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Assessing the profitability of growing dedicated energy versus food crops in four European countries

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Summary

Dedicated energy crops are a widely-considered option for biofuel production, as they may reduce impacts on food markets compared to biofuels produced from food crops. However, energy crops could impact food production and cause indirect land use change (ILUC) if they displace food crops on existing agricultural land. Global economic modeling studies have generally predicted minimal ILUC for dedicated energy crops. These types of studies are sensitive to assumptions about yields, prices, and production costs.

In this study, we conduct an investigation into the potential for energy crops to displace food crops in four countries in Europe based on the relative profitability of these crops. We compare the profitability of Miscanthus, a perennial grass, and short rotation coppice willow to that of top food crops produced in Denmark, Germany, and the United Kingdom, taking into account regional production costs, yields, and market prices of each type of crop. This study also compares the profitability of a perennial cane crop *Arundo donax* in Sardinia, Italy, to food crops grown there. Specifically, we estimate energy crop profitability on productive agricultural land in order to more accurately assess the competitiveness of dedicated energy crops when not restricted to marginal, underused lands.

The study finds that dedicated energy crops are generally not competitive with major food crops. In some cases, energy crops could be expected to produce a slightly greater profit than rye and oats, but the difference in profit potential may not be high enough for farmers to assume the risks inherent in switching to energy crop production, which requires investment in long-term cultivation systems. Neither Miscanthus nor willow are found to be competitive with wheat in Denmark and Germany, suggesting that these energy crops are unlikely to displace the most widely-produced food crop in those countries. The most promising energy crop in terms of profitability is *Arundo donax*, which outperforms cereal crops grown in Sardinia. However, the success of the crop depends greatly on achieving high yields and a favorable farm-gate price. *Arundo donax* is not estimated to be profitable when compared to wine grapes, supporting the finding that the highest-value, economically important crops in a region tend not to be at a high risk of displacement by dedicated energy crops.

This study supports global economic modeling studies' findings that energy crops carry low ILUC risk, corroborating the findings with detailed analyses at a regional level. Biofuels produced from these energy crops may therefore deliver high greenhouse gas savings, if grown in adherence with strong sustainability criteria, and could form a key element of post-2020 transport fuel decarbonization strategies in Europe.

Introduction

Dedicated energy crops are a widely-considered option to produce low carbon, sustainable biofuels as part of Europe's strategies to decarbonize the transport sector. Energy crops, if grown on unused, low carbon land, could avoid some of the greenhouse gas accounting issues that have plagued first generation, food crop biofuels, namely indirect land use change (ILUC) emissions resulting from food price impacts. For example, a literature review in Searle et al. (2016) found that energy crops have the potential to increase carbon storage on abandoned agricultural land in Europe.

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However, energy crops could still impact food production and prices if they displace food crops on currently-used agricultural land. Global economic models used to predict ILUC from biofuel demand have generally reported energy crop ILUC emissions to be lower than from food-based biofuels. In some cases ILUC emissions from energy crops are estimated to be negative. For example, a recent study performed for the European Commission using the GLOBIOM model estimated ILUC emissions of perennial grasses and short-rotation coppice (SRC) crops to be -12 and -29 g CO_2e MJ^{-1}, respectively (Valin et al., 2015). Similarly, another study using the GTAP econometric model estimated that the ILUC emissions from perennial grasses ranged from -10 g to 19 g CO_2e MJ^{-1} (Dunn et al., 2013). The low ILUC values from these studies stemmed from a small degree of land use change in response to energy crop demand, carbon savings from increased soil carbon sequestration, and relatively high biomass stocks from the energy crops themselves, which more than offset other land use change emissions.

While these economic models offer valuable insight into the likely land use impacts of biofuel demand, they are dependent on and sensitive to assumptions for parameters such as crop yields and production costs, which can be locally variable. In particular, yields of energy crops on different types of land in different regions are not clearly understood and are sometimes overestimated (Searle & Malins, 2014). Inaccurate or imprecise assumptions about these parameters could affect results from global economic models by a) affecting the total land area needed to meet a certain level of biofuel demand, and b) affecting the relative profitability of biofuel feedstock compared to other land uses.

In this paper, we conduct a detailed investigation into the risk that energy crops will displace food production on agricultural land by comparing the relative profitability of growing dedicated energy crops versus food crops at national and regional scales. We compared two biofuel crops—perennial grass and SRC—to the top food crops produced in Denmark, Germany, and the United Kingdom. This study also compared the profitability of *Arundo donax* in Sardinia, Italy, to food crops grown there. By estimating the potential energy crop profitability on productive agricultural land, we assessed the degree to which energy crops could compete with food crops when they are not restricted to marginal, underused lands.

For Denmark, Germany, and the United Kingdom, this study assesses the dedicated energy crops Miscanthus (*Miscanthus spp.*) and willow (*Salix spp.*). Miscanthus is a perennial, C4 grass endemic to eastern Asia (Clifton-Brown & Lewandowski, 2002). The most common variety grown in energy crop trials is *Miscanthus x giganteus* Greef et Deu (Searle & Malins, 2014), although a range of genotypes has been tested for yield performance traits across Europe (Clifton-Brown et al., 2001). *M. x giganteus* is a sterile triploid and thus is propagated by transplanting rhizomes (Searle & Malins, 2014), which contributes significantly to the start-up costs of Miscanthus plantations (Witzel & Finger, 2015). *M. sinensis* outperformed *M. x giganteus* in overwintering trials, making *M. sinensis* genotypes more likely candidates for dedicated fuel crop cultivation in colder, northern European climates (Jørgensen, 1997).

SRC willow is part of the genus *Salix,* which is taxonomically complex and includes hundreds of species worldwide (Verwijst et al., 2013). Its distribution is primarily in cold regions of the northern hemisphere, and it has been cultivated in Europe for 2000 years (Verwijst et al., 2013). Willow readily hybridizes but requires adequate precipitation or irrigation (Searle & Malins, 2014).

Arundo donax (commonly referred to as giant cane) is a perennial cane that is native to eastern Asia and invasive in Europe (Pilu et al., 2013). It was introduced to Sardinia hundreds, or possibly even thousands of years ago and has since been naturalized (i.e., naturally reproduces) across the island. It propagates readily from rhizomes and grows in dense thickets, outcompeting other species. *A. donax* requires considerable irrigation to thrive and thus can only be successfully cultivated where sufficient water resources are present.

Methods

The profitability of dedicated energy crops is compared to the profitability of several food crops in Denmark, Germany, Italy and the United Kingdom. Energy crops are chosen for the study based on the availability of yield data in a particular study region. Because dedicated energy crops are not yet included in agricultural databases, energy crop data was collected from the primary literature. A detailed summary of Miscanthus and willow yield data is presented in Appendix 1. Because Miscanthus yields are low in the first years of plantation establishment (Searle and Malins, 2014), only yields after the third harvest season are included in this study.

The five most common food crops in each country are considered for this study, but some crops were eliminated or replaced if sufficient yield, production cost, and price data are not available. Five-year averages (2010-2014) are calculated for food crop yields and farm-gate prices. Exceptions are made when data spanning five years are not available, in which case the mean of all available data post-2010 is used. Regional food crop yield data is obtained from Eurostat (2016), and national food crop yield data is obtained from (FAOSTAT, 2016). Farm-gate price data (FAOSTAT, 2016), defined as prices received by farmers for primary crops as collected at the farm-gate or at first point of sale, is used to calculate profitability. National statistics for each food crop in each country are presented in Table 1.

Miscanthus profitability is assessed on a regional scale for central Denmark, southern England, and southern Germany, which represent productive agricultural regions of each country. Miscanthus yields and profits are estimated from studies in a single region and then compared to food crop data from that specific region, when available. An estimate of Miscanthus farm-gate price for the EU is taken from Witzel & Finger (2016) and applied at the regional level, as regional or national price data are not available for Miscanthus.

Willow profitability is measured at the national scale, and estimates of willow yields include data from studies across all of Denmark, Germany and the United Kingdom (Figure 1). Similarly, willow profits are compared to food crop profits at the national scale. Willow farm-gate price is taken from Witzel & Finger (2016) and Stolarski et al. (2015).

In Carbonia, Sardinia, Italy, the profitability of growing *A. donax* is assessed in comparison to two cereal crops and two high-value crops. *A. donax* is not grown at a commercial scale in the region, but plans are in place for a biorefinery in Carbonia, and the choice between food and fuel crops could soon be available to most farmers within 60 km of the biorefinery. Probable yields are taken as 40 t ha^{-1} under fully irrigated conditions, based on a local case study (Searle et al., 2016).

A sensitivity analysis is conducted for A. donax, in which a range of farm-gate prices and yields are used to calculate potential profits from growing the crop. Current trials have returned varying yields, with increasing outputs expected as cultivation methods are refined. This sensitivity analysis allows for the estimation of break-even prices in comparison to food crop production. Food crop data is obtained at a national level from Eurostat (2016).

Figure 1. Map of Europe with study countries highlighted.

Production costs for Miscanthus are calculated, and production costs for willow, *A. donax* and all food crops are taken directly from the literature. It is assumed that while production costs may vary slightly depending on climate and soil conditions, overall approaches to propagation, planting, harvest and plantation maintenance are comparable amongst countries. The cost to grow Miscanthus, a perennial crop, is calculated using the following equation (Wang, 2011):

$$P = \frac{\sum_{t=1}^{T} \frac{C_t}{(1+d)^{t-1}}}{\sum_{t=1}^{T} \frac{Y_t}{(1+d)^{t-1}}},$$

where T represents the lifespan of the plantation (in years), t represents the year, C_t represents the cost (Euros ha^{-1}), d represents the discount rate, and Y_t represents Miscanthus yield (t ha^{-1}). The cost variable include establishment (propagation), harvest, fixed overhead costs, storage and plantation removal, as well as consideration of plantation establishment subsidies in the case of the United Kingdom (Witzel & Finger, 2016).

Willow production cost is taken as 64.6 Euros t^{-1} based on the mean cost of production, harvest and transport of seven different willow cultivars

(Stolarski et al., 2015). The production cost of willow is assumed to be the same across all countries included in the study. The cost of producing *A. donax* in Italy is taken as 87.2 Euros t^{-1} and includes all aspects of production, harvest and transport (Christou, 2013).

Food production costs are taken from the literature, and when appropriate, adjusted for country-specific yields. Wheat and barley production costs are estimated from European Commission—EU FADN (2014). Oats and rye production costs are estimated from European Commission—EU FADN (2011). Potato production costs are taken from AHDB (2012). Artichoke production costs in Italy are estimated from Sgroi et al. (2015), and wine grape production costs in Italy are estimated from Strohm et al. (2014).

Basic crop profits are calculated as:

Table 1. National statistics for food crops included in the study. Data for each country are sorted from highest to lowest production amounts. Data are obtained from FAOSTAT (2016).

		Area harvested (1000 ha)	Production (million tonnes)	Gross value (million Euros)	Export (tonnes)
Denmark	wheat	671,000	4,700,000	593	959,000
	barley	639,000	3,560,000	446	885,000
	potato	39,900	1,600,000	309	178,000
	rye	73,600	428,000	40	49,300
	oats	54,200	266,000	33	30,000
Germany	wheat	3,190,000	24,400,000	2,982	7,580
	potato	248,000	10,800,000	1,673	1,840,000
	barley	1,610,000	10,300,000	446	2,080,000
	rye	673,000	3,570,000	40	49,000
	oats	137,000	648,000	68	38,100
Italy	wine grape	725427	7,270,000	3,355	494,000
	oats	117000	743,000	73	8,500
	barley	252000	273,000	147	8,500
United Kingdom	wheat	1,890,000	14,400,000	1,845	1,890,000
	barley	1,040,000	6,050,000	687	817,000
	potato	142,000	5,360,000	1,073	1,180
	oats	134,000	743,000	82	31,200

$$Profit = Yield\ (t\ ha^{-1}) \times [Price\ at\ farm\ gate\ (€t^{-1}) - Cost\ of\ production\ (€t^{-1})]$$

All dedicated energy crops are assumed to be sold at a commercially dry weight of 15% moisture content, and yields are adjusted accordingly.

Results and Discussion

MISCANTHUS

Miscanthus is not competitive with food crops in central Denmark, but it is competitive with oats and rye in southern Germany and with oats in southern United Kingdom (Figure 2). Oats and rye are not significant crops in either country, however, comprising lesser production and export quantities than wheat or barley. As such, the risk of displacement of the highest producing crops in any of the study countries appears to be low for Miscanthus. In all cases, potato greatly outperforms Miscanthus and would likely not be replaced by the energy crop. Our literature review returned a wide range of potato profits, and we report a modest profit here, which is calculated using relatively high production costs. Using any of the available potato profit data, however, would lead to the conclusion that dedicated energy crops cannot compete with potato. Wheat, which has the highest production and export values for Denmark and Germany, also significantly outperforms Miscanthus.

WILLOW

Willow is more profitable than rye in Germany and more profitable than oats in the United Kingdom (Figure 3). Again, oats and rye have the lowest production values among the food crops included in the study. In Denmark, all food crops outperform willow (Figure 3). In all cases, potato greatly outperforms willow and would likely not be replaced by the energy crop. Willow does not compete with wheat in either Denmark or Germany, suggesting that the dedicated energy crop would likely not displace the most widely-produced crop in those countries.

A. DONAX

A. donax is estimated to be more profitable than cereal crops such as barley and oats in Sardinia (Figure 4). Importantly, *A. donax* earns 111 Euros ha^{-1} more than artichokes, which is a staple crop on farms in Sardinia. Although artichokes are a relatively high-value crop, they also incur high production costs (Sgroi et al., 2015). In the case of labor and capital-intensive food crops, a dedicated energy crop that earns more money and requires little investment could displace the food crop. This finding was qualitatively supported by personal communications with farmers in Sardinia, who expressed interest in growing and profiting from *A. donax* (Searle et al., 2016). When compared to a high-value crop such as wine grape, however, *A. donax* earns much less money per hectare. Farmers may choose to replace cereal or labor-intensive crops with the dedicated energy crop but continue to grow specialty crops such as grapes.

In order for *A. donax* to be profitable, yields and farm-gate prices must meet break-even values (Table 2), which is not guaranteed based on trial estimates and market forecasts. The minimum yield included in the sensitivity analysis is 25 t ha^{-1}, which has been achieved only in trials that received adequate irrigation (Christou, 2013). At a yield of 25 t ha^{-1}, farm-gate prices would have to be 65 Euros t^{-1}, which is slightly higher than expected prices. The profitability of the crop is ensured by having a higher yield and a minimum price point of 60 Euros t^{-1}. It is important to note that there is some variability and uncertainty in yields and prices for all of the energy and food crops and regions included in this study, and while we present a sensitivity analysis for *A. donax* for illustrative purposes, outcomes for all of the energy crops in question could change with fluctuations in input parameters.

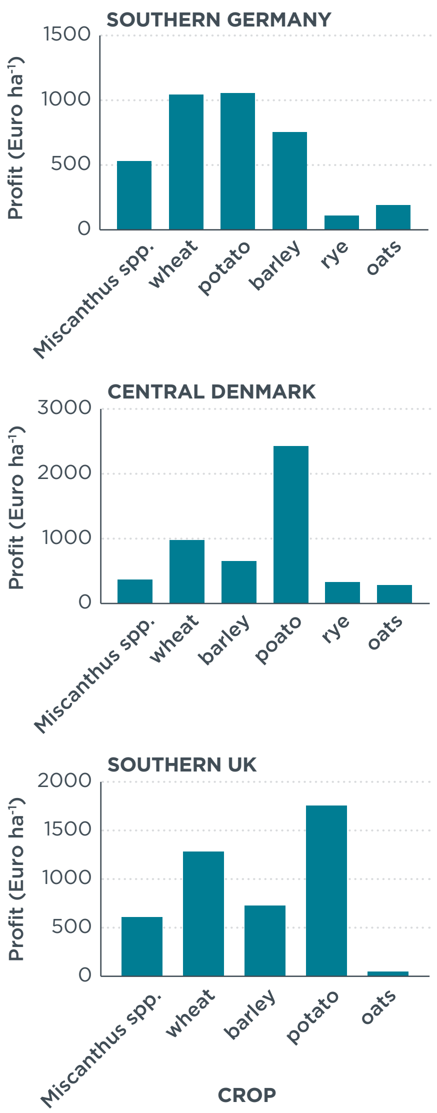

Figure 2. Profit at farm gate for *Miscanthus spp.* versus food crops in specific regions of Germany, Denmark and the United Kingdom. Food crops are ordered on the x-axis from highest to lowest national production quantities.

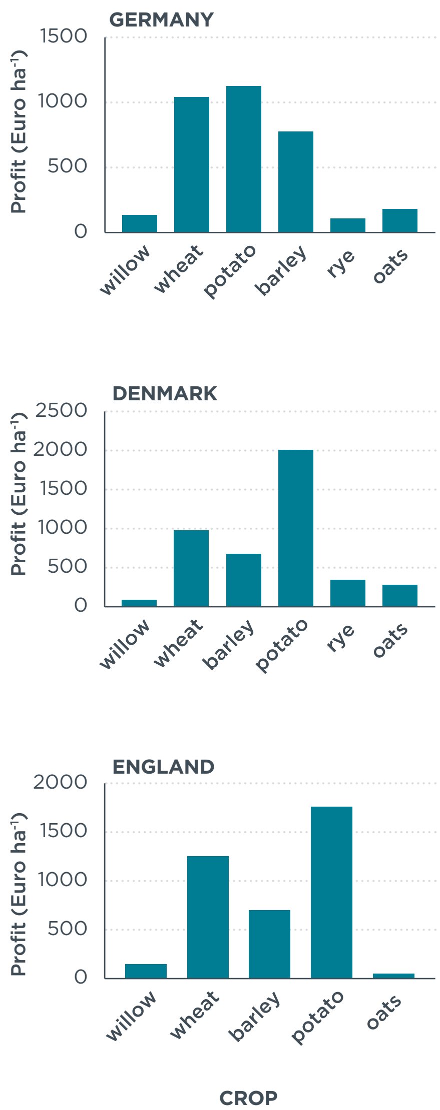

Figure 3. Profit at farm gate for willow cultivars versus food crops in Germany, Denmark and the United Kingdom. Food crops are ordered on the x-axis from highest to lowest national production quantities.

For all of the energy crops included in this study, a long-term commitment to the crop is required. While plantation lifespans for Miscanthus range, a typical plantation lifespan is 20 years (Witzel & Finger, 2015). *A. donax* plantation lifespan is expected to be 10-15 years (personal communication, 2015). The long-term investment required to begin cultivation of these energy crops may make it less likely for farmers to take the risk in growing them, even when the energy crop is more profitable than the existing food crop. Growing energy crops may be more advantageous if farmers are able to form long-term offtake contracts with biorefineries (Wang, 2011).

Of the crops included in the study, wheat and potato have the highest production and export values, and they are much more profitable than dedicated energy crops. These significant crops are not likely to be displaced by energy crops. It should be noted that while crops such as rye and oats have relatively low production quantities as compared to other crops included in the study, they also represent some of the top crops grown in the country, and their significance cannot be discounted if they were to be replaced by dedicated fuel crops.

This study assesses the profitability of growing energy crops given current likely biomass prices. However, it is important to note that energy crop profitability could change with relevant policies. A plantation establishment subsidy of 1,005 Euros is included in the United Kingdom analysis, and energy crops would likely be less profitable if the subsidy were to be revoked. Strong policy support for cellulosic biofuels in Europe could potentially increase the profitability and thus ILUC risk for energy crops. However, this effect would depend strongly on the type of policy and on how the policy support is shared along the product chain. A subsidy given directly to producers of cellulosic feedstock would be more likely to support energy crop profitability compared to a subsidy for advanced biofuel blending, for example: in the latter case, the bulk of the policy value would likely be absorbed by the biofuel facility, as production of advanced biofuels is not currently economically viable without policy support (see Peters et al., 2016).

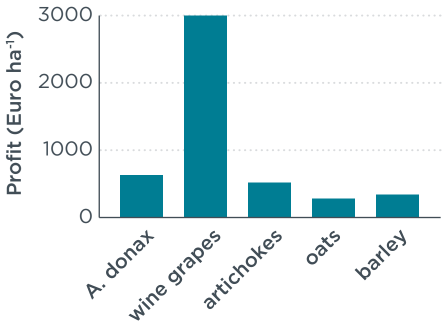

Figure 4. Expected profit at farm gate for *A. donax* (giant reed) versus food crops in Sardinia, Italy. Food crops are ordered on the x-axis from highest to lowest national production quantities.

Conclusion

Overall, this study finds that dedicated energy crops are not competitive with major food crops in most cases. At present prices and yields, dedicated energy crops make a slightly greater profit than rye and oats, but the difference in profit potential may not be high enough for farmers to assume the risks inherent in switching to energy crop cultivation, which requires long-term investment. Neither Miscanthus nor willow are competitive with wheat in Denmark and Germany, suggesting that the dedicated energy crop would not likely displace the most widely-produced crop in those countries. Profits from dedicated energy crops are also orders of magnitude lower than potato.

The most promising energy crop in terms of profitability is *A. donax*, which outperforms cereal crops grown in Sardinia, but the success of the crop depended greatly on achieving high yields and a favorable farm-gate price. Importantly, while *A. donax* was competitive with cereal crops, cereals are not important crops in the region in terms of production quantities or profits. *A. donax* does outcompete artichoke by approximately 100 Euros ha^{-1}, and this suggests that artichoke, which is an important fixture in Sardinian farms, could be at risk of displacement by the energy crop. In Sardinia, *A. donax* is not more profitable than wine grapes, which are produced and exported in significantly greater quantities.

This study generally supports findings from global economic modeling studies, which suggest that energy crops are not likely to cause high ILUC by displacing existing food crops on agricultural land. While our results suggest that some displacement may occur, it would not likely be widespread across the top produced crops in European countries. When energy crops would be marginally more profitable than food crops, farmers may not be likely to make the long-term investment needed to switch to energy crop production. Thanks to their low ILUC emissions, advanced biofuels produced from energy crops may deliver high greenhouse gas savings and could make an important contribution to Europe's transport decarbonization goals. However, strong sustainability criteria prohibiting energy crop production on land with high carbon stocks and biodiversity will be important in order to ensure environmental goals are met.

Table 2. Potential *A. donax* profits (in Euros per tonne) as a function of varying farm-gate price and yield. Profits in grey fall below estimated profits for other food crops grown in the region.

		Farm-gate price (Euros)				
		50	**55**	**60**	**65**	**70**
Yield (tonnes per hectare)	**25**	-21.5	103.5	228.5	353.5	478.5
	30	-25.8	124.2	274.2	424.2	574.2
	35	-30.1	144.9	319.9	494.9	669.9
	40	-34.4	165.6	365.6	565.6	765.6
	45	-38.7	186.3	411.3	636.3	861.3

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Appendix A. Dedicated energy crop yields in Denmark, Germany and the United Kingdom.

MISCANTHUS						
Authors	**Publication Year**	**Location**	**Yield (T/Ha/Yr)**	**Species**	**Fertilizer**	**Land Quality**
Clifton-Brown et al.	2001	Rothamsted, England	15.975	M. x giganteus	Yes	Previously agricultural
Clifton-Brown et al.	2001	Rothamsted, England	13.94	M. sinensis	Yes	Previously agricultural
Christian et al.	2008	Rothamsted, England	12.8	M. x giganteus	Yes	Previously agricultural
Clifton-Brown et al.	2001	Central Denmark	15.2	M. sinensis	Yes	Previously agricultural
Clifton-Brown & Lewandowski	2002	Central Denmark	11.06	M. sinensis hybrid	Yes	Previously agricultural
Jørgensen	1997	Denmark	8.9	M. sinensis	Yes	Agricultural soils
Larsen et al.	2015	Denmark	13.1	M. x giganteus		
Venendaal et al.	1997	Denmark	8.5			Preferred soil; Commercial growing conditions
Lewandowski & Schmidt	1997	Durmersheim, Germany	10.275	M. x giganteus	Yes	Field research station; suitable soils
Lewandowski & Schmidt	1997	Stuttgart, Germany	27.4	M. x giganteus	Yes	Field research station; suitable soils
Lewandowski & Schmidt	1997	Gutenzell, Germany	14.95	M. x giganteus	Yes	Field research station; suitable soils
Schorling et al.	2014	southern Germany	27	M. x giganteus		Previously agricultural; Optimal soils and climate
Iqbal et al.	2015	Stuttgart, Germany	18.3	M. x giganteus	Yes	Field research station; suitable soils
Gauder et al.	2012	Stuttgart, Germany	14.1	M. x giganteus	Yes	Field research station; suitable soils
Gauder et al.	2012	Stuttgart, Germany	10.7	M. sacchariflorus	Yes	Field research station; suitable soils
Gauder et al.	2012	Stuttgart, Germany	9.5	M. sinensis hybrid	Yes	Field research station; suitable soils

SALIX						
Authors	**Publication Year**	**Location**	**Yield (t/ha/yr)**	**Genotype/ Clone**	**Fertilizer**	**Land Quality**
Lindegaard et al.	2001	United Kingdom	15.4	Ashton stott		
Aylott et al.	2008	England	9.5	Jorun		Previously ceareal production
Aylott et al.	2008	England	9.1	Q83		Previously ceareal production
Sevel et al.	2012	Denmark	7.0			
Sevel et al.	2013	Denmark	11		Yes	Best growing conditions
Nord-Larsen et al.	2015	Denmark	7.5			Commercially-grown stands
Nord-Larsen et al.	2015	Funen, Denmark	3	Sven, Tordis	Yes	Previously cereal production
Nord-Larsen et al.	2015	North Jutland, Denmark	9.5	Igor, Tordis, Gudrun	Yes	Previously cereal production
Nord-Larsen et al.	2015	Zealand, Denmark	8.2	Sven,Tordis, Torhild, Tora	Yes	Previously cereal production
Larsen et al.	2014	Hojmark; Denmark	4	S. viminalis	Yes	
Larsen et al.	2014	Foersom; Denmark	4.2	S. viminalis	Yes	
Scholz & Ellerbrock	2002	Germany	5.9	S. viminalis		Previously agricultural
Aust et al.	2014	Germany	11.4			Favorable cropland
Aust et al.	2014	Germany	16.3			Very favorable cropland
Aust et al.	2014	Germany	7.5			Medium cropland

Appendix Citations

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