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A full economic analysis of switchgrass under different scenarios in Italy estimated by BEE model

A. Monti[a,*], S. Fazio[a], V. Lychnaras[b], P. Soldatos[b], G. Venturi[a]

[a]*Department of Agroenvironmental Science and Technologies, Viale Fanin 44, 40127 Bologna, Italy*
[b]*Laboratory of Agribusiness Management, Agricultural University of Athens, Iera Odos 75, Boatnikos 11855, Athens, Greece*

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Abstract

Three different scenarios of switchgrass (*Panicum virgatum L.*) cultivation (high, mild and low) in two different environmental conditions (North and South Italy) were economically analysed by the computerized model BEE. The dataset was mostly generated from an 8.6 ha field of switchgrass planted in 2002 at the University of Bologna (North Italy). Annual equivalent costs (AEC) and break-even yield (BEY, i.e. the dry matter yield at which cost equals selling price) of each scenario were calculated to assess the feasibility of each scenario. AEC ranged from €511 to €1.257 ha^{-1} being always higher in northern than southern regions. As expected, BEY varied to an extent depending on input levels. BEY was clearly higher under intensive cropping systems (H_S) compared to mild-(M_S) and low-input (L_S) scenarios. However, even for M_S or L_S, BEY generally exceeded the harvested yield. Therefore, we can conclude that, at the market price of €55 Mg^{-1} (dry basis), switchgrass can be hardly grown both in North and South Italy. However, the biomass market price appeared surprisingly underestimated if compared to the unit energy price of crude oil, therefore a desirable increase of biomass price could be expected in the next few years. Sensitivity analysis showed that biomass price strongly affects BEY, and this was especially found in H_S. Furthermore, the differences in BEY between L_S and H_S clearly decreased with increasing market prices. Therefore, H_S could be better indicated than L_S at high market prices. Switchgrass was found to be more profitable than some conventional crops to an extent depending on the yield higher than BEY (Y_i). At the current biomass price, Y_i was from less than 1 Mg ha^{-1} (maize and alfalfa) to more than 4 Mg ha^{-1} (sugarbeet).

Keywords: Switchgrass; *P. virgatum*; Economic analysis; Energy; Biomass; BEE

1. Introduction

Carbon emission reductions, environmental protection and sustainable energy supply are major objectives of the world energy policy. Energy crops seem to match these goals as it has been widely demonstrated that they can supply high dry matter yields, to be converted into energy, while sinking large amounts of carbon into the soil [1–3]. Furthermore, carbon emission into the atmosphere due to the combustion of energy crops, is roughly equal to the CO_2 absorbed by the crops during their growth. Among the energy crops, the perennials have received growing attention due to their high dry matter yield with low input techniques [4]. Besides, unlike annual crops, the perennials need soil tillage only at the establishment year, and this was found to significantly reduce soil degradation [5,6].

Several perennial herbaceous crops have been evaluated in the past few years for energy purposes (electricity and heat). Among them, giant reed, miscanthus and switchgrass appeared as the most promising because of the yield levels, environmental attributes and possible economic return to the farmers [7].

Giant reed and miscanthus generally showed higher potential biomass yields than switchgrass [4]. However, unlike switchgrass, they are sterile and propagated by expensive rhizomes, while switchgrass produces seeds. This makes switchgrass establishment likely to be much more economic and easier to mechanize than that of the other two crops [8]. For instance, in Italy the farm-gate cost of

*Corresponding author. Fax: +39 51 2096241.
E-mail address: a.monti@unibo.it (A. Monti).

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each rhizome of giant reed is about 0.5 €, hence the cost of genetic material would be about 5000 € ha^{-1}, which is likely to be too expensive for this kind of use. In contrast switchgrass seeds cost (US market) is only about 100 € ha^{-1}, thus making switchgrass a more feasible energy crop over the short term.

Switchgrass (*Panicum virgatum* L.) has been introduced in Europe as a potential energy crop only recently. However, several studies on growth and yield showed encouraging results, and it is now clear that switchgrass can be cultivated both in North and South Europe [7,9]. Despite the management practices, biological and physiological features of switchgrass are quite well documented [10–12], little is know about the economic performance of this crop in Europe, and this is surprising as the feasibility of switchgrass will mostly depend on it. Some studies in North America showed that switchgrass has the lowest cost per dry tonne of biomass among competing perennial and annual energy crops [13–15]. In a recent study McLaughlin and Kszos [10] estimated that switchgrass, at a market price of \$44 Mg^{-1} (dry weight basis), would be more profitable than conventional crops on at least 13 Mha of American farmland. This result is very encouraging as Hallam et al. [13] reported a market price of switchgrass of \$56 Mg^{-1}, and Samson et al. [16] of \$94 Mg^{-1}, though the later referred to the pellet price [16]. Again, Fox et al. [17] estimated a break-even cost of switchgrass of \$50 Mg^{-1}, but they envisaged that the reasonable price of switchgrass biomass could be in the range of \$70–\$85 Mg^{-1}.

Market price of switchgrass will be likely determined by its potential dry matter yield, which was found to change noticeably with environment and cultivar [12,18,19]. Literature reports a very wide range of switchgrass yield [11,12,20–22], which can be explained by different environmental conditions, plant age and techniques. For instance, Heaton et al. [23] found a positive effect of nitrogen on biomass yield; still, they showed irrigation to significantly increase biomass yield. However, high yields do not necessarily correspond to high return, which in turn depends on the best compromise between yield and production costs. The goal of the present work was therefore to estimate the break-even yields of some possible scenarios in North and South Italy, i.e. the yield threshold below which the cultivation of switchgrass is no more economically viable. The calculations below are based on data recorded on an 8.6 ha field of switchgrass at the University of Bologna, to our knowledge the only available historical data on switchgrass under commercial agricultural system in South Europe. For the economic and technical analysis the computerized model BEE (Biomass Economic Evaluation) was used [24].

2. Materials and methods

2.1. Scenarios and data collection

The six scenarios of switchgrass considered are summarized in Table 1. The differences between the scenarios concerned both the establishment and production years. Low-input scenarios (L_S) may be expected when soil tillage and field operations are generally arduous and the environmental impact must be kept low (e.g., in hill fields against soil erosion). The high-input scenarios (H_S) are suited for intensive agricultural systems with adequate farm facilities. The mild-input scenarios (M_S) can be associated with the most common Italian situations. We also considered different input levels between southern and northern scenarios as severe dry conditions generally occur in South in summertime.

To our knowledge, there was no large field of switchgrass in Italy under commercial agricultural conditions before this research. The literature on production cost of switchgrass indicates a very large range of variation (see [25] for an extend review), and this was mostly due to the uncertainty of the potential yield of switchgrass. Therefore, in order to assess the potential yield under mechanized

Table 1
Description of the six considered scenarios in North and South Italy. H_S, M_S and L_S indicate high-, mild-and low-input scenarios, respectively

Period	Operation	Units	North			South		
			H_S	M_S	L_S	H_S	M_S	L_S
Establishment year	Plough depth	m	0.5	0.3	—	0.5	0.3	—
	Weed control	n	3	2	1	3	2	1
	Vibrocultivating	n	—	1	—	—	1	—
	Harrowing	n	2	1	—	2	1	—
	Sowing	n	1	1	1	1	1	1
	Rolling	n	1	1	—	1	1	—
	Irrigation	$l\,m^{-2}$	90	60	—	180	90	60
	Fertilization (P)	$kg\,ha^{-1}$	44	44	44	44	44	44
Production years	Weed control	$n\,y^{-1}$	1	1[a]	—	1	1[a]	—
	Fertilization (N)	$kg\,ha^{-1}$	160	80	40	160	80	40
	Cutting frequency	$n\,y^{-1}$	2	1	1	2	1	1
	Irrigation	$l\,m^{-2}\,y^{-1}$	90	—	—	180	60	—

[a]2nd year only.

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Table 2
Cost of machinery per hour and time-consumption of high-(H_S), mild-(M_S) and low-(L_S) input scenarios in South and North Italy

Machinery type	Cost	North			South		
		H_S	M_S	L_S	H_S	M_S	L_S
	(€ h^{-1})	(h ha^{-1} y^{-1})					
Establishment year							
Tractor[a] (145 kWh)	8.2	3.5	3.0	—	3.5	3.0	—
Tractor[a] (80 kWh)	5.3	4.2	4.2	2.0	4.2	4.2	2.0
Tractor[a] (52 kWh)	4.4	5.4	4.9	1.7	5.4	4.9	2.7
Plough[a] bi-ploughshare	0.9	3.5	3.0	—	3.5	3.0	—
Weeder[a]	0.7	2.0	2.0	—	2.0	2.0	—
Vibrocultivator[a]	0.6	—	1.0	—	—	1.0	—
Disk-harrow	0.8	1.2	—	—	1.2	—	—
Rotating harrow[a]	2.2	1.0	1.0	—	1.0	1.0	—
Drill[a]	1.4	1.5	1.5	—	1.5	1.5	—
Sod-seeding drill	2.1	—	—	2.0	—	—	2.0
Rolls[a]	0.4	0.7	0.7	—	0.7	0.7	—
Fertilizer distributor[a] (0.6 t)	0.6	1.0	1.0	1.0	1.0	1.0	1.0
Herbicide barrel[a] (1000 l)	1.6	1.2	0.7	0.7	1.2	1.2	0.7
Traveling gun (100 m^3 h^{-1})	2.7	9.0	6.0	—	15.0	9.0	6.0
Production years							
Tractor[a] (80 kWh)	5.3	3.0	3.0	3.0	3.0	3.0	3.0
Tractor[a] (52 kWh)	4.4	10.1	8.5	6.3	10.1	9.5	6.3
Fertilizer distributor[a] (0.6 t)	0.6	1.5	0.8	0.8	1.5	0.8	0.8
Herbicide barrel[a] (1000 L)	1.6	0.6	0.6[b]	—	0.6	0.6[b]	—
Traveling gun (100 m^3 h^{-1})	2.7	9.0	—	—	15.0	6.0	—
Cutter[a]	1.3	2.5	1.5	1.5	2.5	1.5	1.5
Windrower[a]	0.5	2.5	1.5	1.5	2.5	1.5	1.5
Round baler[a]	8.8	3.0	3.0	3.0	3.0	3.0	3.0

Not including labour cost and raw materials costs.
[a]Measured data (the remaining data were collected from literature [24]).
[b]Second year only.

cultivation techniques, an 8.6 ha field was established at the experimental farm of the University of Bologna, in Ozzano dell'Emilia (lat. 44° 25′ N; lon. 11° 28′ E, 80 m a.s.l.). Switchgrass was planted in May 2002 according to a mild-input technique. Ploughing was performed at 30 cm depth followed by mechanical weeding, rotating-harrowing and vibrocultivating. The lowland variety Alamo, seeded at 8.0 kg ha^{-1}, was chosen because of the good tolerance to northern Italian climates [12] and the relative high dry matter yield [11,12]. Emergence occurred 15 days after sowing with a plant density of 106 ± 18 plants m^{-2}. Maintenance dose of P (44 kg ha^{-1}) was applied, whereas K was not supplied as soil chemical analysis showed high concentration of available K. All mechanical equipment and time-consumption during field management were monitored and a specific dataset for switchgrass was generated. Data concerning machinery equipment, raw materials, labour and operation timing are summarized in Tables 2 and 3. Winter harvest was performed in the 3 years 2003–2005: dry standing biomass was cut and baled and each single bale was weighted. After that, randomized samples of about 1 kg of bulk biomass were collected, weighed and dried at 105 °C for 24 h and the dry matter content was determined. The harvested area was measured by an handheld GPS unit (GEKO 201, Garmin Ltd.), and the dry matter yield per hectare was than calculated.

2.2. Cost analysis methodology

The economic analysis of energy crop production consists of the cost and financial analysis of all agricultural production stages [26]. The proposed methodology in the context of the computerized model that has been adopted, demands the decomposition of the project into a number of activities[1] which sufficiently describe all required jobs for plant instalment, cultivation and harvesting activities [27]. Each operation is characterized by its timing (both duration per hectare and seasonality within each year) and its requirements for labour, equipment and materials (Tables 2 and 3).

Mechanical equipment may be hired if own machinery is insufficient or non-existent. When hired, its cost is equal to the rent paid; otherwise its hourly cost is the sum of depreciation, interest, maintenance, insurance and fuel. Fuel consumption depends upon operation and machinery used and can easily be estimated if required. In the present analysis it was assumed that all operations are

[1]Activity based costing (ABC) analysis.

Table 3
Description and cost of raw material, labour and land under high- (H_S), mild- (M_S) and low- (L_S) input scenarios in North and South Italy. Labour cost includes welfare and insurance contributions

Category	Description	Unit	Cost (€ unit^{-1})	North			South			Ref.
				H_S (unit ha^{-1} y^{-1})	M_S	L_S	H_S	M_S	L_S	
Establishment year										
Labour (North)	Unskilled	H	13	14.2	13	4.2	—	—	—	[37]
Labour (South)	Unskilled	H	12	—	—	—	14.2	13	5.2	[37]
Fuels	Diesel	L	0.65	147	120	24	181	132	52	[38]
Seeds	—	kg	11.5[b]	8	8	8	8	8	8	
Fertilizer	0-21-0	kg	0.2	200	200	200	200	200	200	[39]
Herbicides	Gliphosate	L	15	3	3	3	3	3	3	[39]
Herbicides	Mecop. + Ionixil	L	12	2.5	—	—	2.5	—	—	[39]
Herbicides	Nicosulfuron	L	10	0.5	—	—	0.5	—	—	[39]
Water (North)	—	m^3	0.15	900	600	—	—	—	—	[36]
Water (South)	—	m^3	0.16	—	—	—	1800	900	600	[36]
Production years										
Labour (North)	Unskilled	h	13	15	9.5	8.5	—	—	—	[37]
Labour (South)	Unskilled	h	12	—	—	—	15	10.5	8.5	[37]
Fuels	Diesel	L	0.65	107	53	50	143	89.0	50	[38]
Fertilizer	46-0-0	kg	0.25	160	80	40	160	80	40	[39]
Herbicide	Gliphosate	L	15	3	3[a]	—	3	3[a]	6	[39]
Water (North)	—	m^3	0.15	900	—	—	—	—	—	[36]
Water (South)	—	m^3	0.16	—	—	—	1800	900	—	[36]
Land rent cost										
Northern Italy	Irrigated	ha	250	1	1	—	—	—	—	[40]
Northern Italy	Non-irrigated	ha	150	—	—	1	—	—	—	[40]
Southern Italy	Irrigated	ha	280	—	—	—	1	1	1	[40]

[a]2nd year only.
[b]US average market price.

performed by own means. The details of machines are listed in Table 2.

Land is in most cases a major cost item. In this research the land cost was estimated by its rent market cost properly of each area.

Labour cost was evaluated at its opportunity cost, i.e. the amount of income forgone for shifting family labour from current activity due to the needs and requirements.

2.3. Annual equivalent cost

When overall plant cost estimation is required, inspecting the individual cost per year is of no use because some operations are not performed regularly and uniformly year after year and therefore, annual cost may differ among the years of the plantation's life. For example, the cultivation of perennial energy crops is characterized by a high cost for the establishment year and lower annual costs for the rest of its productive life.

From the economist's point of view, the overall approach is to estimate the average annual cost over the whole economic life of the crop, which allows direct comparisons among different crops. This approach should include the initial investment cost and also should take into account the time value of money. In such cases, the overall cost estimates should be calculated as 'annual equivalent costs' (AEC), i.e. costs that express lifetime averages incorporating the time value of money (see e.g., [28,29]). To calculate AEC, the present value of all costs over the useful life of the plantation is transformed into an equivalent annuity with annual payment equal to AEC.

Given a discount rate (d) and the plantation useful life (n),

$$AEC = \frac{PV \times d}{1 - (1+d)^{-n}},$$

where

$$PV = \sum_{t=0}^{n} TC_t \times (1+d)^{-t}$$

and TC_t is the total cost of plantation in year t. In this research n was assumed equal to 15 years and d equal to 10%.

2.4. BEE model—brief description

BEE is a computerized model developed by the Laboratory of Agribusiness Management of the Agricultural University of Athens [24,30], which performs a full economic analysis of energy crop production [29]. The model is composed of two main modules: (i) cost analysis and (ii) financial. The first performs cost estimation of biomass cultivation, both by activity and by input factor of production. The second carries out financial analysis, based on calculated future balance sheets, financial results and expected cash-flows. The model can analyse annual and/or perennial energy crops. It can analyse single or multiple crop systems.

The most relevant features of BEE are the following: (a) it is a standard MS Win XP application with internet support were the user may also find download database files of case studies (http://www.bee.aua.gr); (b) it performs detailed monthly monitoring of activity levels and operation needs (labour, raw materials, machinery usage, etc.); (c) it carries out full economic analysis by agricultural activities and by factor of production. The estimated cost is reported by tonne or hectare; (d) it performs full financial analysis in standard accounting formats. The model estimates all principal financial statements (monthly balance sheets, income and cash flows statements) for every crop; (e) it identifies all relevant cash flows of each crop in order to consolidate results of projects incorporating more than one crop; (f) it has user friendly input forms and reports.

2.5. Input data

The recording of cost elements was performed in physical units rather than in financial terms, (for example machine-hours, man-hours, quantities of raw materials, etc.), according to BEE methodology [24].

The agricultural data was categorized as follows: (a) general financial data that consist of economic data concerning a region or the whole country, such as currency, short/long-term borrowing rate, inflation rate, risk premium etc. For the present analyses, the discount rate (cost of capital) used was 10%; (b) agricultural project data, such as total occupied land, percentage of cultivated land (cultivation coefficient), own buildings, overheads and other agricultural project related data. The analysis of each scenario was performed for an assumed total area of 10 ha (95% cultivated); (c) technical and economic data of energy crop, such as economic life of the plantation, annual yields, selling price of biomass, subsidies, cost of agricultural land by type (for example irrigated, marginal, etc). For every scenario, the economic life of switchgrass was assumed to be 15 years. The crop yields in each year are still uncertain, so a break-even yield (BEY) was estimated based on an approximate selling price of €55 Mg^{-1} (dry weight basis). BEY (expressed as $\mathrm{Mg\,ha^{-1}\,y^{-1}}$) was obtained by the ratio of AEC (see Section 2.3) and selling price. This selling price of dry biomass was not available because there is no switchgrass market in Italy. Therefore, the price of switchgrass was estimated based on conclusions and estimations of several national meetings on dedicated energy crops (Gianpietro Venturi, personal communication) and the US market price of switchgrass (i.e. \$56 Mg^{-1}, [13]). The specific subsidy of 45 € ha^{-1} for energy crops (Council Regulation EC 1782/2003) was also included in the calculations of the BEY. Conversely, the set-aside subsidy was not included; (d) production factors regarding agricultural land, machinery, raw materials and labour. In this analysis three land types were considered: irrigated and non-irrigated lands for North Italy and irrigated land for South Italy. Machinery technical and economic data that were used for the analysis were from Italy. Raw materials prices for Italy were also recorded. Finally, labour rates for North and South regions of Italy were used for the corresponding scenarios.

3. Results

3.1. Harvested biomass

Conventional machinery showed a good suitability to harvesting and baling switchgrass. Furthermore, the time-consumption of field operations was not significantly different from the most common forage crops.

Switchgrass was harvested and baled in February with a dry matter content of $85 \pm 5\%$ in the fist year and $68 \pm 3\%$ in the second and third year. The high dry matter content of the first year was mostly due to the thinner stems and the higher incidence of leaf weight on whole biomass (35% in 2002 and 17% in 2003 and 2004). As expected, the dry matter yield was substantially lower in 2002 (establishment year) than in the following years. On average, the harvested dry biomass was 5.3, 8.6 and 10.6 $\mathrm{Mg\,ha^{-1}}$ in the 3 years, respectively.

3.2. Economic analysis

Three cost items, namely irrigation, harvesting/baling and land rent, accounted for more than 80% of the AEC. AEC ranged from €511 to €1.257 ha^{-1}, and it was always higher in South than in North Italy under the same input level (Table 4). The higher AEC of southern regions was mostly explained by the need for irrigation which led to an increase of over €200 $\mathrm{ha^{-1}\,y^{-1}}$ under the high input scenario. In addition, the land rent cost was also higher in South than North Italy, especially under L_S where non-irrigated land rent cost was assumed for North. Conversely, the overall cost of field management was lower in South than North areas due to the lower cost of labour in the South.

AEC of H_S resulted more than double than that of L_S and 55% higher than that of M_S (Table 4). The high cost of harvesting and baling of H_S was mostly explained both by two cut per year and higher and split nitrogen fertilization.

Break even yield (BEY) of H_S were more than double than that of L_S, and they were higher in the southern regions (Fig. 1).

On average, BEY of M_S was 31% higher than that of L_S, while that of the H_S was more than double than that of L_S.

Table 4
Estimated annual equivalent costs per hectare of field operations and land rent of high-(H_S), mild-(M_S) and low- (L_S) input scenarios in South and North Italy

Operation	North						South					
	H_S		M_S		L_S		H_S		M_S		L_S	
	(€)	(%)	(€)	(%)	(€)	(%)	(€)	(%)	(€)	(%)	(€)	(%)
Sown	18	1	18	3	21	4	17	1	18	2	21	3
Irrigation	240	23	19	3	—	—	452	36	182	23	19	3
Fertilization	97	9	55	8	43	8	89	7	50	6	40	6
Weed Control	54	5	21	3	9	2	50	4	20	2	8	1
Harvest/baling	356	34	281	41	280	55	324	26	214	27	257	40
Add. operations	32	3	28	4	—	—	30	2	26	3	—	—
Land	263	25	263	38	158	31	295	24	295	37	295	47
Total	1060	100	686	100	511	100	1257	100	804	100	640	100

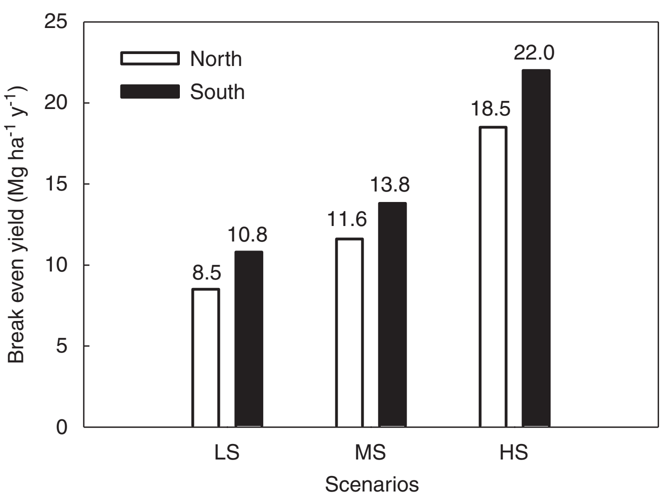

Fig. 1. Break-even yields (annual equivalent dry matter) calculated under low- (L_S) mild- (M_S) and high-input (H_S) scenarios in North and South Italy. Numbers on the top of each bar indicate the break-even yields.

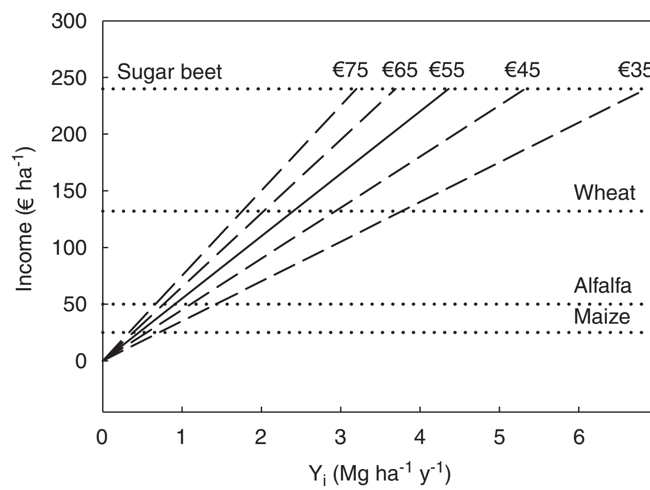

Fig. 2. Incomes (oblique lines) deriving from switchgrass cultivation as a function of the yield higher than break-even (Y_i). Y_i was calculated for variable biomass market prices from €35 to €75 Mg^{-1}. Continuous oblique line refers to the current market price €55 Mg^{-1}, while broken lines are simulations. Dotted horizontal lines are the incomes deriving from the cultivation of maize, alfalfa, wheat and sugarbeet as given by Zagnoli [41] for Italy (year 2005). The intersection between horizontal and oblique lines corresponds to the minimum biomass yield that should be produced by switchgrass to be more profitable than the specific crop.

Still, BEY of M_S (12.7 Mg ha^{-1} on average of South and North) was slightly higher than the harvested dry biomass of the most productive year (10.6 Mg ha^{-1}).

The yield higher than break-even (Y_i), in order for switchgrass to be more profitable than specific conventional crops, is shown in Fig. 2. At market price of €55 Mg^{-1}, switchgrass can be a reliable alternative to maize and alfalfa, Y_i being only 0.46 and 0.90 Mg ha^{-1} y^{-1}, respectively. In contrast, Y_i was found to be fairly high in the case of sugar beet (4.4 Mg ha^{-1} y^{-1}). However, the possible increase of market price would drastically change these scenarios. For instance, at a market price of €35 Mg^{-1} BEY of M_S is about 20 Mg ha^{-1} y^{-1} compared to only 7 Mg ha^{-1} y^{-1} at 75 € Mg^{-1}. That is, at a biomass price of €75 Mg^{-1}, switchgrass would be more gainful than sugarbeet with only 10 Mg ha^{-1} y^{-1} (i.e. 7 plus the Y_i of 3 Mg ha^{-1}). Similarly, at a biomass price of €35 Mg^{-1}, the total dry matter yield of switchgrass should exceed 27 Mg ha^{-1} y^{-1} to override sugarbeet (Fig. 2).

3.3. Sensitivity analysis

Since there are still many doubtful points about the market price of energy crops, sensitivity analysis was performed in order to assess the variation of the BEY at different market prices and scenarios (Fig. 3). Within the explored range, the market price significantly affected the BEY, especially in H_S. For instance, a decrease in biomass market price from €55 to €35 Mg^{-1} increased the BEY by about 12 Mg ha^{-1} y^{-1} under H_S and 5–7 Mg ha^{-1} y^{-1} under L_S (Fig. 3).

We also estimated the biomass market price on the base of fossil fuel (barrel of crude oil) by calculating the cost per unit energy of crude oil. It was somewhat surprising to find

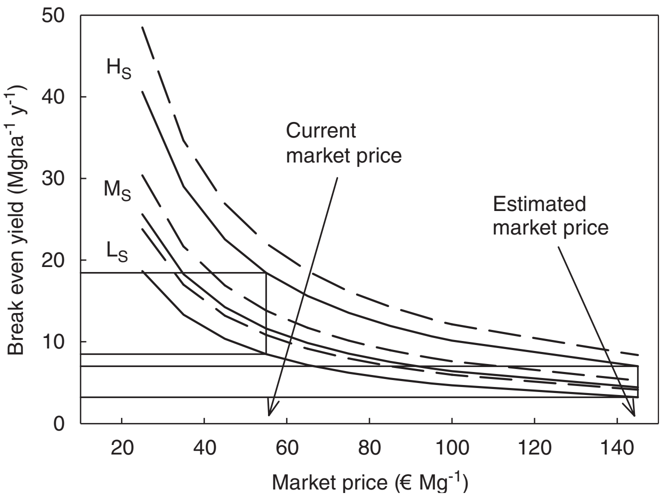

Fig. 3. Estimate of the break-even yield (BEY) with varying biomass price under low (L_S)- mild (M_S)- and high-input (H_S) scenarios in South (broken lines) and North Italy (continuous line). BEY of L_S and H_S are shown as calculated by the current and estimated market price of, respectively, €55 and €146 Mg^{-1} (dry basis). Estimated market price was calculated on the base of crude oil energy price of €367 Mg^{-1} (i.e. the product of crude oil weight (0.129 Mg barrel^{-1}) for the oil barrel cost (€47 barrel^{-1})), and the lower calorific value of crude oil (42 GJ Mg^{-1}). Oil energy price resulted €8.74 GJ^{-1} (i.e. 367/42). Therefore, with a lower calorific value of switchgrass of 16.7 GJ Mg^{-1} [31], the estimated biomass market price (oil energy price basis) would result equal to €146 Mg^{-1} (i.e. 16.7×8.74).

the unit cost of non-renewable energy (€8.74 GJ^{-1}, see Fig. 3 for details on calculation) higher than that of biomass (€3.29 GJ^{-1}). The later was calculated by the ratio of biomass market price (€55 Mg^{-1}) to the lower calorific value of switchgrass (16.7 GJ Mg^{-1}, [31]). All things being equal, with an equal market price per unit energy (i.e.€8.74 GJ^{-1}), the biomass price would result much higher than €55 Mg^{-1} (Fig. 3). As a consequence, BEY was also found to sharply decreased with a biomass price weighted on the energy cost of fossil fuel (Fig. 3). Still, the differences in BEY between L_S and H_S were clearly higher with €55 Mg^{-1} then higher market price (Fig. 3). Briefly, the higher the biomass price the greater the profitability of H_S compared to L_S.

4. Discussion

In this research we showed that, at a market price of €55 Mg^{-1}, switchgrass is unlikely to be grown under H_S and M_S. BEY under these scenarios was always clearly higher than the measured biomass yield under M_S.

Increasing input levels gets higher costs but of course is expected to increase the biomass production as well. Therefore, the harvested biomass measured in this research could be not representative of the yield under H_S. The yield response to intensive cropping systems could not be evaluated in this research and therefore unequivocal conclusions cannot be addressed here. However, several researches showed that, though intensive cropping systems can increase the dry matter yield of switchgrass [22,23], the biomass potential yield is generally lower than BEY shown here (Fig. 1). For instance, Muir et al. [32] showed a very positive effect of nitrogen on biomass production, but the highest dry matter yield obtained under the optimal nitrogen dose (170 kg ha^{-1} y^{-1}) was substantially lower (13.7 Mg ha^{-1}) than BEY shown in Fig. 1 (18.5 and 22.0 Mg ha^{-1} y^{-1}, for North and South, respectively). Similar results were obtained by other authors [11] on small hand-harvested plots, which likely give an over-estimate of biomass yield than that obtained with mechanized systems. For instance, comparing mechanized to hand-harvested switchgrass yields, we found almost 30% of biomass yield loss (unpublished data), and Sanderson et al. [33] showed up to 6% of biomass loss. Therefore, switchgrass cultivation under M_S or H_S does not seem feasible at this market price.

L_S appeared slightly more feasible as it required a lower BEY than the two other scenarios. Again, we cannot argue on the effects of the low input technique on yield, however the differences between M_S and L_S mostly concerned the level of nitrogen dose (see Table 1), whose effects on dry matter yield are still debatable. For instance, Miur et al. [32] reported several equations of yield response to nitrogen dose from which it can be predicted an average increase of biomass yield of about 3 Mg ha^{-1} from 40 to 80 kg ha^{-1} of N. In contrast, Monti et al. [34], in agreement with Sanderson and Reed [11], found negligible effects of N fertilization between zero and 120 kg ha^{-1}, and this was explained by the soil nitrogen reserves, rapid mineralization processes and the high nitrogen use efficiency of switchgrass. However, even considering the biomass yield of L_S equal to that of M_S, the measured switchgrass yield appeared higher than BEY only in the most productive year under rainfed conditions (North Italy, 10.6 Mg ha^{-1}). Therefore, our results showed that, at the current market price of €55 Mg^{-1}, switchgrass is unlikely to be cultivated even under low-input techniques.

Market price of switchgrass was gathered from several personal communications at congresses on the herbaceous energy crops, and it is conventionally expressed per unit weight (€ Mg^{-1}). However, though there is a general agreement on this price (Gianpietro Venturi, personal communication), it appeared surprisingly underestimated compared with that of crude oil when calculated on the basis of unit energy (€ GJ^{-1}). No clear explanation was found for this; it may depend on the rapid increase of oil price and the different energy efficiency of biomass and fossil fuel during energy conversion, biomass efficiency being about 25% (for electricity only) compared to 38–40% of crude oil [35]. Therefore a further increase in the price of energy crops would be justified by the high price per unit energy of the fossil fuels. In addition, the competitiveness of energy crops could also be favored by the negative trend of conventional crops. For instance, in this research we showed that switchgrass can be more profitable than maize or alfalfa when biomass yield slightly exceeds BEY (Fig. 2).

5. Conclusions

At the assumed market price of €55 Mg^{-1} switchgrass can be barely cultivated economically under the considered scenarios, both in South and North Italy. BEY was found to be generally higher than switchgrass potential yields. The assumed market price seemed substantially underestimated when the biomass price was calculated on the basis of unit energy cost of fossil fuel. Therefore, the increase of market price of energy crops can be justified, also taking into account the environmental benefits by the use of renewable sources. In addition, the clear negative economic trend of conventional crops may increase the competitiveness of biomass crops. Our results showed that, at present, switchgrass can be more profitable than some important conventional crops when biomass production slightly exceeds BEY.

A limit of this research is that the biomass yield was directly measured only under a conventional agricultural practices and therefore we cannot exclude that switchgrass yield may exceed the BEY under high- or low-input techniques. However, according to the literature, potential productivity higher than BEY seems very improbable for switchgrass at the assumed price.

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