Preliminary analysis on mowing and harvesting grass along riverbanks for the supply of anaerobic digestion plants in north-eastern Italy

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Abstract

The increasing demand of vegetal biomass for biogas production is causing competition with food production. To reduce this problem and to provide new opportunities it is necessary to take into consideration different kinds of vegetable biomass that are more sustainable. Grass from the maintenance of non-cultivated areas such as riverbanks has not yet been fully studied as a potential biomass for biogas production. Although grass has lower methane potential, it could be interesting because it does not compete with food production. However, there is a lack of appropriate technologies and working system adapted to these areas. In this paper, different systems that could be available for the mowing and harvesting of grass along riverbanks have been preliminarily assessed through the evaluation of the field capacity, labour requirement, economic and energy aspects. The splitting of the cutting and harvesting phases into operations with different machinery seems to be the best system for handling this biomass. However, these solutions have to take into consideration the presence of obstacles or accessibility problems in the harvesting areas that could limit the operational feasibility and subsequent correct sizing.

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Introduction

The intensification of biogas plants is arousing concern about the sustainability of their supply chain (Crutzen *et al*., 2008). The recent interest in cultivating energy crops on arable lands (Amon *et al*., 2007) has increased the competition between food and non-food products (Tilman *et al*., 2006; Müller *et al*., 2008; Timilsina *et al*., 2011; Triolo *et al*., 2012; De Moor *et al*., 2013). As a consequence, there is the necessity to verify the possibility of using alternative biomass sources for the production of methane by anaerobic digestion (Thompson and Meyer, 2013).

The competition with food could be reduced through the exploitation of feedstock from non-cultivated areas. In this respect, grass from marginal lands could be an important source in order to produce more sustainable energy (McKendry, 2002; Molari *et al*., 2014). According to different authors (Blokhina *et al*., 2011; Hensgen *et al*., 2011; Shi *et al*., 2013; Thompson and Meyer, 2013), the main reasons for using grass as biomass source for methane production are: i) no direct production costs; ii) no competition with food production; and iii) reduction of landscape management costs. Nonetheless, the short harvesting period, the physical limitations and the storage and energy conversion sites location are critical constraints (Rentizelas *et al*., 2009; Gunnarsson *et al*., 2010). In particular, grass as biomass source for methane production needs to be mowed and harvested at the appropriate maturation phase because of the later accumulation of lignin and hemicelluloses (Lindsey *et al*., 2013). These compounds have a strong influence on the degradation process during anaerobic digestion (Taherzadeh and Karimi, 2008; Harmsen *et al*., 2010).

These concerns can be minimised by identifying suitable technological solutions for the mowing and harvesting. According to some authors, the technologies for grassland would consider the use of mowers or shredders for the cutting, and self-loader wagons or round balers for the successive harvesting, or machines like self-propelled forage harvesters (Berg *et al*., 2006; Popp and Hogan, 2007; Prochnow *et al*., 2009). All these kinds of machines can provide a mechanical pretreatment that reduces the size of the grass, which is a fundamental parameter for methane production and for the ensiling process (Sharma *et al*., 1988). However, it is important to consider that in other areas like riverbanks or roadsides, it is fundamental to assess appropriate mowing and harvesting technologies because of the presence of physical obstacles that can restrict the access for the machineries and reduce the efficiency of the whole system. To achieve this, a preliminary evaluation of some available mowing and harvesting systems in non-cultivated areas could help to identify the most appropriate technologies and working systems.

Again, the economic and energy advantage of exploiting grass as biomass source in Italy has not been carefully assessed compared to Central Europe where grass for methane production is already seen as a viable option (Gunaseelan, 2007, 2009; Prochnow *et al*., 2009;

Weiland, 2010; DLG, 2012; Pick, 2012), even its potential can only be achieved when the harvesting, transport and processing are cost-effective (Blokhina *et al*., 2011).

This paper presents a preliminary analysis on the available technologies for the mowing and harvesting of grass in non-cultivated areas such as along riverbanks in north-eastern Italy, in order to compare different mowing and harvesting systems from an operative, economic and energetic point of view.

Materials and methods

Machines and working systems

By preliminary surveys of operators working in north-eastern Italy and of national mowing and harvesting machinery manufacturers, different types of machinery were identified as adapted for use in grass mowing and harvesting along riverbanks (Tables 1 and 2). For each machine, the hourly costs were calculated according to the methods proposed by ASABE (ASABE, 2011, 2007). The number of working-hours per year were computed taking into account that the number of working days per year amounts to about 80 days/year, assuming other uses for the tractors during the rest of the year. The lubricants and fuel consumptions were assessed according to the ASABE standards (ASABE, 2011). Fuel cost was fixed at 0.90 €/L (subsidized price).

According to a questionnaire in the north-eastern Italy in 2014, the average value of interest rate for these type of machines was approximately 3% whereas the labour costs was 14.5 €/h.

The number of passages was used to classify the mowing and harvesting systems for grass on riverbanks (Table 3). According to the different types of machines reported in Tables 1 and 2, the likely systems can be classified according to the number of operations and as a consequence the number of machine passages for mowing and harvesting the grass, as also proposed by Salter *et al*. (2007). The mowing and harvesting systems

Table 1. Main characteristics and economic values of the most common tractors currently used for mowing and harvesting grass on riverbanks.

No.	Tractors	Mass (kg)	Estimated life (h)	Annual usage (h)	Purchase value (€)	Hourly cost (€/h)
1	Tractor (110-120 kW)	6370	8000	600-800	75	53
2	Tractor (85-95 kW)	5200	8000	600-800	60	45
3	Tractor (70-80 kW)	4347	8000	600	45	39
4	Tractor (40-50 kW)	3200	6000	400	28	32

Table 2. Main characteristics and economic values of equipment considered for mowing and harvesting grass.

No.	Equipment	Work length (mm)	Mass (kg)	Estimated life (h)	Annual usage (h)	Purchase value (€)	Hourly cost (€/h)
5	Arm brush cutter with vacuum self-loader equipment	1250	2500	2000	300	30	24
6	Front disc mower	2000	550	2000	200	6000	10
7	Rear disc mower	2200	650	2000	300	7000	10
8	Front flail mower	1800	700	2000	200	4500	4
9	Rear flail mower with tedder	2200	900	2000	300	15	15
10	Rotary rake for levees	2600	500	2000	200	4000	8
11	Round baler with wrapping system	2000	3500	2000	300	50	38
12	Self-loader wagon (load capacity 40 m^3)	2000	5000	2000	300	40	33
13	Trailer (load capacity 18 m^3)	-	4100	3000	300	20	10

Table 3. Potential mowing and harvesting systems for grass on riverbanks.

Mowing and harvesting systems	1st Passage Operation	Machines used*	2nd Passage Operation	Machines used*	3rd Passage Operation	Machines used*
1	Shredding-vacuum self-loader	2;5;13	-	-	-	-
2a	Shredding-wrapping	1;5;8	Baling with wrapping	2;11	-	-
2b	Shredding-wrapping	1;5;8	Harvesting	3;12	-	-
3a	Mowing	2;6;7	Wrapping	4;10	Shredding-baling with wrapping	2;11
3b	Mowing	2;6;7	Wrapping	4;10	Harvesting-shredding	3;12
4a	Chopping-wrapping	1;8;9	Baling with wrapping	2;11	-	-
4b	Chopping-wrapping	1;8;9	Harvesting	3;12	-	-

*The types of the machinery are numbered according to the listing in Tables 1 and 2.

identify 4 types of combined mowing equipment (shredding-vacuum self-loader; shredding-wrapping; mowing; chopping-wrapping); for systems 2, 3 and 4, two types of harvesting equipment (a and b) are selected. Systems 3a and 3b require the grass to be wrapped after mowing for the following harvesting phase. Each mowing and harvesting system differs on the working width and its flexibility under different operative conditions. When the arm brush cutter is used (systems 1 and 2) the grass can be more easily managed than with the use of single mowers or shredders, also when there are physical obstacles on the riverbanks such as linear barriers. When after the mowing operation the grass is stockpiled along the riverbanks, systems 2b, 3b and 4b seem to be the most appropriate; instead the use of the round-baler in systems 2a, 3a and 4a considerably reduces the harvested volume in pressed bales and therefore increases the efficiency of the logistics (Cundiff, 1996). However, it is necessary to take into account that the utilisation of round balers is possible only when the accessibility along riverbank is adequate to the machine width. Therefore, larger riverbanks without obstacles that restrict the access can be the best condition for the harvesting operation with round balers.

Costs balance

To calculate the unit costs of the grass, the following equation was used:

$$C = \frac{\sum Su}{Co \cdot p} \quad (1)$$

C= Unit cost of the operation (€/t)
ΣSu= Sum of the hourly costs of the tractors and equipment involved in the system (€/h)
Co= Field capacity (ha/h)
p= Grass yield (t/ha)

The field capacity of each mowing and harvesting system (reported as time unit hour) was obtained through field surveys on working time and the idle time of the single operations. Grass yield was assumed, on the basis of previous experiments (Elsäßer, 2001, 2003), at 6 t/ha (fresh matter) per cut, with moisture content ranging between 75 and 80%.

Energetic and CO_2 analysis of mowing and harvesting operations

The energetic analysis was evaluated by using the gross energy demand method (Slesser and Wallace, 1981; Pezzuolo *et al*., 2014), also including the energy value related to labour (Sartori *et al*., 2005; Balimunsi *et al*., 2012). Table 4 summarises the coefficients used, while the values of the mass, fuel consumption, and labour were based on those reported in Tables 1, 2 and 5.

The direct CO_2 emissions were computed from the average fuel consumption of the tractors and an emission coefficient of 3106 CO_2/kg, which reports the amount of carbon dioxide released in the atmosphere by the combustion of one kilogram of Diesel fuel.

Results

Field capacities and labour requirements

The operative analysis of the mowing and harvesting systems shows that there are some differences in the field capacity, productivity and labour requirement (Table 5). The mowing and harvesting system 1 (shredding-vacuum self-loader) is the system with the least field cutting capacity and harvesting productivity. It amounts to about 0.3 ha/h with a harvesting productivity of 1.5 t/h. This system shows the highest labour requirement. In fact, the small working width of the arm brush cutter and the necessity to pull a trailer for the contemporary loading limit the productivity of the system. Instead, the system that can manage the grass in more passages presents a higher field capacity and harvesting productivity with less labour requirement due to the greater working width and the possibility to work without interruptions for offloading the product when the trailer is full. In particular, mowing and harvesting systems 3 and 4 report an average field capacity that is threefold if compared with system 1 and a labour requirement that is half of the systems 4a and 4b.

Economic analysis

From the economic point of view, the use of mowing and harvesting systems in different passages (2 or more) seems to be the best solution for the management of grass (Figure 1; Table 6). In fact, system 1 shows the highest costs for processing the grass (53 €/t). In particular,

Table 4. Average energy content of the inputs required for the cutting and harvesting of grass.

Inputs	(MJ/kg)	References
Fuel	50.23	Biondi *et al.* (1989)
Lubricant	78.13	Carillon (1979)
Labour	1.93	Pimentel and Pimentel (1979)
Tractor	80.23	Hornacek (1979)

Table 5. Field capacity and productivity, and labour requirement of the different systems.

Mowing and harvesting systems	Field cutting capacity (ha/h)	Harvesting productivity (t/h)	Labour requirement (h/ha)
1	0.3	1.5	4.0
2a	0.7	6.6	2.4
2b	0.7	6.8	2.3
3a	1.1	6.6	2.9
3b	1.1	6.8	2.8
4a	0.9	6.6	2.0
4b	0.9	6.8	1.9

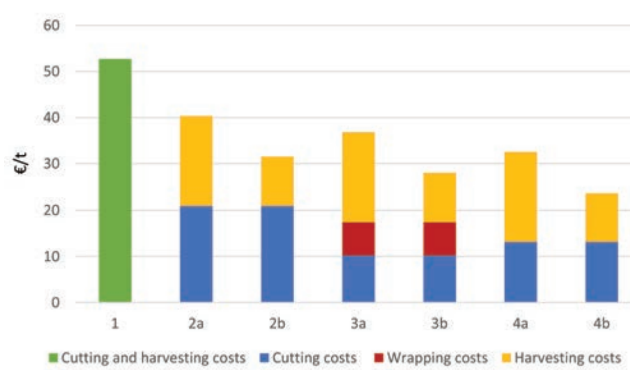

Figure 1. Economic comparison between mowing and harvesting systems.

Table 6. Economic balance of mowing and harvesting systems.

Mowing and harvesting systems	Cutting and harvesting costs (€/t)	Cutting costs (€/t)	Wrapping costs (€/t)	Harvesting costs (€/t)	Total (€/t)
1	53	-	-	-	53
2a	-	21	-	19	40
2b	-	21	-	11	32
3a	-	10	7	19	36
3b	-	10	7	11	28
4a	-	13	-	19	32
4b	-	13	-	11	24

Table 7. Energetic analysis of the systems and CO_2 emissions.

Mowing and harvesting systems	Energy input (MJ/ha)	Energy input (MJ/t)	CO_2 emissions (kg CO_2/ha)	CO_2 emissions (kg CO_2/t)
1	4796	799	229	38
2a	3028	505	157	26
2b	2894	482	147	24
3a	2682	447	144	24
3b	2547	424	134	22
4a	2405	401	128	21
4b	2271	378	118	19

the systems with lower total costs are 3b and 4b; the system 4b results as the most cost-effective, being 15% less than system 3b.

Taking into consideration just the mowing phase, the use of the disc mowers seems to decrease the cutting costs (mowing and harvesting systems 3a and 3b) than the use of flail mowers (systems 4a and 4b). However, the system 3 requires one more passage for the collection of the grass, increasing the total costs.

For the harvesting phase, the adoption of the self-loader wagon decreases the costs by about 45% with respect to the use of round balers. However, it is important to consider that the use of round balers allows the logistic and storage costs to be reduced.

Energetic and CO_2 analysis

The energetic analysis highlights differences between the mowing and harvesting systems (Table 7). System 1 requires the highest energy input, about 799 MJ/t. Instead, the systems 2a and 2b show a lower energy requirement. In addition, the systems 3a and 3b allow a reduction of the inputs compared to system 1. Systems 4a and 4b report less energy requirement than all the others, with an average diminution of the inputs of 51% compared to system 1.

Considering the CO_2 emissions, it is possible to underline a fairly similar trend between the mowing and harvesting systems that use round balers and those that are equipped with a self-loader wagon.

Conclusions

This preliminary analysis points out some aspects of the mowing and harvesting of grass for energy purposes along riverbanks in north-eastern Italy.

First of all, the mowing and harvesting system 1 (shredding- vacuum self-loader) differs from the others due to a low field capacity, high costs and high-energy requirement.

The best mowing machinery could be flail mowers or disc mowers, whereas the more appropriate solutions for harvesting could be the self-loader wagons thanks to slightly lower economic and energy costs. However, even though this study has not taken into account the logistics and storage phases of grass, the harvesting with round balers, due to the pressing of the grass, would seem to involve lower costs for these successive phases.

In conclusion, it is necessary to focus on the notable variability of the working sites found in north-eastern Italy, where the mowing and harvesting are not always easily adapted to the conditions because of the presence of obstacles such as a linear barrier along the riverbanks. The operational feasibility and the subsequent correct sizing of the mowing and harvesting system is of fundamental importance for the exploitation of grass along riverbanks to supply anaerobic digestion plants.

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