

ECONOMIC ASSESSMENT OF CEREAL RESIDUE HARVEST AND TRANSPORT SYSTEMS IN RELATION TO THE DISTANCE BETWEEN THE FIELD AND THE STORAGE CENTRE

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ABSTRACT: The work has been developed under the AGROinLOG Project, aimed at demonstrating the technical, environmental and economic feasibility of Integrated Biomass Logistics Centres (IBLC) for food and non-food products. The goal of the project is to give support to one of the agroindustries selected in the Project, dehydrating facility, to build an IBLC extending the utilization of their equipment used for regular activity to new business chain based on the valorisation of agricultural residues, cereal straw and maize stalks. In particular, the purpose of this work is to evaluate the maximum distance between the fields and the storage centre from which it is more economically convenient to gather the biomass with balers instead of forage hauling equipment, regularly utilized in their activity. To this aim the performance of the machines (working times, yield and material losses) and fuel consumption in each operation (harvesting, loading, transport and unloading) of both yards have been evaluated. With the data collected in field, machine costs analysis was performed. The total costs per ton of biomass harvested (€ t^{-1}) are about 59% higher for baling system and from the analysis of unitary transport costs, resulted a cost per ton per km three times higher when the biomass is transported with the self-loading wagon.

Keywords: agricultural residues, harvesting, biomass, wheat straw

1 INTRODUCTION

The new European Union Directive on the promotion of the use of energy from renewable sources [1], includes a binding target of a 20% share of renewable energy in energy consumption in EU by 2020. Biomass is expected to contribute to around two-thirds of the renewable energy share in 2020 according to projections.

Therefore, the use of biomass for bioenergy production must consider the use of all available resources in a sustainable way, without causing negative impacts. There are several possible sources of procuring solid biomass for energy. It can be procured either by establishing plantations of bioenergy crops including short rotation woody perennials or by removing residue from cropland or forest. Crop residue is defined as the non-edible plant parts that are left in the field after harvest [2]. The different residues resulting from the production of agricultural crops might contribute to the achievement of the renewable energy targets. Significant amounts of agricultural residues are generated from agricultural crop production and partially remain in the field after harvest [3]. The availability of residues depends on the amount that can be removed from land to maintain land fertility and on their competitive use for agricultural or industrial purposes. There are economic and environmental concerns associated with the removal of crop residues from land. Agricultural crop residues play an important role in maintaining or improving soil characteristics, protecting the soil from erosion, maintaining or increasing soil organic matter, maintaining mineral nutrients in soil and improving water retention [4]. Removing crop residue could reduce soil quality, lead to loss of soil organic matter, soil carbon and nutrient content, and increase erosion. A part of the crop residues may be removed from land while avoiding soil degradation and depletion of organic matter and without reducing soil fertility [5]. Appropriate crop residue removal rates should be based on the minimum level of crop residue that must be kept on land to maintain the soil quality, soil organic matter and reduce the risk of erosion [6].

One of the potential renewable energy feedstocks is corn stover because of its high cellulose content and abundance [7].

The effect of biomass removal depends on crop, farming practices (crop rotation, tillage, fertilisation), site conditions (soil type, soil fertility, soil organic matter, soil carbon, moisture, topography and slope, risk of erosion, etc.), climate conditions (wind, precipitation patterns), and harvesting equipment [8].

The harvesting of cereal residues is normally made by using the forage hauling equipment (i.e. self loading trailer, baler, etc.), but no attention is paid on the selection of the logistic chain. If the biomass is baled is then required to upload the bales on the trailer, transport and download all the biomass to the storage centre, instead if the self-loading trailer is used, is required to discharge the biomass every time the wagon is completely full. Furthermore, the final use of the biomass influences the harvesting system because if wheat straw is baled it can be stored whether if it is harvested with a self loading trailer it must be rapidly processed. The distance from the centre where the biomass is stored to the field, where the residues are collected, also affects the cost of transportation and should influence the choice of the logistic chain.

The European project called AGROinLOG, has the objective of improving the competitiveness of the Integrated Biomass Logistics Centres (IBLC) by finding new mechanical solutions to exploit its own residues or non-used resources, to create new activities and obtain new bio products, such as biomass, biofuels or raw materials for other sectors.

The objective of this study was to evaluate the performance and costs of two systems for harvesting and supplying cereal residue. In this study, wheat straw was collected with a prismatic baler and a self-loading wagon and transported to the logistic centre with a trailer or directly by the wagon, respectively. Furthermore the study evaluates which is the maximum distance to the logistic centre from which it is more economically convenient to gather the biomass in bales instead of using a self-loading wagon.

2 MATERIALS AND METHODS

2.1 Logistic chains

The tests were performed in Zaragoza, Spain, in July 2017 during wheat straw harvesting. During the harvesting test, two harvesting systems were tested and compared, the baling (A) and the self loading trailer (B) (Table I).

Table I: Items of the machinery chains

System A – Baling		
Baling	Loading/unloading	Transport
Tractor 1	Tractor 2	Tractor 3
Baler	Fork	Trailer
Worker 1	Worker 2	Worker 3
System B – Self Loading		
Harvesting	Loading/unloading	Transport
Tractor 1		
Self loading trailer		
Worker 1		

The baling system (A) was composed by a prismatic baler and the tractor that was driving it, by a second tractor for loading the bales on the trailer and by a third tractor used for discharging the bales at the storage center. The transport of the biomass from the field to the storage center was performed by the second tractor and the trailer.

The self loading system (B) was composed by a self loading trailer and the tractor that was driving it, performing all the steps of the logistic chain.

A common data collection methodology was used during the harvesting tests to acquire the whole set of parameters foreseen in the harvesting tests.



Figure 1: Logistic chains

2.2 Work time study and fuel consumption

The experimental design chosen for each harvesting test was the split plot. The fields were divided in three replicates (block) for each treatment (baling and self loading trailer).

The surface (m^2) of each plot was measured before the harvesting stage, in order to create plots of the same area. The study of the machine performance was carried out during the two different logistic chain. All the operations were analyzed following the CIOSTA (Comité International d'Organisation Scientifique du Travail en Agriculture) methodology and the recommendations from

the Italian Society of Agricultural Engineering (A.I.I.A.) 3A R1. A reference to these methods can be found in [9].

Operation time, distance harvested, surface of each experimental field and weight of products collected were measured during the harvesting operation in order to assess the following working parameters: field efficiency (%), operating speed ($m s^{-1}$), effective field capacity ($ha h^{-1}$), productivity ($t h^{-1}$) and yield ($t ha^{-1}$).

The main working times were:

TO = total operating time (%)

TA = accessory time (% of operating time, TO)

TE = effective operating time (%), was derived from

$$TE = TO - TA$$

The accessory time included the time for turning and maneuvering. No rests or delays occurred.

Fuel consumption was determined through machine tank refilling until full level at the end of each experimental unit (block) using a volume cylinder to define the volume of fuel consumed (l/ha or l/t of biomass harvested). Each block was started with the tank completely full. The fuel consumed was proportioned to the exact surface of the block tested in order to define the fuel consumed per hectare in that experimental unit. Working time study and fuel consumption assessment were performed for all the steps involved in the logistic chain: harvesting, loading and unloading, transport and biomass discharging at the storage center.

In the case of the self loading trailer, each step was performed by the same tractor and the wagon.

2.3 Post harvesting

After the harvesting operations, the biomass losses were estimated by gathering and weighting the material not harvested during passage of the machine but left on the ground. Three random plot of $10 m^2$ were chosen per each block, the biomass present in each plot was collected and weighted with a portable scale. Percentage of losses (%) were then estimated as the ratio of residue losses to the sum of biomass yield and residue losses, for each block. The sum of biomass yield and biomass losses represented the total yield potential ($t ha^{-1}$). The sum of net biomass yield and biomass losses represented the total yield potential.

Three samples of cereal residue, were randomly collected from the biomass of each block (bales or loose biomass), weighed and put in vacuum-packs to measure the moisture content. The moisture content (MC %) of the different biomass was determined according to ISO 14774-2:2009 [10]. The bulk density (kg/m^3) of the biomass harvested by the self loading trailer was assessed taking 3 samples of biomass for each block, randomly selected from the biomass discharged by the machine and was measured according to ISO 17828:2015 [11]. The bulk density (kg/m^3) of the baled biomass was measured after weighting and calculating the volume of three bales for each block.

2.4 Evaluation of the economic threshold distance

The maximum distance between the fields and the storage centre from which it is more economically convenient to gather the biomass with balers instead of forage hauling equipment (self-loading wagon), was evaluated comparing the unitary costs per tons ($€/t$) of biomass transported (baled or loosed) per km, calculated for both logistic chain, as follows.

2.4.1 Cost analysis

According to the methodology proposed by CRPA in 2015 [12], the hourly costs for all the machineries and implements, involved in each step (harvesting, loading, unloading and transport), were calculated for both logistic chains (baling and self-loading) (Table I).

The economic analysis was focused both on ownership and operating costs, according to the parameters measured during the field tests, when they were available, or by using standard values provided by the CRPA methodology (Table II). Interviews with agroindustry owners and with their usual suppliers have provided further costs items and have validated the data measured during the field tests (Table II).

Table II: Main economic parameters and their sources

Parameters	Source
Investment (€)	Enquiry
Service life (years)	Enquiry
Resale (%)	Enquiry
Annual usage (h y ⁻¹)	Enquiry
Interest rate (%)	Enquiry
Insurance (%)	Enquiry
Labour (€/h)	Enquiry
Fuel consumption (l h ⁻¹)	Measured
Field capacity (ha h ⁻¹)	Measured
Material capacity (t h ⁻¹)	Measured
Repair factor (%)	Literature
Maintenance factor	Literature

2.4.2 Unitary transport costs

The hourly costs for transport were used to calculate the unitary costs per tons of biomass (baled or loosed) transported for 1 km. For doing this the bulk density of biomass (baled or loosed), the load capacity and the mean transport velocity of both transport systems were considered. The mean transport velocity was evaluated as the average of three measurements of the transport from the field to the storage centre and return.

3 RESULTS AND DISCUSSION

Results of straw harvesting are described in table III.

The self loading system showed lower values of field capacity and material capacity respect to the baling system, even if these values do not take into account the loading, transport and unloading of the biomass. The straw yield recorded during the harvesting with the self loading trailer was lower than baling (2.32 and 2.39 t h⁻¹, respectively), however it should be considered that also the percentage of losses were lower (0.88 and 1.19 %, respectively). The moisture content was lower for the loose biomass respect to the baled biomass (4.17 and 6.76 %) and so it was for the bulk density (18.45 and 145.75 kg m⁻³).

Table III: Machine performance of straw harvesting

STRAW HARVESTING		
Machine performance	Baling	Self loading
Field capacity (ha h ⁻¹) (*)	4.67 ±0.23	4.65 ±0.68
Material capacity (t h ⁻¹) (*)	11.18 ±1.15	10.76 ±1.75
Yield (t ha ⁻¹)	2.39 ±0.2	2.32 ±0.07
Losses (%)	1.19 ±0.42	0.88 ±0.18
Fuel consumption (l t ⁻¹)	1.86 ±0.38	1.97 ±0.35
Moisture content (w-% ar)	6.76 ±1.87	4.17 ±0.52
Bulk density (kg m ⁻³)	145.75 ±6.63	18.56 ±6.46

(*) Excluding loading transport and unloading

The baling chain has a initial cost for purchasing all the machineries, double then the self-loading system. The cost analysis showed a total hourly cost three times higher for the baling system (depending for 58% by variable costs, 42% by fixed costs) respect to the self-loading system (72% variable costs, 28% fixed costs).

The total costs per ton of biomass harvested are about 59% higher for baling system (Table IV).

So, excluding the transport to the storage centre, the self-loading system seems to be preferable.

From the analysis of unitary transport costs, resulted a cost per ton per km three times higher when the biomass is transported with the self-loading wagon. As result, the economic benefit with this system fade out rapidly with the distance and at about 10 km from the field, the baling system resulted cheaper (Figure 2).

Table IV: Costs for baling and self-loading systems

	Baling				Self loading	
	Harvesting	Loading	Transport	Total	Harvesting	Transport
Investment (€)	152,000	72,000	82,000	306,000	150,000	
Fixed costs (€/h)	37.7	8.6	13.7	60.0	13.7	
Variable costs (€/h)	36.7	20.6	26.5	83.8	35.5	
Total hourly costs (€/h)	74.4	29.2	40.2	143.8	49.1	
Cost / ton s (€/t)	6.6	1.7	0.34 ^(a)	-	5.23	1.02 ^(a)

(a) cost per tons calculated for 1 km

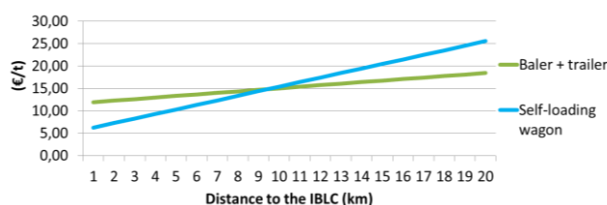


Figure 2: Chain costs according to distance from fields to the IBLC and machinery chain

4 CONCLUSIONS

The amount of biomass harvested with the two systems confirms that this feedstock must be considered as possible source of bioenergy production. The cost analysis revealed as it is crucial to pay attention in the definition of the logistic chain according to the distance from the field and the storage centre. In fact the economic analysis showed that the threshold distance was about 10 km far from the storage centre. Therefore, the harvesting of cereal straw in fields farther than 10 km from the storage centre, should be performed by using the baler system. Instead, in field closer than 10 km the harvesting will result cheaper by using the self loading trailer system.

Further studies will be focused on other cereal residue such as maize stalks and on the convenience of the storage of the loose of baled biomass.

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7 LOGO SPACE

