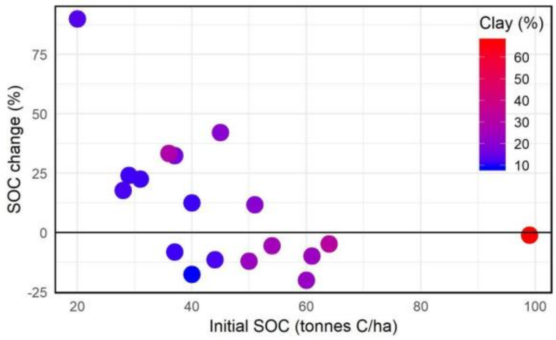

Figure 3: Changes of soil organic carbon content (SOC) after land-use change from cropland to short rotation coppices (SRC) in relation to initial SOC (derived from control plot of cropland) and soil clay content. Each point represents a topsoil (0-30 cm) sample mean of one Central European SRC ([30])

5.3 Innovation acceptance by farmers

For all study cases discussed in the workshop, the biggest barriers were cost and risk related (Fig. 4).

Tradition and habits also were important barriers, but consistent biomass quality was less relevant. We also saw that either “lack of standards and regulation” or the “lack of knowledge of environmental constraints” (e.g. invasiveness, soil quality) were high weight barriers for the implementation of innovations by farmers.

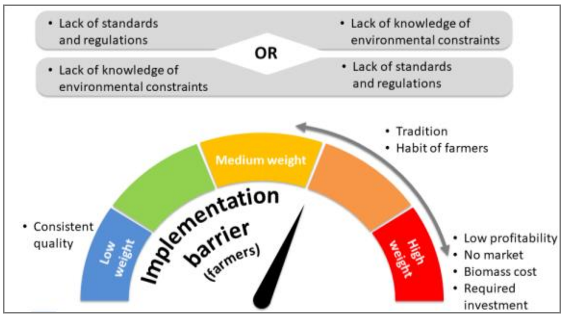

Figure 4: Summary of workshop results for the 5 study cases on the weight some selected features have as barriers for implementation. The arrow shows the range of impact for different study cases

5.4 Innovation acceptance by the public

After the implementation of innovations their success also depends on the acceptance by the public (Fig. 5).

The acceptance can be low due to competing interests (e.g. for food and feed), but also due to the lack of knowledge by the public. An upscaling of the cropping area can e.g. lead to shared costs as increased traffic of heavy trucks. In contrast, shared benefits might include employment increase or positive environmental effects.

Only few publications exist concerning these aspects, but in the end they might decide about the success of innovations.

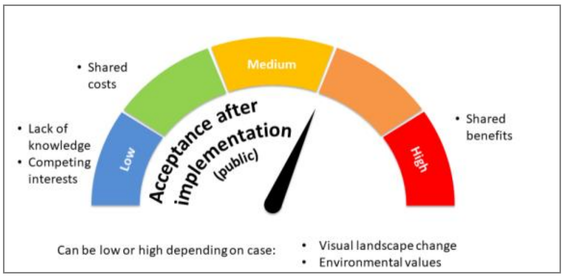

Figure 5: Summary of workshop results for the 5 study cases on the level of impact of selected features on innovation acceptance after implementation by the public

6 CONCLUSION AND RECOMMENDATION

The highest potential to reduce biomass costs is by the combination of several innovations at once and we called it the "learning effect". Therefore the aim should be to accelerate this learning effect. The ongoing H2020 project Panacea is a good example of the establishment of a network of actors with the aim to (a) create an inventory of scientific results and communication of results, (b) networking, and (c) training.

The second conclusion is that the evaluation of cropping innovations is very complex and highly case specific. To cope with this complexity we need a tool.

The Magic project is developing a DSS as a tool with guidelines for growing industrial crops under marginal conditions. In the long term such a system needs to include info on costs, sustainability and social acceptance. But for this we need reliable data. We need to assess and store a minimum standard dataset per study case.

While in the Panacea network the data is collected actively by the project, we need to ensure that future study cases report their standard dataset in a central and freely assessable database. A perfect example for a suitable and open accessible database is the one compiled by Wei Li [8]. It contains almost 2000 data points on yield at for 124 study sites in Europe. Beside yields it includes info about site location, climate, soil, plantation and management if given in the reviewed publications.

Even though some other features would be needed to add for the evaluation of sustainability, this is already a great basis to set up a freely assessable database with data from European study cases on lignocellulosic study cases. Such a database can assure the adequate reuse of data generated through European projects and evaluate study cases in terms of their economic potential and sustainability.

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8 ACKNOWLEDGEMENTS

The AdvanceFuel project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement N.°764799.

9 LOGO SPACE

ADVANCEFUEL

Horizon 2020 projects that participated in the workshop: