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A conceptual framework for the introduction of energy crops

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ABSTRACT

There is currently limited experience on the introduction of new commercial crops as a source of raw material for energy uses. The present paper analyses the introduction and development of commercial willow plantations in Sweden during the period 1986–2005. A general framework is constructed in order to identify all the factors and interrelations that can describe the introduction and expansion of willow as an alternative crop for the production of raw material for energy. The factors are identified and analysed based on a broad database of information from commercial plantations, covering almost all existing plantations, and on documents referring to existing academic literature or official reports. The analysis provides with lessons that can be useful for the introduction of new energy crops in other countries and shows the possible contradictions in policy applications. The analysis confirms that stable policies and long-term contracts reduce the uncertainties associated with the cultivation. The results of this study can be of value for other countries aiming at the introduction of new crops for bioenergy.

1. Introduction

Biomass from short rotation plantations with woody crops is an important option for meeting renewable energy targets in the expected shift towards a more sustainable energy supply infrastructure. It has been speculated that a large amount of land for fast growing wood species will be needed in order to accomplish the goals targeted in the energy policy [1,2]. Estimates by the European Environmental Agency show that most of the potential biomass production in the European Union will rely on energy crops, which can account for more than half of the total biomass supply in 2030 [3].

The estimates of the importance of short rotation woody crops is based on its potential role in the reduction of the CO_2 emissions through the production of biomass for fossil substitution and CO_2 storage in vegetation and the soil (e.g. Ref. [4]). In addition, the advantages they present are wide: for example, efficient land use in combination with the increasing demand for renewable energy resources, potentially positive effects on rural economies as the result of the diversification of farm crops [5], and additional possibilities for environmental control and wastewater treatment [6,7].

Today, out of the different fast-growing woody crop species proposed for energy uses, willow (*Salix*) is one of the few planted commercially to a significant extent in the EU [8]. Willow cultivation presents several characteristics that favour its use for energy production: it is a high-yield species, providing large amounts of lignocelluloses in a short interval after establishment, it has a broad genetic base which allows potential for improved and adapted varieties, it is easy to breed and to expand through vegetative propagation, it has the ability of re-growth (coppice) after multiple harvests, and it requires low economic investments after its establishment [9]. Also, the energy efficiency of willow plantations has been estimated to be higher than alternative crops. For instance, the energy input needed in a willow production chain is about 4% of their energy output, whereas the equivalent value for a chain based on forest logging residues or straw is about 5%, and in the case of cereals or oil seed plants, is estimated to be 15%–20% [10]. In addition, among other fast growing species, willow has shown better energy profiles than e.g. poplar in terms of energy requirements, estimated about 11.3–17.4 MJ ha^{-1} yr^{-1}, compared to poplar 12.8–15.5 MJ ha^{-1} yr^{-1} [10].

In Northern Europe, the cultivation of willow provides additional advantages: good yield performance even in cold conditions,

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management practices that are already familiar to most farmers and winter harvests that reduce the impact on other agricultural operations and minimise soil compaction resulting from the use of heavy machinery, as the ground is invariably frozen during the harvesting period [11].

The plantations are mainly established on agriculture land, involving less intensive practices than most of the conventional agricultural crops. However, the use of short rotations translates into more intensive management practices than in conventional forestry. The plants are usually cut back after the first growing season in order to promote sprouting. Whole-shoot harvesting is usually conducted every three to five years [8,12]. The plantations are established between late April to early June, using one-year old cuttings, and the most widely used current design in Sweden is the double-row system, with distances between rows of 0.75 m and 1.5 m, which permits the use of machinery, and spacing between cuttings, within the rows, of 0.6 m.

Currently, Sweden is the leader in short rotation plantations for energy in Europe [13,14]. Since its introduction at a commercial level in the mid-1980s, Sweden has planted about 14–16,000 ha [8]. In this context, Sweden is a unique case in Europe for its experience regarding the introduction, at a commercial level, of a new energy crop on agricultural land, both concerning years of research and area planted. The performance and expansion of the Swedish willow plantations is, therefore, an invaluable precedent and source of information for analysis, and dissemination to other suitable countries. The present paper analyses the introduction and development of commercial willow plantations in Sweden since the first commercial plantations were established. In order to achieve this, different aspects are examined, e.g.: the yield performance of the plantations, the changes and trends of productivity, the role of the policy framework and the different actors involved in the development of the sector. Finally, the paper aims at drawing concepts and lessons in a conceptual framework that can be useful for the introduction of new energy crops in other areas.

2. Material and methods

A general framework was constructed to conceptualise and analyse the introduction of willow cultivation in Sweden, based on data analyses as well as on a review of existing literature. The framework aims to identify all the factors and interrelations that can describe the introduction and expansion of willow as an alternative crop for the production of raw material for energy. The identification of the factors and the interrelations were based on a broad database of information from commercial plantations (Table 1). Concerning the details affecting the cultivation and the policy framework, the data was based on documents referring to existing academic literature or official reports. Regarding the analysis of quantitative data (e.g. the specific location of the plantations, yields and performance, number of growers) the data was based on a series of datasets, the most important one provided by Lantmännen Agroenergi AB (formerly known as Agrobränsle AB), which manages planting and administrates the harvesting of commercial willow plantations. The data included, among others, the location of the plantations, the harvest records from the first, second and third cutting cycles, as well as data concerning the ownership of the plantations, the area planted, and the establishment and harvesting dates, during the period 1986–2005. Some human errors were detected resulting in inconsistent records, and were excluded. In other cases, some information regarding the ownership, harvesting dates, total area planted or the location of the plantation, was missing, resulting in their exclusion from the calculations according to the needs of the studies where they were used.

Table 1
Sources of the main datasets used in the analysis.

Data	Source
Size, yield, location of plantations	Agrobränsle AB (1986–2005)
Ownership of the plantations	Agrobränsle AB (1986–2005)
Consumption of wood chips and location of district heating systems	Svensk Fjärrvärme AB
Location and establishment of district heating systems	[15,16]
Land uses	Corine land uses map [17]
Yield and release of commercial varieties	[18]
Economics and cost reductions	[19]

All plantations were geo-referenced to a 1 km precision, covering the area from 55° 20' N to 61° 29' N and from 11° 33' E to 18° 56' E. The biomass production of the willow plantations was calculated by dividing the total harvested biomass of the cutting cycle by the planted area. The yield (mean annual growth) was calculated by dividing the biomass production by the rotation length of the cutting cycle (the number of years since the previous harvest or cut back). The number of growers across time was also derived from the datasets, as well as their experience in growing willow (see Ref. [20]).

Additional datasets were also collected to analyse other factors identified in the analysis. The consumption of wood chips by district heating and power systems during the period studied was based on records by Svensk Fjärrvärme AB. The release of willow varieties to the market was based on [18]. The land uses were based on the Corine land uses map 250 m [17].

3. Results

3.1. Conceptual framework for the introduction of a new crop

The resulting framework (Fig. 1) assumed that the area planted with the crop is a result of the adoption of the crop by the local farmers, subject to different incentives. One clear incentive is the profitability of the cultivation, being a result of the cost and the revenues, including incentives. Those are defined by the productivity, which is a result of a combination of local climatic and soil factors and restrictions, management practices, and by the effects of the economies of scale, as well as by the demand for the resulting chips. The resulting level of productivity affects the profitability of the plantations and the willingness of local farmers to plant willow, and thus to expand the initial area planted. In addition, the existence of a local demand and market for willow chips, the local perception of the cultivation and the costs of management significantly affect the adoption and therefore the expansion of the cultivation. This amount of planted area with willow will determine the development of an economy of scale, which will reduce costs, release higher yielding varieties, and contribute to a better understanding of willow management, which will in turn result in higher yields.

The role of the policies implemented to develop the sector directly affect adoption, e.g. through subsidies. In addition, policy affects the market, e.g. through taxation of alternative energy sources, subsidies on wood-fuelled district heating plants, promoting a framework for long-term contracts between the farmers and the wood-fuel consumers. Finally, the policies also affect the yield performance, e.g. through investments on research of new plant varieties and better management practices.

3.2. Changes in the policy framework

The introduction of willow cultivation in Sweden was stimulated by the government through the implementation of different