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Assessment and characterization of reed canary grass plantations for energy

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Abstract

Research Highlights: (1) Reed canary grass (RCG) is analysed in Sweden compared to willow and poplar for 2001-2020 (2) Each crop presents a different land-use and climatic profile (3) Average yield records of reed canary grass are similar to willow and poplar (4) There are divergences between trial-based and commercial yields (5) Existing LUC patterns suggest meadow>RCG and RCG>cereal (6) RCG land area is very sensitive to policy incentives.

Background and objectives: RCG is an alternative crop for biomass-to-energy due to high yield and frost tolerance. We assess the cultivation in Sweden by using an extensive compilation of data, with emphasis on the extension of the cultivation, areas planted, climatic profile, land use patterns and yield levels.

Material and methods: All RCG plantations are analysed for 2001-2020. A geostatistical analysis is performed to characterize where is cultivated and the land uses associated. Climatic, productivity and yield profiles are compared to willow and poplar plantations, from experiments and from commercial plantations.

Results: The results show that the cultivation of reed canary grass expanded after 2005, with a maximum of 800 ha in 2009 to then decrease to the current levels of about 550 ha. It is mainly grown in colder climatic areas, with lower agricultural productivity than willow and poplar. Mean yields from trials are 6 odt ha^{-1} yr^{-1}; commercial yields are 3.5 odt ha^{-1} yr^{-1}. RCG replace meadow land and is replaced by cereals, when abandoned.

Conclusions: Reed canary grass is an interesting alternative, growing on colder areas but on similar yield levels than other energy crops. The cultivation is more sensitive to policy incentives

Keywords: energy crops; land use; biomass; bioenergy

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1. Introduction

Perennial grasses have been considered in Europe as alternative energy crops due to several characteristics which make them attractive for intensive biomass production compared to annual crops, *i.e.* high yield potential, high lignin and cellulose contents in their biomass, high heating value, low water content, lower management inputs such as soil tillage, and others [1]. They also offer advantages compared to perennial trees for energy since they do not need special equipment for management practices and can use common existing equipment for annual crops. In addition, they can enhance conditions for biodiversity and provide a number of ecosystem services, e.g. phytoremediation, erosion control, enhanced soil organic carbon, mediation of water flows, and retention of nutrients and other agrochemicals [2;3].

In Northern Europe, reed canary grass (*Phalaris arundinacea* L.) has been used at commercial level in Finland [4;5;6] and Sweden [7;8] presenting advantages due to its frost resistance and adaptability potential to hard climatic conditions. In Sweden, research was performed since the late 1980's [9], initially aiming as an alternative biomass source for the pulp industry, and later for energy purposes producing pellets, briquettes or for direct combustion. In fact, it was considered as one of the most interesting species for biomass production in Sweden [10], due to its high yield, sustainability of the production and the fact that it is native to Sweden. Moreover, crop management activities could be easier compared to other lignocellulosic energy crops, with lower establishment costs due to the use of existing and conventional equipment, and the use of seeds in the establishment phase [11].

Reed canary grass can complement the present and future mix of energy crops in the country, since it has different management regimes and typical geographical locations than other existing biomass production systems, such as willow, poplar or hybrid aspen. However, despite its current commercial use, extensive research on trials and management regimes (e.g. [12;13], biology of the crop (e.g. [14]), and even biomass properties for energy uses (e.g. [15]), there have been few attempts to provide a comprehensive assessment of the cultivation, especially with regards to other lignocellulosic energy crops grown for similar purposes.

This paper reviews and characterizes the present situation of reed canary grass cultivation in Sweden using an extensive compilation of records, with emphasis on the current extent of the cultivation, areas planted, land use patterns and yield levels, compared with other lignocellulosic energy crops in the area.

2. Material and Methods

2.1. Description of the cultivation

Reed canary grass is a perennial grass with high frost tolerance that grows in northern latitudes in Europe, where it is native. The crop makes large stands with a height of about 1.5-2 m. In

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Sweden, its use has been documented since 1749, mainly for forage in Scania, and studies in the 1800s already highlighted the high yield potential, particularly in Northern latitudes [16]. In the 1980s, it started being considered for large-scale industrial production of biomass [17], and new varieties started in 2001 to be dedicated for energy production [18]. Since then, it has been established in wet areas and along the whole country [10]. The main commercial varieties have been *Palaton* and *Venture*, and more recently, a new variety, *Bamse*, has been developed and tested [17].

Under Swedish conditions, the soil is prepared by plowing before sowing. Perennial weeds such as couch grass are controlled the previous year. Sowing occurs in early spring with a row spacing of 10-15 cm. Growth in the beginning is rather slow until the root system is established, and weeding could be necessary during the first year. The first harvest occurs the second year after sowing. A well-managed field can be productive 10-15 years before re-establishment is required [17]. Reed canary grass grows well on most kinds of soils but works well in poorly drained soils as it tolerates waterlogging better than many other grasses [19]. Due to its deep root system once well-established, it is also more drought-resistant than other grasses [20].

In the 1990s, the fertilization recommendations were 150, 100 and 30 kg per hectare N, P and K, respectively in the first year, and 80, 30 and 10 kg per hectare during the rest of the production period [18]. This has been changed in recent decades, and fertilisation with 40, 15, and 50 kg in the year of sowing, 100, 15, and 80 kg, the year after sowing, and 50, 5, and 20 kg in spring per hectare of N, P, and K, respectively, have been recommended [21]. To reduce fertilization costs, application of mixtures of sewage sludge, wood and grass ash have been practiced [18;22].

Harvest takes place in the second year after sowing, preferably in early spring because the grass then has the lowest moisture content (ca 10-15%) and can be used in power plants without drying. The first harvest can be 20% lower than subsequent harvests. Moreover, Na, K and Cl concentrations are the lowest in early spring, which makes it a better fuel with decreased corrosion risks for the boiler [17]. Harvesting is a critical operation, as increasing the harvest height from 5 cm to 10 cm can result in harvest losses exceeding 25% of biomass [23]. In general, ordinary hay harvesting equipment is used and transportation from the field usually occurs in bales. The final removal of the crop is often performed by conventional soil tillage operations [18].

2.2 Data sources

Several databases for agricultural production were combined for the analysis. The location of the commercial plantations for the period 2001-2017 was retrieved from the land register, using the IACS (Integrated Agricultural Control System) database maintained by the Swedish Board of Agriculture. This database permits to extract the land use of each polygon (*blocks* in the databases), defined as a uniform land area that remains quite constant from one year to the next [24], although the use of the land may be altered. Land use data from 2001 to 2016 were included in the analysis. The method to deal with the land uses was based on Xu and Mola-Yudego, 2021

[25]. The total area planted for 2017-2020 was retrieved from Statistics Sweden, but in this case, was aggregated.

A database of existing trials was constructed, including records from reed canary grass, willow, and poplar/hybrid aspen (given the limited area planted, in this paper will be referred together). For reed canary grass, trial records were retrieved from Landström et al [10], Lindvall et al [22], Nilsson et al [8], Lindvall et al [12] and Lindvall [19], during the period 1991-2015 (N=201). For willow, a trial database was used based on Mola-Yudego et al, 2014 [26] (N=290) and for poplar, from Dimitriou and Mola-Yudego, 2017 [27] (N=58). Concerning commercial records, the annual yield for reed canary grass for Sweden was extracted from the Eurostat database [28] as well as from records supplied by Statistics Sweden, and, for Finland, from Luke [29].

To analyze the agricultural profile of the cultivations, the data was based on the standard yield estimates by agricultural districts [30]. For the climatic profile, data was retrieved from the *WorldClim* database for Sweden, using the last standard period 1960-1990 at a resolution of 1x1 km, for the monthly minima and maxima temperatures and precipitation [31].

2.3 Statistical methods

All plantations of reed canary grass existing in Sweden were identified and geo-located for the period studied. The total cultivated area and average size of the plantations were quantified for each year during (2001-2017) and compared to similar records of willow and poplar. The geographical distribution of the plantations was further analysed by using spatial kernel methods [32;33]. Kernel density estimation is a non-parametric method that allows to define *core areas* (areas with the highest density of the cultivation) and *home areas* (area entailing most of the cultivated area). The method was applied following Mola-Yudego and González-Olabarria [34]. The *core area* was the smallest area to include 50% of all existing plantations for a given period, and the *home area* defined the area including nearly all plantations (90%). The same analysis was performed to willow and poplar plantations.

For each plantation, monthly estimates of temperature (maximum and minimum) and precipitation were calculated in order to provide a climatic profile. The monthly mean values for all plantations were then averaged for the whole country, in order to provide a climatic profile for each cultivation. Similarly, the estimated standard yield of cereals was used as an indicator of land productivity. Among the options, barley is the most common crop in most areas where plantations are established. To reduce the effect of climatic variations on specific years, the average was estimated for several years (2003-2017) using the same approach as in Xu and Mola-Yudego [25]. This yield was assigned to each plantation, and the country's average was calculated on a yearly basis for the three main plantation systems, in the same way as for the climatic variables.

The yield levels of reed canary grass were assessed using records from trials and commercial yields and compared to the performance of the other plantation systems. The estimates from experimental plots were investigated by observing the ranges and geographical distribution of the trials, compared to the equivalent levels of willow and poplar from similar trials and experimental plots. These values were also contrasted to the official averages resulting from commercial plantations, both in Sweden and in nearby areas in Finland.

Finally, changes in land uses were also investigated; prior land uses in each plantation were identified and grouped in three main categories (cereal production, fallow land and meadows), and the changes in area were estimated annually.

3. Results

Prior to the data available in the land registry, there were records of ca 4000-5000 ha planted with reed canary grass in 1991, mainly dedicated to forage and animal use [17]. These plantations nearly disappeared by the end of the 1990s, as the area planted was around 675 ha in the first year of detailed records. After 2005, the area planted increased significantly to 800 ha in 2009 (Figure 1), mainly for energy purposes. Prior to this year, reed canary grass could get support only when there was contract for an industrial use (mainly energy), when grown on land without support rights for set-aside land [35]. This level lasted until 2013; after that, there was a steady decline in the area planted, to the most recent figure (ca 550 ha). The distribution of the size of the planted fields followed a logarithmic distribution with prevalence of small plantations over large ones. Fields larger than 10 ha were very rare, and over 5 ha were seldom. The average plantation size increased over time, from ca. 2.18 ha in 2005 to 2.4 ha until recent years.

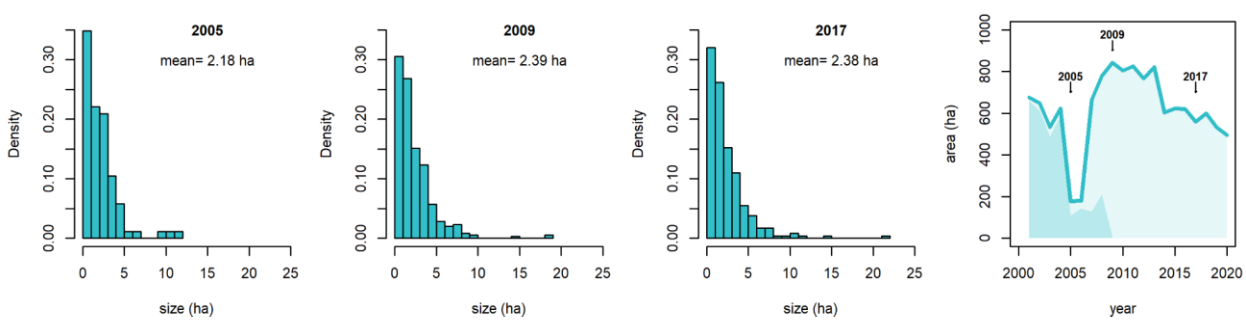

Figure 1. Evolution of area planted with reed canary grass land for the period 2001-2020, and distribution of the plantations according to their size. Shaded area refers to non-contractual plantations (largely before 2009).

Although reed canary grass plantations are distributed along the whole country, the largest concentration is at the north east, around the regions of West and North Bothnia, and, to a lesser extent, in the central and southern parts of the country, where the share of agricultural land is larger and other lignocellulosic energy crops, such as willow and poplar, are typically planted (Figure 2).

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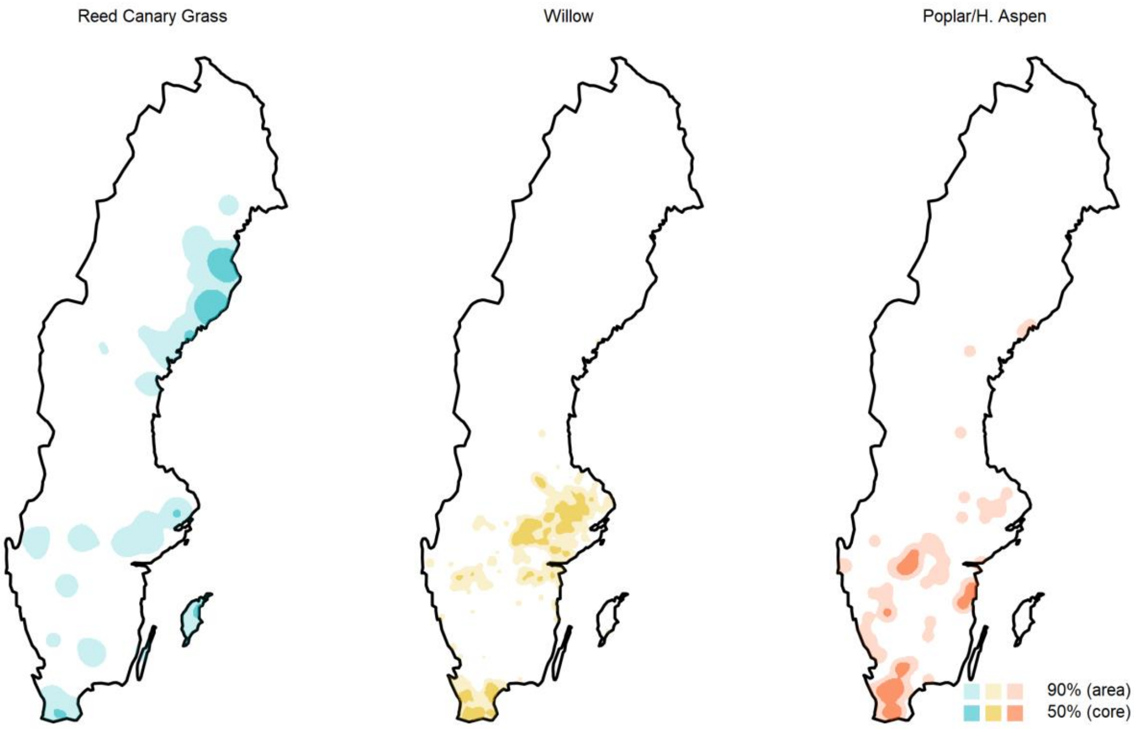

Figure 2. Location of reed canary grass plantations in Sweden, including all planted fields and extension of the cultivation area and *core areas* with the highest concentration of plantations, compared to willow and poplar/hybrid aspen, for the same year.

The geographical location of the plantations is reflected in the climatic profiles. The mean annual precipitation of a plantation of reed canary grass in Sweden was 582 mm, compared with 605.5 mm and 654.7 mm for willow and poplar aspen, respectively. The mean annual temperatures were between -0.44 °C (minimum) and 7.56 °C (maximum), which represents a colder average than the 2.78 °C (minimum) and 9.99 °C (maximum) for willow, and 3.16 °C (minimum) and 10.05 °C (maximum) for poplar (Figure 3).

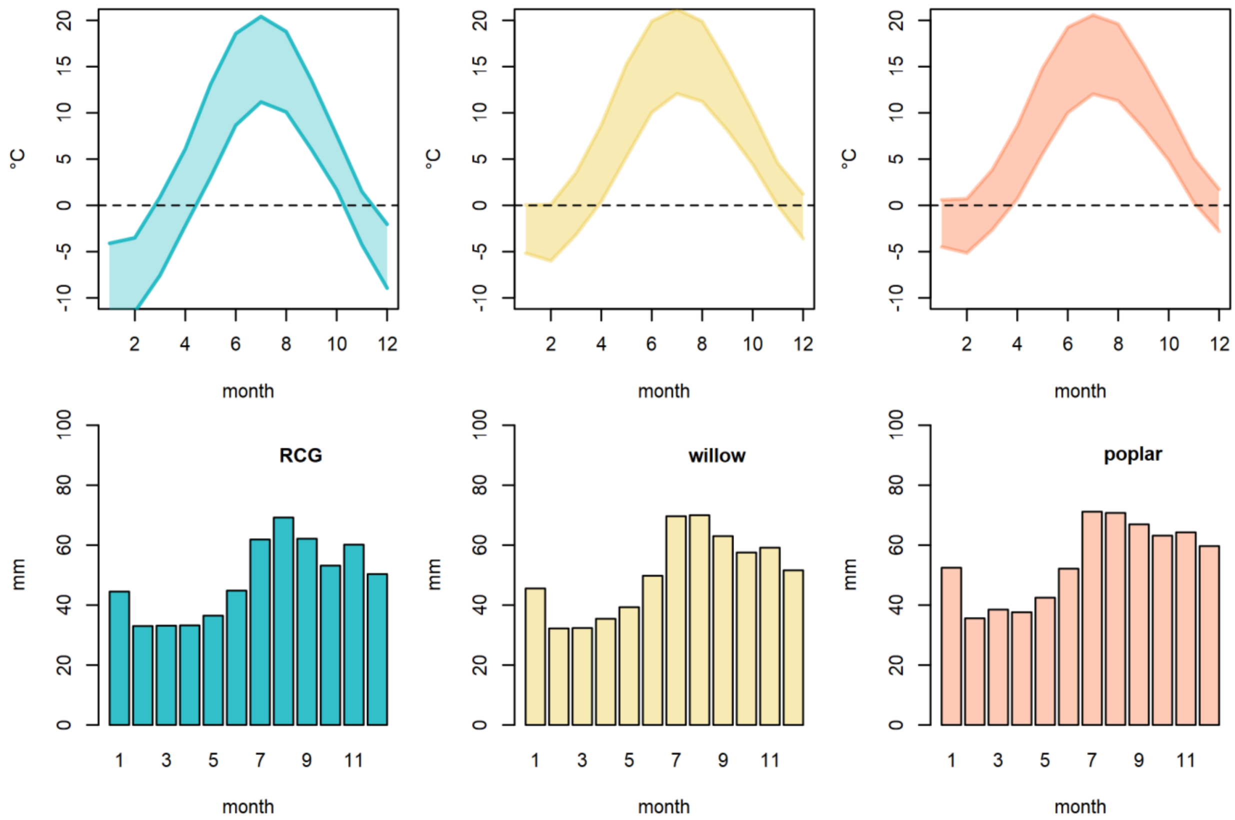

Figure 3. Agro-climatic profile of reed canary grass (RCG) compared to other fast-growing plantations in Sweden. The profiles represent the mean monthly maxima and minima temperatures and precipitation records of all plantations of RCG (N=350), willow (N=3305) and poplar/hybrid aspen (N=253), for a reference year (2009).

The analysed trials represent the geographical distribution of the commercial plantations (Figure 4), and the results show large ranges. The maximum record from the trials is close to 15 odt ha^{-1} yr^{-1} (comparable to poplar). Yields over 10 odt ha^{-1} yr^{-1} are more common in the case of willow plantations. In general, the mean yields from trials for reed canary grass, willow and poplar, are similar, despite the fact that reed canary grass is often located in less favourable climatic areas, with lower average agricultural productivity (Figure 4).

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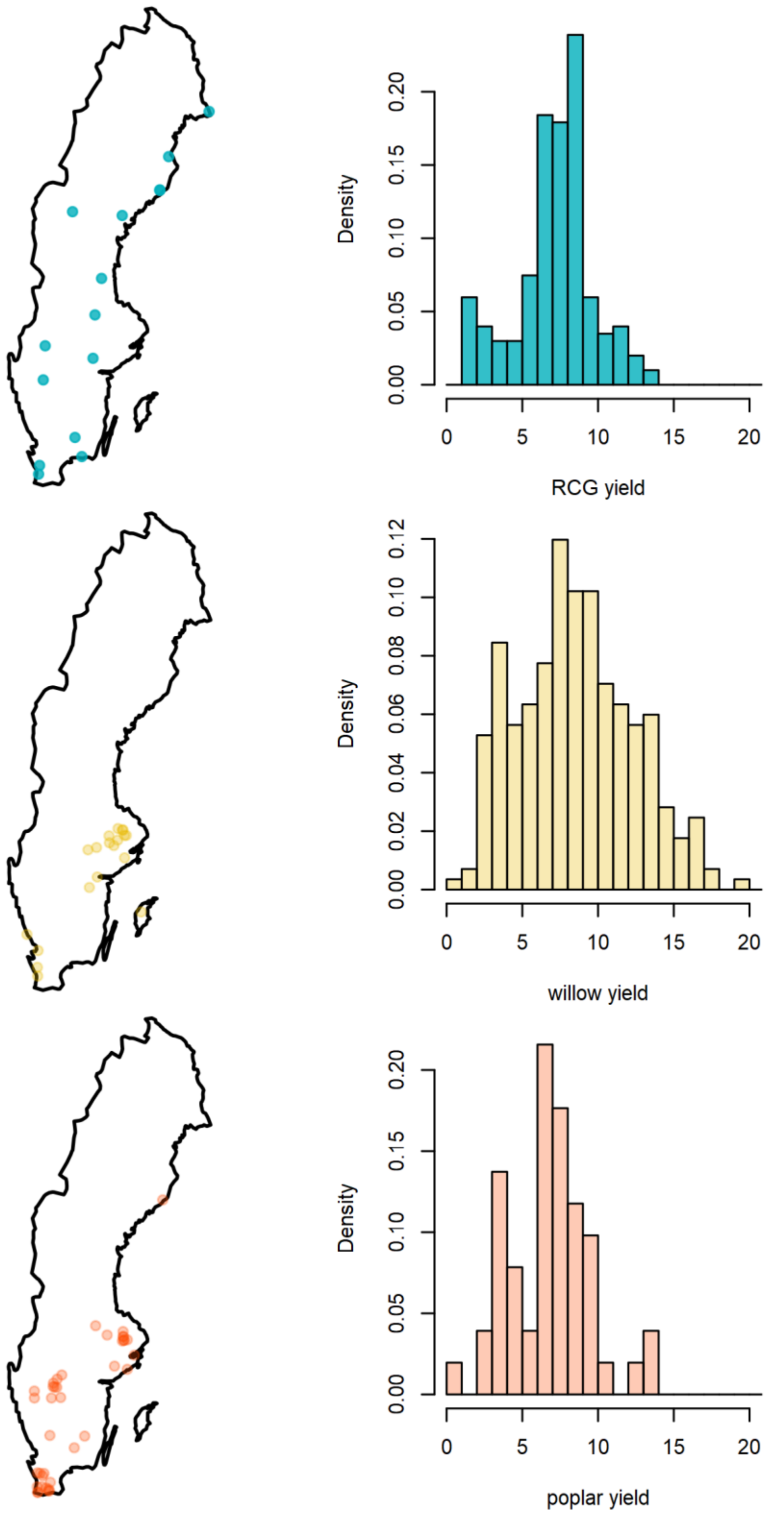

Figure 4. Estimated distribution of yields (odt ha^{-1} yr^{-1}) for reed canary grass compared to willow and poplar in different trials along the country (see maps) for the period of 1991-2010.

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The yield levels from trials, however, are largely overestimating the commercial yield of reed canary grass, estimated around 3.37 odt ha^{-1} yr^{-1} in Sweden (Figure 5). Nearby areas in Finland present similar values for commercial plantations; for example, around 3.6 in Lapland and 4.2 in South Ostrobothnia. The Finnish average is even lower (3.1 odt ha^{-1} yr^{-1}). The corresponding values for commercial willow plantations in Sweden are 2.6 odt ha^{-1} yr^{-1} and 4.2 odt ha^{-1} yr^{-1} for the first and second rotation, respectively.

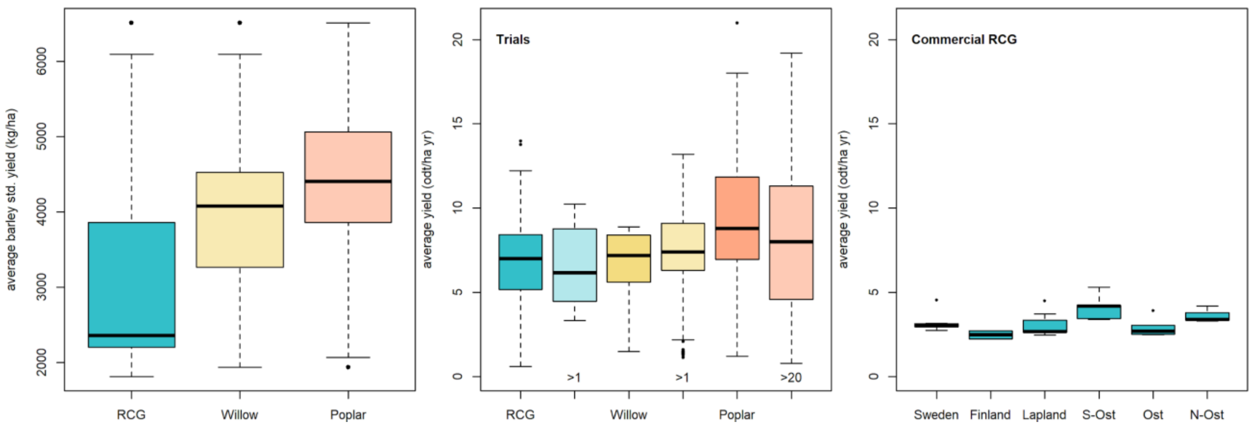

Figure 5. Land productivity yields of the trials for reed canary grass (RCG), willow and poplar in Sweden. Left: Averaged agricultural productivity of all established plantations using the standard yields of barley by agricultural district. Centre: Average yield (oven dry tonnes, odt) from trials in Sweden, for reed canary grass (1991-2010), willow (1986-2004) and poplar (1980-2015), where >1 refers to second harvest and subsequent and >20 refers to plantations over 20 years. Right: Average yield for RCG (oven dry tonnes, odt) from commercial plantations for the period 2011-2017 in Sweden and Finland (counties: Lapland, South Ostrobothnia, Ostrobothnia, and North-Ostrobothnia).

Finally, changes in land use show that reed canary grass is mainly replacing meadow and cereal land, in that order, starting in 2005. However, after 2009, reed canary grass plantations were replaced by cereals to a larger extent than meadows (Figure 6).

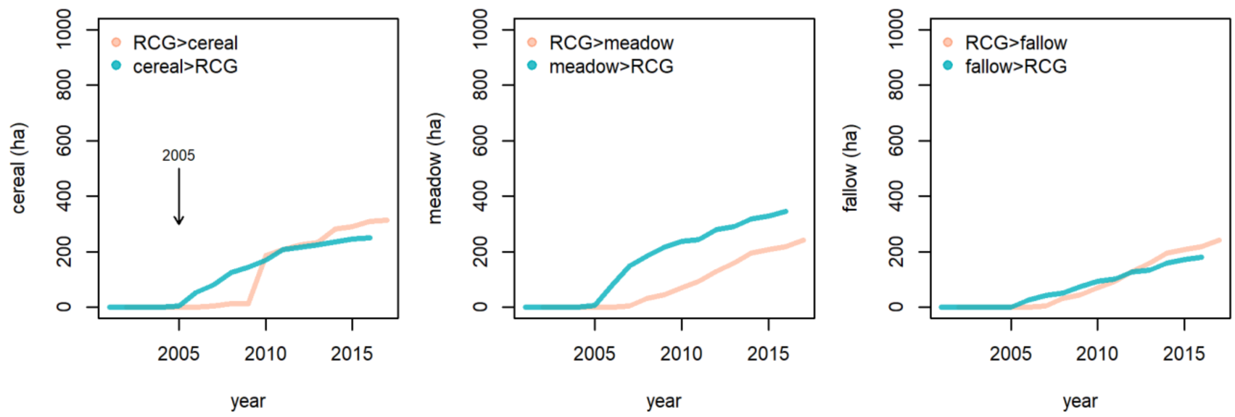

Figure 6. Changes in land uses related to reed canary grass (RCG) used for energy in Sweden. The line *cereal>RGC* refers to the area with cereal replaced by RCG, and *RCG>cereal* refers to plantations being abandoned and replaced by cereal fields, likewise for meadow and fallow land.

4. Discussion

Reed canary grass has had a long history in Sweden. This study aims at providing a detailed overview of the cultivation, based on multiple sources of different character. The crop is also compared with the other two existing lignocellulosic biomass production systems, willow and poplar (including hybrid aspen), grown in the country.

In 1991, the area with reed canary grass peaked at around 4000-5000 ha, mainly used for forage [17]. The expansion was driven by earlier support schemes for converting land from food into non-food crops [18]. These early incentives were established in order to deregulate the agricultural sector, reduce the overplanted food crop areas, and restructure agricultural land use. Subsidies for energy crops were introduced as a compensation tool in the period 1991-1996 [36], stimulating establishment of energy crops such as willow, and opening for using reed canary grass for energy rather than fodder [7;37]. As bioenergy markets had not matured before the incentives were removed in the mid-1990s, combined with increased food crop subsidies, the area of both crops decreased [36], leading to the stagnation of new willow plantation areas and the removal of most of the reed canary grass established by that time.

According to the results, by the beginning of the 2000s, there were less than 800 ha of reed canary grass in Sweden, compared to over 10 000 ha of willow and 1000 ha poplar, in the same period [25]. There was a steady decline that almost supposed the removal of all planted areas in 2005, followed by a new rapid expansion, reaching nearly 1000 ha by 2009. The same increment was observed in Finland, parallel to subsidies and policy incentives for its cultivation, which resulted in about 20 000 ha by 2009 [29]. In 2009, the set-aside requirement, i.e. the EU requirement for farmers producing high quantities of cereals to leave a percentage of their land (ca 10%) out of production, or grow it with industrial crops, was decided to be removed [38], which is one explanation for the progressive decrease in planted area after that period.

Concerning yield levels, reed canary grass compares well with the other lignocellulosic energy crops in the country [27]. The yield levels from experiments are at similar ranges for all three crops compared, and are at similar levels as indicated in other studies in Finland, Estonia and Lithuania, with spring harvest yields of ca 6 odt ha^{-1} yr^{-1} [39;40;41]. These levels must be taken as an upper threshold in optimal management conditions, as yield observations resulting from experimental plots tend to largely overestimate commercial levels [26]. In addition, there are important harvest losses, which are significant in this case; the effective harvest yield can be only 45–56% of the biological yields [6;42]. In fact, the results confirm this divergence, as the official commercial averages for Sweden and for Finland (in similar climatic regions) are ca. 50% lower (3.3-3.5 odt ha^{-1} yr^{-1}). These levels match the commercial averages for willow [43], indicating similar performance of both energy crops, despite reed canary grass being mainly located in less favourable climatic, thus less fertile, areas than willow.

This can be seen as a competitive advantage for reed canary grass; as it is planted in less favourable areas for agriculture than other energy crops, presents a similar performance, and has a lower establishment cost compared with the willow plantations [11]. However, at the same time, the abrupt changes in planting areas suggest the cultivation to be more sensitive than willow to the existing policy framework. This is also confirmed by previous studies highlighting that farmers' willingness of growing reed canary grass is highly sensitive to subsidy levels [44]. This could be related to the lower establishment costs, limiting potential losses when abandoned earlier, and to the shorter lifespan, around 10 years, while willow cultivation extends over 25 years [45]. A more dramatic example took place in Finland in the same period of study, as the plantation area decreased from ca. 19 000 ha (2007) to merely 6 600 ha (2013) and further down to 3 000 ha (2020) [29;46].

It is noticeable, however, that although the total area planted in Finland decreased abruptly, the total number of farms cultivating reed canary grass remained more stable, from 367 (2013) to 317 (2019), a reduction by a factor of 2 in area planted, but only by 15% in the number of farms [29]. This suggests that farmers already cultivating reed canary grass decided to continue growing it after the subsidies were removed but chose to reduce the land dedicated to the crop. Overall, the dependency on subsidies can be explained by the narrow economic margins of the crop. Larsson [7] estimated that the minimum farmgate price of reed canary grass required for being profitable would be 56 SEK MWh^{-1} at that time in Sweden. Whereas transportation cost could be reduced by baling [47], losses still occurred due to outdoor storage, especially in long rainy and snowy seasons [18]. In addition, management costs can be relatively high when reed canary grass is planted on marginal land, due to e.g. deep soil preparation [48].

There were ambitious plans for the expansion of the cultivation. For example, the area nearby Skellefteå planned to expand to 3 000 hectares of reed canary grass in the late 2000s [9, 49], and in Finland it was expected to reach 100 000 ha by 2015 [50;51], which in both cases did not occur, since most of the policy incentives were removed before these levels were reached. Additional challenges that precluded reed canary grass to reach these levels include larger-than-expected harvest losses and lower fuel quality, in terms of higher ash content and higher alkaline concentrations, increasing corrosion risks for the boiler [17]. In addition, reed canary grass has a negative perception among some farmers [44], and it is often regarded as an invasive species [2].

Notwithstanding the negative perception, reed canary grass can have multiple positive environmental effects. Besides the production of sustainable biomass, it has demonstrated its role in carbon sequestration [52], enabling a net carbon sink on organic soils [53]. The effect on soil carbon is, however, dependent on the land on which it is established (e.g. [54]). For example, positive effects on soil carbon can in general be expected when established on former cropland, while such effects should be less profound when established on past pasture. The results show that reed canary grass was originally established on previous meadows, although after a few years, many plantations were being replaced by cereals. This pattern is likely linked to the changes related to set aside land as well as the increase in cereal prices after 2007, as observed in Xu and Mola-Yudego [25]; the larger implications of this land-use change pattern should be subject to further study.

Despite some studies suggesting its landscape dominance to have a negative effect on biodiversity [55], the typical cultivation in small areas separated by other land uses may indeed favour a mosaic-based land use pattern, creating diverse niches for fauna and flora [56]. In addition, strategic introduction of perennial crops into agricultural landscapes can in general result in multiple positive effects, by supporting ecosystem services that can mitigate existing environmental impacts related to, e.g., soil and water [3;57]. For instance, the potential of reed canary grass to mitigate GHG emissions from abandoned peat extraction areas has been shown [58].

The success of reed canary grass will depend on a predictable and sustainable economic profit for the farmers. In general, further cost reduction in management practices and higher revenues in terms of energy prices will be required, in order to avoid the excessive dependence on direct policy incentives. Technical and management aspects related to the reduction of harvesting losses can also contribute to a better economic output. Finally, financial compensation for environmental benefits associated with its cultivation would enable the crop to compete with fallow land when planted on marginal land, which is usually the case in Sweden [8].

5 Conclusions

Compared to willow and poplar cultivation in Sweden, reed canary grass presents a good level of commercial yield, despite harvesting losses and less productive locations for cultivation. The different profiles of the three main biomass production systems for energy shows regional complementary features. However, there are important limitations that prevent expansion of the crop, such as insufficient markets for the biomass and lack of compensation for environmental benefits, and the establishment of new plantations is therefore currently highly sensitive to direct support schemes. Finally, there are ongoing land-use trends favouring cereal cultivation, possibly due to more favourable prices. The analysis provided in the study, concerning cultivation areas,

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land use, yield performance and climatic profiles, can serve as a basis to future analysis of the status of energy crops in Northern Europe and elsewhere.

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