Project acronym: BECOOL

Project full title: Brazil-EU Cooperation for Development of Advanced Lignocellulosic Biofuels
Grant Agreement Number: 744821

Project start date: 01.06.2017

Deliverable D1.3

Title: **Definition of best harvesting logistics for agricultural residues, and for specialist annual and perennial lignocellulosic crops**	
Author(s):	Luigi Pari, Simone Bergonzoli, Alessandro Suardi
Reviewers	
Date:	(submission due date 31/5/2019, M24)

Dissemination Level: Public

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Table of Content

1. Introduction ... 3
2. Biomass resources of interest ... 5
2.1 Agricultural residues: ... 5
2.1.1. Wheat chaff ... 5
2.1.2 Maize cobs ... 6
2.1.3 Olive tree prunings ... 6
2.2 Dedicated annual and perennial crops ... 8
3. Data collection methodology ... 10
3.1 Machine performance ... 10
3.2 Biomass characterization and quality of the work ... 11
4. Results from BECOOL assessment ... 13
4.1 Olive pruning harvesting test ... 13
4.2 Wheat chaff harvesting test ... 17
4.3 Maize cob harvesting test ... 19
4.4 Fiber sorghum value chain ... 26
4.5 Eucalyptus storage test ... 33
5 Conclusions ... 39
6 References ... 40

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

1. Introduction

The European Union Directive on the promotion of the use of energy from renewable sources (RED), includes a binding target of a 20 % share of renewable energy in energy consumption by 2020 (Boldrini and Aldrup, 2015, Buratti et al., 2012; Scarlat et al., 2013) in order to reduce the emissions of greenhouse gasses and bring down energy import dependency. Bioenergy production systems, as a part of the solution to this problem, have attracted much attention in recent years because they can be appropriate substitutes for the traditional energy production systems which are finite, non-renewable, and cause of environmental problems (Sathre, 2014).

Currently, around 4 % of the total primary energy consumption of the European Union is met from biomass, and it will become 13 %. This makes biomass the most important renewable energy source, providing two thirds of the total energy produced from renewable (Wiesenthal et al., 2006). In the short to medium run, agricultural residues and annual and perennial lignocellulosic crops could provide a remarkable amount of cellulosic biomass currently untapped, that might contribute to the achievement of the renewable energy targets.

However, unlike other renewable energies, the bioenergy production necessitates the flow of the biomass feedstock from the supply sites to the demand centres. Along this route, the biomass passes through some facilities and undergoes various pre-treatments called the biomass supply chain. Each part of the supply chain (including growing, harvesting, transporting, integrating, storing and distributing) needs specific knowledge, technology and activities. The rising demand for biomass and the increased complexity of the often-multi-level involved supply systems outline the need for comprehensive biomass supply chain management approaches. The optimal design of this supply chain is an important factor in the enhancement of the economic, environmental, and social performance and efficiency of the biomass supply chain (Ghaderi et al., 2016).

In this context BECOOL project aims at evaluating innovative value chains from key resources that will be most likely considered in future biomass plans. More concretely, BECOOL project focused on maize and wheat residues, olive prunings, arundo donax, fiber sorghum and eucalyptus. The most critical aspects of the supply chain of these resources were identified and evaluated within WP1 with the aim of filling the gap whether the problem were technical or the dissemination of the technology/chain model.

The project has placed special attention to the harvesting operation, since it represents one of the most critical bottlenecks in the sustainability of the supply chain. In fact, over the last fifteen years several enterprises have identified cost-effective technologies for harvesting agricultural residues and energy crops. CREA-IT had performed harvesting tests of maize cobs, wheat chaff and olive tree prunings with innovative systems in order to understand their advantages and restrictions in comparison with traditional ones. Innovation is intended here as prototypes, new commercial systems available in the market or new harvesting practices not normally carried out in an area.

Storage is another essential step of the supply chain. Storage can be an opportunity to decrease the moisture content and therefore increase the quality of the product to be efficiently converted. Moreover, storage can be considered one of the rare processes where no costly operations are carried out during the active phase, but where correct preventive measures can improve the quality of the fuel even an increase of the energy

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

content respect to the starting conditions as demonstrated by authors. Scientists showed that biomass fuel quality is determined in specific cases by the storage process and important fuel quality characteristics such as calorific value, moisture content and ash content are influenced by storage dynamics. For that reasons the project carried out storage trials on eucalyptus (MRC) while on Arundo donax is still on-going.

Given the interest of the consortium of the project on the fiber sorghum, the CREA-IT within the project and in collaboration with COPROB sugar beet cooperative, who has undertaken a productive strategy towards the energy production from biomass, has studied the value chain of fiber sorghum. The objective was to describe the fiber sorghum harvesting machineries and the supply chain built-up by COPROB for an energy purpose.

.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

2. Biomass resources of interest

This report is the first deliverable elaborated by CREA-IT for WP1 'Definition of best harvesting logistics for agricultural residues, and for specialist annual and perennial lignocellulosic crops' of the BECOOL project. It presents a description of the essential aspect of the resources considered by the project, highlighting their interest as new biomass for energy production.

Based on the feedstocks and cropping systems selected in WP1 and the advanced biofuels conversion technologies selected in WP3 and WP4, a number of harvesting and storage test will be presented in this report as well as value chain description.

2.1 Agricultural residues:

The European policy for energy encourages the utilization of agro-forestry residues, limiting the energy crops plantations (European Parliament, Directive 2009/28/EC; EU 2015/1513, ILUC Directive). In this scenario, it is crucial to exploit the potential of biomass resources that are currently unexploited (Paiano and Lagioia, 2016). In fact, significant amounts of agricultural residues are generated from agricultural crop production.

2.1.1. Wheat chaff

Among the agricultural residues, cereal chaff has gained interest due to its availability and properties both for energy purposes and for animal feeding (Hutton 2008, Saidur 2011). Chaff is made up of seed glumes, seed husk and rachis. This material can be estimated in about 7 % of the threshed product (40 % are seeds, 48 % straw, 5 % stubble). According to EUROSTAT, more than 300 Mt grain is harvested yearly in EU28 (EC, 2007) and considering a mean chaff to grain ratio of 0.17, more than 52 Mt yr^{-1} could be available to be collected in Europe (McCartney et al., 2006). During cereal harvesting, the chaff is normally dispersed in the field together with straw and other fine residues retained by the combine sieves, such as un-threshed heads, short straw, leaf material, weed seeds and whole or cracked kernels from the harvested crop. Moreover, from agronomic point of view, the collection of the chaff reduces the weed seed stock in the soil avoiding the herbicide treatments (Shirtliffe and Entz, 2005). However, such resource is generally left on the ground after cereal harvesting, in fact is simply left on the ground, and covered by the straw. Therefore, being in direct contact with the ground cannot be collected with the pick-up in the following baling operation. However, the growing interest in the exploitation of these residues both for energy (combustion, biogas) and for animal husbandry (fodder, litter), and also the need to reduce the load of seeds of resistant weeds (in the case of organic farming), has pushed some constructors to develop systems for the recovery of the chaff, separately or together with the straw. The main chaff collection technologies available on the market that, basically, implement the following mechanical chains:

- Chaff discharged on the top or inside of the straw swath for baling all together in a second time.
- Chaff discharged to an integrated back container, while straw can be both baled or spread on the ground.
- Chaff discharged to a towed trailer or no-stop baler.

The first method of collection can be preferred when biomass is used for energy production. In fact, baling the straw and chaff together, increases the amount of total biomass collected per hectare and the bales

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

density (Lundin and Rönnbäck, 2010). On the other hand, collecting chaff separately from straw allows to obtain a product with a higher nutritive value than straw, suitable for husbandry feeding.

From all the system commercially available, BECOOL tests focused on a device that spreads the chaff on the windrow of straw that is afterwards baled. This system was selected because, after reviewing the already existing technologies, it was considered of special interest due to the cost, harvesting systems and scope of the project.

2.1.2 Maize cobs

Among the un-tapped resources and the agricultural residues, the maize cobs have risen the interest due to its abundance, low cost and favorable properties (Jansen and Lübberstedt, 2011). According to EUROSTAT, more than 9 Mha in EU28 are cultivated yearly with grain maize. Considering an average yield of 1 t ha^{-1} of cob this would mean that more than 9 Mt yr^{-1} of maize cob could be available to be collected in Europe (Pollex and Zeng, 2012; Khawaja and Janssen, 2015) Maize cob is the central core of an ear of maize (*Zea mays* ssp.) and the part of the corn ear on which the kernels grow. Its interesting properties enable a wide array of applications such as: 1) biomass for energy 2) absorbent for animal bedding or substrate in hydroponic cultivation 3) adsorbent for production of active carbon for water treatment, among other applications 4) abrasive material for metal or wood surface conditioning.

Turning cobs into a valuable and cost-effective feedstock greatly depends on the harvest technology. Currently, the maize cobs are rarely used, being normally left on the soil uncollected or collected with the stover (Shinners et al., 2007). In Italy, the company AGRICINQUE Gruppo Racca srl has designed and patented a system to be applied in some of CASE commercial harvester, for that reason this machine was selected to be studied during cob harvesting. The system consists of a device to separate maize cob from the other residues (leaves, stem, culm, etc.) and collect it in an additional tank (9 m^3).

BECOOL carried out harvesting tests in order to study the innovative harvesting systems, the only one patented in Europe, and to acquire reliable data on machine performance and biomass quality.

2.1.3 Olive tree prunings

Prunings from permanent crops in Europe are a substantial reservoir of renewable biomass for energy and industrial use (Pari et al., 2017). The 10.6 Mha currently covered by permanent crops generate 13 Tg. (oven-dry basis) of pruning. However, the rational use of this biomass source is being hindered (Garcìa-Galindo et al., 2016a and 2016b). Firstly, by an increase in surfaces, and a conversion from traditional to intensive systems is forecast as well as a growing demand for fuel biomass (Garcìa-Galindo et al., 2016a, Magar et al., 2011, Spinelli et al., 2012) Secondly, there are various barriers tied to the use of prunings and the development of a sustainable logistic chain to produce energy from it (Dyjakon et al., 2014, Romanski et al., 2014). Pruning (branches and shoots of fruit trees) is considered a problem rather than an opportunity and, hence, it is not used or incorrectly disposed of (Spinelli et al., 2010)

BECOOL project performed harvesting test were carried out on olive tree prunings with the goal to study the harvesting systems at present and the quality of the biomass. This resource was selected because some successful examples of well-designed pruning supply chains for energy production are already available in Europe. In fact, although is just one aspect of the overall process, harvesting prunings plays a pivotal role in building a sustainable and profitable collateral production and hence it needs to be defined correctly. For

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

instance, Fiusis s. r.l. (Calimera, LE, Apulia) use olive prunings produced by nine municipalities around the 1 MWe cogeneration plant which produces electricity (which is then sold on to the national grid) and heat. Fiusis's well-established harvesting solution entails the use of three shredders for use on farms that have up to 400 olive trees. For farms with a higher number of olive trees, prunings are collected at the edges of the fields and chipped with a stationary shredder, with a production capacity of 10 t h^{-1}. Chipping in both cases is carried out after a 25 - 30 day period in which the prunings are left in the field to ensure drying and leaf shedding

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

2.2 Dedicated annual and perennial crops

In recent decades, some annual and perennial crops became very interesting sources for the production of lignocellulosic biomass aimed at the production of heat, electricity, and second-generation biofuels. In Europe some herbaceous crops and Eucalyptus have been indicated as promising for energy production. Due to the considerable amount of biomass produced the harvesting and the storage presents several drawbacks that weigh on the supply chain.

Among perennial grasses, *Arundo donax L*. (Poaceae family) presents several attractive characteristics as dedicated biomass crop. This species is a hydrophyte that grows spontaneously and abundantly in southern Europe and in many subtropical temperate regions of the world (Pilu et al., 2013, 2012). Since the 80s, in Europe, several studies regarding the *Arundo donax L*. biomass potential for energy production have been carried out (Cosentino et al., 2006; Nassi o Di Nasso et al., 2007; Angelini et al., 2009; Lewandowski et al., 2003). *Arundo donax* L. has received much attention from researchers for its vigorous growth, high productivity, low agronomic inputs (fertilizers, pesticides), high tolerance to environmental stress, and suitability to be cultivated in unproductive soils or marginal lands. Furthermore, in 2011, an Italian company constructed a commercial-scale for cellulosic ethanol production facility that use also giant reed, so a strong demand increased for this crop as feedstock. Some other herbaceous species have been receiving increasing attention recently, such as fiber sorghum (*Sorghum bicolor L*. Moench), which has a growing cycle similar to that of traditional food crops and demonstrates a high potential energy related both to anaerobic digestion and second-generation bioethanol production (Amaducci et al., 2000). The characteristics of sorghum for electricity production have also been evaluated in different Italian areas, showing interesting potential (Trebbi, 1993). In recent decades, fiber sorghum (*Sorghum bicolor* L. Moench.) has become one of the most interesting species for the production of lignocellulosic biomass aimed at the production of heat, electricity, and second-generation biofuels (Murray, 2005; Ban et al., 2008; Sipos et al., 2009; Ratnavathi et al., 2010; Davila-Gomez et al., 2011). The ample genetic variability in terms of morphological and physiological traits has allowed the selection of genotypes to be more productive with a sensible improvement of energy yield.

The giant reed and sorghum value chain aroused a great interest for the BECOOL project. The special interest is due to the availability of this biomass all around the Europe and the world and to its specific yield and quality for further processing. Nevertheless, some bottlenecks still exist for these two energy crops. For that reason, CREA-IT focused the attention on the harvesting of sorghum and on the storage of giant reed. Considering the fiber sorghum, this further activity was not carried out as field test but studying and describing an already existing and developed value chain

Short and medium rotation coppice (SRC and MRC) appear to be an interesting strategy for supplying bioenergy plants at global level. The fast-growing capacity and the low agronomic input requirements offer the opportunity to produce high quantities of biomass in low-productive soils, without competing with food crops for fertile arable land (Lenz et al., 2017). Such crops are recognized to work as mechanism for decentralising energy supplies and promoting the local use of bioenergy (Boll et al., 2015), contributing also to improve local biodiversity and playing an important role in the sustainable intensification of agriculture (Haughton et al., 2016). According to production strategy, woody biomass can be obtained exploiting fast-growing hardwood species to be harvested at biennial or quinquennial cycles (Faasch and Patenaude, 2012). Large eucalypt plantations have been established in Europe, South America, China and South East Asia, and their importance to global wood supply keeps increasing. The world-wide area of eucalypt plantations

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

amounts to 19 million hectares, mostly devoted to pulpwood production. However, to reduce carbon release to the atmosphere and to ensure supply of energy, there is an expanding interest in using the tree biomass energy for fossil fuel substitution. While many companies are exploring the potential of eucalypt plantations for structural wood, more are looking at establishing dedicated short-rotation plantations for producing energy biomass.

The efficiency of the cultivation of dedicated energy crops depends, as well as on a correct energy and environmental evaluation, on farm cost-effectiveness. In relation to this latter aspect, harvesting can represent a critical phase in relation both to the costs and technique used. Indeed, while many studies have been conducted on production techniques, research on the type of equipment for harvesting energy crops is limited. In general, harvesting and handling of annual and perennial lignocellulosic crops have not been sufficiently investigated thus large room exists to reduce yield gaps

BECOOL has assessed in this case the storage of eucalyptus, monitoring the evolution of moisture and dry matter of two type of formats that could be supplied to bioenergy plants: only stems or whole trees.

.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

3. Data collection methodology

The following common methodology was used during field tests, even if the experimental design and some parameters acquired were defined for each test and will be explained inside the specific section. The storage test followed a specific methodology described inside the section.

3.1 Machine performance

In each treatment and repetition, the performance of the machines will be evaluated through the study of the working times. 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 Assirelli and Pignedoli, 2005). All the gathered data were used to define the performance of the machine. Down below are explained in detail how these data should be collected.

Field speed: the field speed (FS) is the average rate of machine travel in the field during an uninterrupted period of functional activity (Km h^{-1}).

Average field speed can be easily measured by marking off a fixed distance (at least 100 m) in the field, placing a mark at each end, and counting the seconds it takes to drive between the marks. Average field speed can then be calculated from equation deriving from the physic formula of the velocity:

Velocity (v) = Space/Time

In this case, the space is intended as the linear meters covered by the machine between a mark and the other.

Working times: the study of the working times and the evaluation of the field speed will allow determining parameters such as **Theoretical filed capacity** (ha h^{-1}), **Effective field capacity** (ha h^{-1}), the **Material capacity** (t h^{-1}), and the **Field efficiency** (%). By knowing the yield of the field (t ha^{-1}), it is possible to obtain also another good indicator of the machine performance called **Material capacity** (t ha^{-1}).

***Theoretical field capacity* (TFC):** depends only on the full operating width of the machine and the average travel speed in the field. It represents the maximum possible field capacity that can be obtained at the given field speed when the full operating width of the machine is being used. It is calculated multiplying the field speed for the working width of the machine.

***Effective field capacity* (EFC)**: The Effective Field Capacity of a farm machine is the rate at which it performs its primary function, i.e., the number of hectares that can be harvested per hour.

EFC = *worked area (ha)* / *OT* (*h*)

Measurements or estimates of machine capacities are used to schedule field operations, power units, labor, and to estimate machine operating costs. The effective field capacity (EFC) of a machine in the field can be easily calculated by dividing the hectares completed by the hours of **Operative Time (OT)**.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

The operative time is the real time necessary to complete the harvest of the surface object of the test, including also turnings, stops, machine regulations, etc.

The formula used for the estimation of the operative time is the following:

Operative Time (OT) = ET + AT

ET = is the effective time, i.e. the time in which the machine is actually harvesting the product.

AT = are the accessory times which includes *accessory time for maintenance* (ATM), that includes the pauses required for filling or unloading the hoppers (seeds, fertilizers, grains, etc.); *accessory time for turning* (ATT), corresponding to the time needed to reverse the direction; *accessory time for regulations* (ATR), corresponding to the times for adjustments in relation to the conditions of the field or the work.

***Field efficiency** (FE)*: expressed as percentage, the field efficiency is the ratio of actual or effective field capacity (EFC) to theoretical field capacity (TFC).

FE (%) = EFC (ha h^{-1}) / TFC (ha h^{-1})

Material Capacity (t h^{-1}): The working capacity of harvesting machines can be measured also by the quantity of material harvested per hour. This capacity is called the machine's material capacity (MC), expressed as tons per hour (t h^{-1}). It is the product of the machine's EFC and the average yield of crop per hectare and can be calculated from equation (5).

MC (t h^{-1}) = EFC (ha h^{-1}) x crop yield (t ha^{-1})

3.2 Biomass characterization and quality of the work

Fuel consumption: the fuel consumption is another indication of the machine performance since it is the direct parameter for the evaluation of the harvesting costs. Fuel consumption was determined through machine tank refilling until full level at the end of each experimental unit (plot) using a graduated large cylinder to define the volume of fuel consumed (l ha^{-1} or l t^{-1} of biomass harvested). Each experimental unit (plot or field) was started with the tank completely full. The fuel consumed was proportioned to the exact surface of the experimental unit tested in order to define the fuel consumed per hectare in that trial.

Crop yield was measured by weighting all the biomass produced in each repetition of the specific test separately. Concerning baling test, the last bale collected from each repetition, even if was not completely formed, was expelled before starting the following repetition. The bales obtained during each repetition were weighted separately. Each bale was marked with a univocal code indicating the specific plot to which it belonged.

The bulk density (kg_{fm} m^{-3}) is a key parameter directly related to logistic issues. A higher density, in fact, substantially affects the cost of the biomass handling, decreasing the number of total transports and, therefore, the cost. The bulk density of the biomass harvested was measured using a steel cylinder of known internal volume according to ISO 17828:2015. A cylinder of 0.026 m^3 was filled with the biomass and then

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

weighed using a dynamometer. The ratio between the net weight of samples in the cylinder and its internal volume represented the bulk density, expressed in kg m^{-3}.

Samples of different biomasses were randomly collected in each sampling plot, weighed and stored into vacuum-packs to measure **the moisture content**. The moisture content (MC, w-% ar) was determined according to ISO 14774-2:2009.

Biomass losses correspond to the biomass left on the soil during harvesting. For the identification of the biomass losses 3 plots for each repetition, randomly selected, were identified, and the biomass present was collected and weighed. Percentage of losses (%) were then estimated as the ratio of biomass losses to the sum of crop yield and biomass losses, for each experimental field. The sum of net yield and biomass losses represented the total yield potential (t ha^{-1}). The sum of net yield and biomass losses represented the total yield potential.

The Heating Value was performed according to EN ISO 18125. The HV represents the amount of thermal energy generated by the combustion of one kg of dry matter (considering the water in biomass at atmospheric pressure and at a liquid state of 15°C).
The determination of the ash content was carried out according to the EN ISO 14775.
The nitrogen was obtained according to EN ISO 15104.
The chlorine and sulfur content were determined according to EN ISO 16994.

Statistical analysis: After verifying the normality of the distributions, the data statistically significant were analysed by ANOVA (Onofri, 2007). The Tukey test ($P<0.05$) was used as post-hoc test to separate the means.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

4. Results from BECOOL assessment

4.1 Olive pruning harvesting test

During the project BECOOL tests of harvesting of prunings have been carried out in Agios Konstantinos (Fthiotida region, Greece) in order to test the performance and the quality of the work of shredder FACMA in hilly and flat lands. There is not so much information in literature about the harvesting behavior of this machine in hilly land, and a comparison of the performance and fuel consumption of the machine in different field conditions is useful to clarify the convenience of its use. Table 1 shows the results of the harvesting tests of olive pruning carried out in Greece with the FACMA shredder, on the plain and on the hills. In both cases, the harvesting involved a first phase of raking the product on the ground, and subsequent harvesting of prunings arranged in swaths using the FACMA shredder.

Table 1: Results of the pruning harvesting tests carried out in Greece during the project BECOOL.

Machine performance	**Pruning rake (Flat land)**	**Pruning rake (Hillyland)**	**FACMA Combi (Flat land)**	**FACMA Combi (Hilly land)**
Area (ha) – Slope (°)	0.60	1.42– 8.1(±0.9)	1.66	0.93 – 8.1(±0.9)
Yield (t_{fm}/ha)			2.29(±0.54)	5.01(±1.61)
Pruning charact.: Ø – length (cm)	2.99(±0.98) | 204(±49)	2.60(±0.78)|194(±53)	2.99(±0.98)|204(±49)	2.86(±0.88)|215(±55)
Windrow charact.: width – height (cm)	140(±27)|55(±17)	142(±8)|52(±11)	140(±27)|55(±17)	162(±33)|55(±9)
Ro (work efficency)	0.53	0.56	0.53	0.50
Theor. Field capacity (ha/h)	1.13	1.57	2,98 ±0.39)*	1.56(±0.10)*
Effective Field capacity (ha/h)	0.60	0.88	1.57(±0.16)*	0.79(±0.21)*
Working speed (km/h)			3.85	1.94
Material capacity (t/h)	n/a	n/a	3.56(±0.68)	3.75(±0.44)
Losses (%)	n/a	n/a	23(±12)	27(±7)
Moisture content (w.b.) (%)	n/a	n/a	26.8(±0.2)	27.1(±1.6)
Bulk density (kg/m^3)	n/a	n/a	220(±8)**	266(±14)**
Fuel consumption				
Fuel consumption (l/ha)	3.01	2.11	8.1(±0.3)	18.5(±3.9)
Fuel consumption (l/t_{fm})	0.74	0.75	3.7(±0.7)	3.8(±0.8)
Fuel consumption (l/h)	1.81	1.85	12.7(±0.8)	14.2(±1.7)

* p<0,05 ; ** p<0,01 (Procedure: Tukey HSD method)

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

The raking phase, in hilly land and flat land reported no significant differences in performance (0.60-0.88 ha h^{-1}) and in the fuel consumption that resulted 1.8 l h^{-1}.

All tests were carried out by the same tractor driver, tractor and shredder (Facma mod. Combi). The amount of biomass harvested in the hill was twice as much as in the flat land, while the losses (about 23 % in the flat land and 27 % in the hills, $\alpha>0.05$) and the pruning characteristics in both fields were similar (diameter and length of the branches - Table 1). Harvesting efficiency was higher in the hills than in the flat land.

Significant differences were found in terms of field capacities, working speed, and bulk density of the hog fuel produced, but no significant differences were observed in terms of fuel consumed (liter of diesel per hour, and ton of woodchip produced – l h^{-1} and l t^{-1}).

In the flatland the machine has gone at a speed twice that of the hills because the pruning to be chipped was in lower quantities. Although usually at a higher speed correspond to higher fuel consumption, it is evident how much, the greater consumption in the hills (where the machine has worked more slowly) is linked not so much to the movement of the machine itself, but rather to the greater amount of pruning to be processed. In fact, consumption per ton of product harvested is the same, while hourly consumption (l h^{-1}) is not significantly different.

It should also be added that the test conducted in the hilly land, having been carried out both uphill (with an increasing effort due to the progressive accumulation of material collected in the container - a parameter that is difficult to monitor during the test) and downhill (with fuel savings due to the potential energy of the system and zero fuel consumption), has led to a balance of fuel consumption related to the movement of the tractor-shredder system. For this reason, considering that the slope of 14 % is starting to be burdensome for the tractor, the results show a higher fuel consumption in the uphill harvesting (14.2 l h^{-1} in the hills compared to 12.7 l h^{-1} in flat land), but that statistically it was not significant.

During the test, the quality of the shredded product was also evaluated. The results showed a significant difference in the bulk density of the shredded product during the harvesting of pruning in the hills (higher density, 266 kg m^{-3}) rather than in the flat land (lower density, 220 kg m^{-3}). Since the moisture content of the wood was the same in both chopped wood products, the lower working speed of the tractor that worked on the hill produced a finer wood chips which, having less space between the wood particles, resulted in a higher bulk density.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

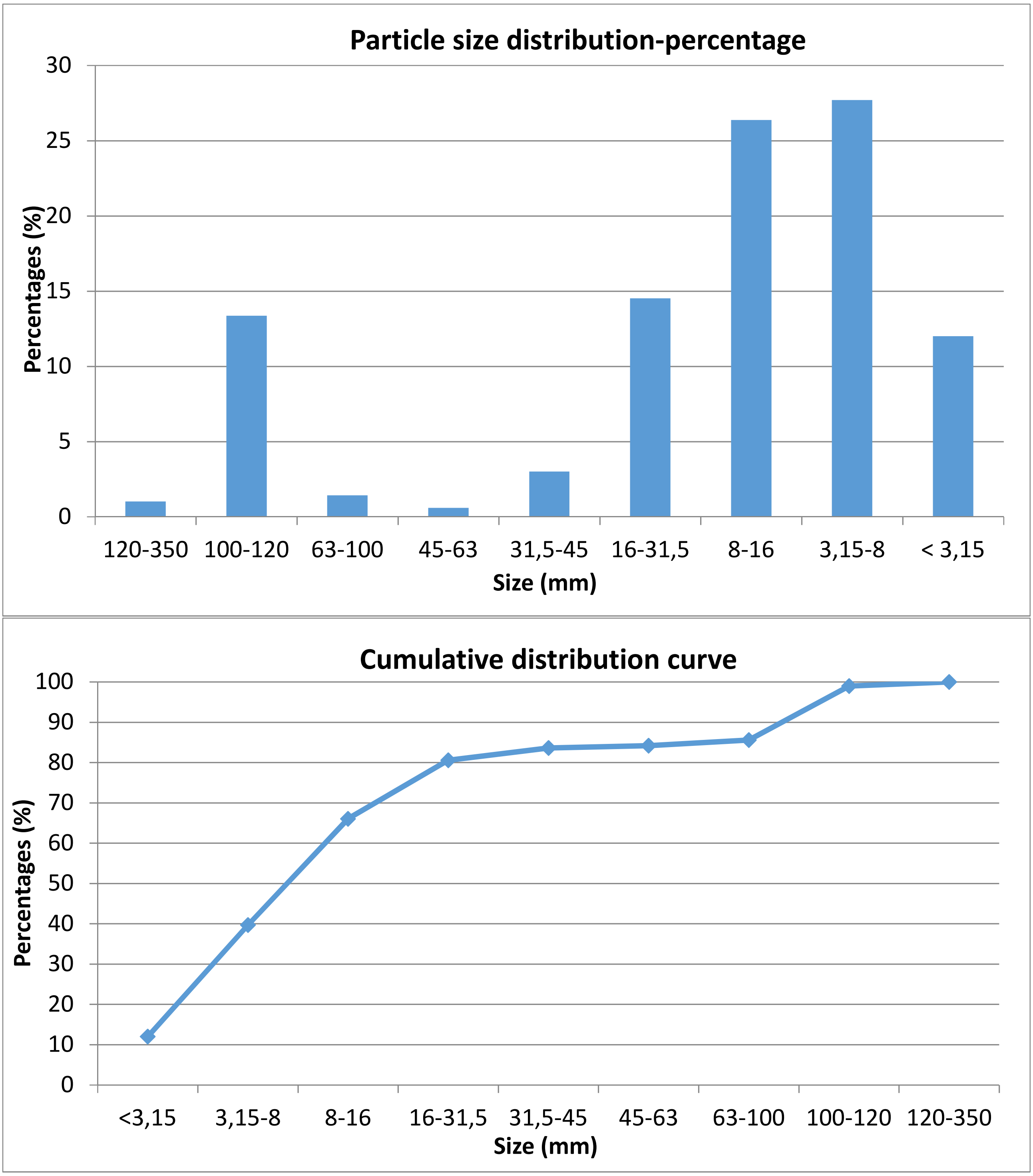


Figure 1- Particle size distribution and comulative distribution curve of the hog fuel produced by Facma mod.Comby TR200

The particle size distribution (PSD) analysis of the hog fuel produced by Facma was found to be in particle size class P31.5 (60 % of the product with particles between 3.15 and 31.5 mm) and a fine fraction class F15 (fine fraction <15 %). The cumulative distribution curve analysis showed that 50 % of the wood particles were smaller than 11.33mm (D50).

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Therefore, from the comparison of pruning harvesting carried out by the shredder Facma mod. Comby, in the hills at a measured slope of 8° (14 %) and in the plains, it was possible to verify that:

- Fuel consumption is essentially linked to the chopping phase;

- the forward speed of the machines in the field leads to higher consumption but increases the capacity of the field (ha h^{-1})

- harvesting in the hills does not seem to excessively influence the fuel consumption of the tractor-shredding system if the work is done both uphill and downhill where, with the same length of field, the highest consumption that occurs uphill is counterbalanced by the lower consumption of the work done downhill.

- A lower working speed of the tractor-shredder system in the hills could have promoted the production of a finer chopped wood and therefore with a higher bulk density.

- The hog fuel produced by Facma can be classify as P31.5, F15, D50.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

4.2 Wheat chaff harvesting test

Harvesting tests of wheat chaff were conducted near the city of Nantes (France) during wheat grain harvesting in July 2018. From all the system commercially available, the tests focused on a device that spreads the chaff on the windrow of straw that is afterwards baled. This system was selected because, after reviewing the already existing technologies, it was considered of special interest due to the cost, harvesting systems and scope of the project.

A commercial combine harvester machine equipped with the innovative Thievin system Turbopaille was selected for this purpose and compared to the traditional harvesting system (figure 2).
The purposes of this test were to determine the operating parameters of the machine and the quality and effectiveness of its work in order to assess the performances of the innovative harvesting system to collect the wheat chaff. The harvesting tests were performed in six blocks (replicates), belonging to the same wheat field, of about 0.7 ha each. Three blocks were harvested using the Turbopaille system (Thievin On) and three using the traditional system (Thievin Off).

Figure 2. Thievin system turned on (Left); Thievin system turned Off (Right)

In order to study the crop characteristics, before starting the work, ten sampling plots (replicates) of 1 m^2 were randomly selected inside the field. All plants of each plot were hand-harvested by cutting at ground level and the following biometric and productive characteristics registered: total biomass weight, straw weight, and ears weight. All the ears of each plot were weighted separately in order to study the ratio between ears and the total biomass.
Wheat grain harvested per each block was weighed in the farm scale, while the bales harvested for each block were weighed separately by using different trailers.
The results of work time study are reported in table 2.

Table 2. Machine performance of harvesting test

System	Thievin sst. ON				Thievin sst. OFF			
	Combine harvester		Baler		Combine harvester		Baler	
	Mean	Dev.st.	Mean	Dev.st.	Mean	Dev.st.	Mean	Dev.st.
Theor. Field Capacity (ha h^{-1})	2.57	±0.13	5.23	±0.65	2.71	±0.09	5.99	±0.16

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

Eff. Field Capacity (ha h^{-1})	2.24	±0.11	3.46*	±0.28	2.41	±0.10	4.05*	±0.16
Yield (t ha^{-1})	6.26	±0.24	6.02*	±0.28	6.04	±0.24	4.63*	±0.36
Material capacity (t h^{-1})	13.98	±0.13	20.79*	±0.79	14.39	±0.13	18.73*	±0.79
Fuel consumption (l ha^{-1})			4.65	±0.91			4.66	±0.11
Biomass losses (t ha^{-1})			1.4	±1.3			2.8	±2.5

* Values marked with asterisks are significantly different ($p<0.05$)

No statistically significant differences were found between grain harvesting operations performed using the Thievin system in On or Off mode, highlighting as the innovative system does not influence the combine harvester performance. Considering the baling operation, instead, statistically significant differences were found for what concern effective field capacity, biomass yield, material capacity with no differences for fuel consumption. Therefore, the results demonstrate as the chaff harvesting, performed by the Thievin system, influences the baling performance. In fact, higher values of material capacity and biomass yield and lower values of field capacity were recorded in the plots harvested with Thievin system On whit no differences in terms of fuel consumption. This means that using the Thievin system, no differences are expected during grain harvesting, while during baling with no increase in terms of fuel consumption is possible to harvest 19 % more of biomass per hectare (figure 3) only with a slight reduction in field capacity (ha h^{-1}).

Figure 3. Windrow made by straw and chaff after harvesting with Thievin system On.

When baling was performed on plot harvested by Thievin system Off, higher value of field capacity were highlighted probably due to higher forward speed caused by lower biomass quantity in the windrow.

Table 3. Wheat chaff chemical composition.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Biomass	Moisture content (w%-ar)	N (%w/w)	Cl (%w/w)	S (%w/w)	Ash (%w/w)	LHV (MJ/kg_{db})
Wheat chaff	9.3 ±0.2	0.73 ±0.04	0.04 ±0.01	0.04 ±0.01	9.75 ±0.14	16.27 ±0.03

The aim of the work was also to investigate the potential utilization of wheat chaff as feedstock for advanced biofuel production in areas where these by-products are available but there is still no market. Five samples of wheat chaff were randomly collected by the fields of Nantes (France) during field test to determine the feedstock chemical composition. The analysis were conducted according to EN ISO standards. Results of the analysis are depicted in the table 3.

The proper functioning of the Thievin system and the quantity and quality of the wheat chaff, also considering the availability of this product in EU, makes this untapped material an attractive biomass resource that can be used for many purposes.

4.3 Maize cob harvesting test

The maize cob has become a material of high interest since the most common practice is to leave the cobs on the soil during the harvesting of maize grains, but it could be used as resource for bio-commodities: biomass for energy and others like:

- Absorbent for animal bedding or substrate in hydroponic cultivation (for instance).
- Adsorbent for production of active carbon for water treatment, among other applications.
- Abrasive material for metal or wood surface conditioning.

Some manufacturer companies have developed devices to be implemented in most spread commercial combine harvesters to perform the combined collection of grain and cobs in one step.

In Italy, the company AGRICINQUE Gruppo Racca srl has designed and patented a system to be applied in some of CASE commercial harvester, for that reason this machine was selected to be studied during cob harvesting.

The study was conducted in October 2018 within "Giletta" farm, placed in the Northern Italy at Revello (44.709920 N and 7.435711 E), Cuneo province. The farm is oriented to dairy farming and has a biogas power plant of 250 kWe fed by cow manure and litter and maize residues (cob and stalks). The fields were sown with maize in April 2018. The test was performed during maize grain harvesting carried out with a combine harvester machine, model Axial Flow 7140, equipped with the system to harvest maize cob.

The system is able to separates maize cob from the other residues (leaves, stem, culm, etc.) and collect it in an additional tank (9 m^3). Depending on the final use of the product, the system is able to control the amount of this other residues collected. Inside the tank, the material is chopped, with the possibility to modify the product particle dimensions. The cob is stored till is unloaded with an innovative auger system ensuring no blocking problems. The unloading requires around 3 minutes, allowing the discharging of maize cob and grain at the same time.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Figure 4. View of the Harcob system

The combine can still be used for only grain harvesting, by manually disconnecting the main drive belt. Actually, the adaptation can be mounted only on the self-propelled CASE IH Axial Flow harvester models: 6088-7088, 6130-7130 and 6140-7140. The price of this adaptation can be around 75,000 € (CE-certified and homologation included).

Figure 5. Unloading of grain and cob tanks at the same time

More details on the technical functioning of the system are given below in Figure 6, it can be seen a scheme of the system developed by the company.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

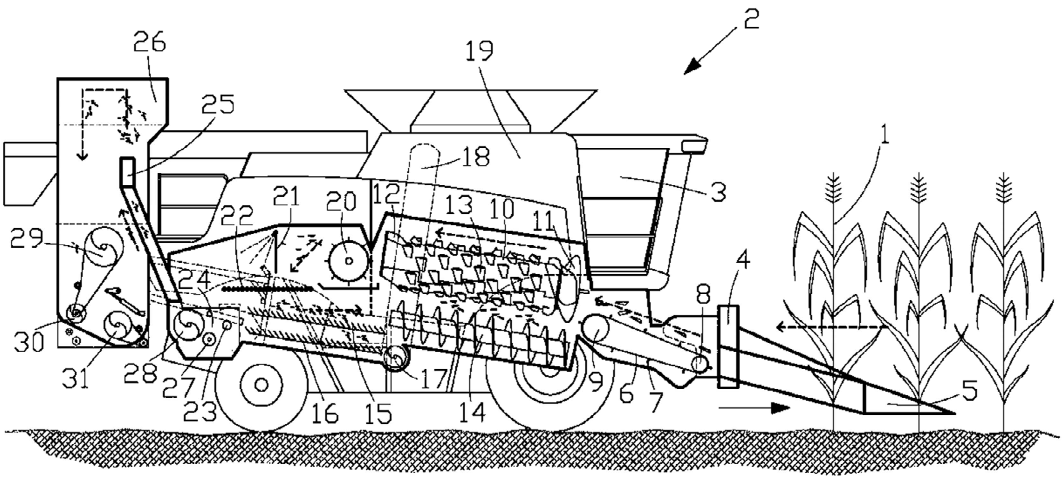


Figure 6. Racca patented system for harvesting cobs.
(https://patentimages.storage.googleapis.com/EP2668838A1/imgf0001.png)

With reference to figure 6, there is shown a corn field 1 on which a self-propelled harvester 2 is working, which in its front part, below and in front of the driver's cabin 3, has a corn collecting head 4. The head 4 is one of those commonly available on the market. Such heads have a series of shrouded conical separators 5 which insert themselves among the plantation rows. Between each pair of separators 5 there is mounted a pair of horizontal grooved, counter-rotating rollers (also called stalk rolls), above which there are provided the husking plates. A pair of longitudinal toothed belts equipped with teeth runs above each plate, which belts together carry the crop towards a transversal auger provided with opposite helical profiles and therefore capable of conveying the crop to the center of the head 4, where a chain elevator 6 operates. The chain is provided with projections 7 and runs between two rollers 8 and 9 taking the product and carrying it to the inlet of the threshing organs. The whole head 4 is hinged to the machine frame so as to be easily replaceable. The head is held by hydraulic actuators which vary its height relative to the ground for better adaptation to the state of the crop. The lower arrow in the figure indicates the forward movement direction, while the upper arrow indicates the opposite direction of the movement of the corn stalks within the head 5. The thickest lines in the figure enclose all those elements that contribute to generate flows of material within the machine for temporary storage and subsequent taking, or for spreading vegetal residuals onto the ground.

The harvester is of the axial type because, although it has higher fuel consumption, it has undoubted advantages over conventional harvesters, such as a lower grain breakage percentage, higher productivity and a stronger mechanical action on residuals. Axiality is referred to the longitudinal arrangement of the threshing cylinder 10, similar to the one described in the introduction. The ends 11 and 12 of the cylinder 10 have a helical profile for promoting inlet and outlet of the flowing material during rotation, whereas teeth 13 arranged along spiral lines project from the cylindrical surface for advancing the material from the inlet end 11 to the outlet end 12. The cage-like counter-thresher is not shown for simplifying drawing. Corn grains mixed with small vegetal residuals fall on a longitudinal auger 14 which conveys them onto a sieve 15, arranged above a sieve 16 having higher clearance at a predetermined distance between the two. Sieve are

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

oscillated for winnowing grains by means of a fan 17 adjoining the lower sieve 16 on the side oriented towards the auger 14. The fan 17 generates an air flow in the axial direction that thrusts vegetal residuals other thank grains towards the back end of the machine. The grains falling through the sieve 16 gather at the bottom, where they feed an auger arranged in a vertical tube 18 which throws them out into a container 19.
In front of the outlet end 12 of the threshing cylinder 10 there is a beating cylinder 20 arranged transversely, the rotation of the beating cylinder 20 throwing the vegetal residual, composed of corncobs, leaves and stalks, more or less broken, towards the back end of the machine. In front of the beating cylinder 20 at a certain predetermined distance therefore there is attached an almost vertical panel 21. The slope of the panel 21 relative to the vertical is adjustable at will in the direction of the back of the machine back end. The function of this panel is to deflect the denser material that hits it, mainly the corncobs, towards a third sieve 22 arranged below it at a predetermined distance. The more the panel 21 is tilted relative to the vertical, the less the corncobs are deflected. The sieve 22 consists of a frame in which parallel cylindrical rods are fixed, said rods being equally mutually spaced so as to let corncobs pass through, the leaves being swept away by the air flow generated by the fan 17. The sieve 22 is partially superimposed to the sieve 15 at a predetermined distance, whereas the deflector panel 21 is approximately in the halfway of the sieve 22. Corncobs are discharged at the distal end of the sieve 22 directly on a transversal auger 23 which feeds a system 24 for chipping corncobs and pneumatically conveying the chips into a duct 25 that terminates in the upper portion of a container 26 arranged on board. it is useful to say in advance that there are provided a cutting rotor assembly 27 and a pneumatic fan 28. Three augers driven in rotation by hydraulic motors are arranged in the cylindrical container 26, of which: an auger 29 in the central portion and a lower auger 30 for continuously mixing chips to prevent them from compacting, thus making discharge faster; and a vertical auger 31 that takes the product from the bottom of the container 26 and conveys it upwards for it to be collected. the container 26 has in its inside a vertical pipe which includes the lifting auger 31.

The purposes of this test were to determine the operating parameters of the machine and the quality and effectiveness of its work in order to assess the performances of the innovative harvesting system to collect the maize cob. The harvesting tests were performed in six blocks (replicates), belonging to the same maize field, of about 0.5 ha each.

In order to study the crop characteristics, before starting the work, ten sampling plots (replicates) of 1 m^2 were randomly selected inside the field. All plants of each plot were hand-harvested by cutting at ground level and the following biometric and productive characteristics registered: number of the plants, stem diameter at ground level, plant height and aboveground biomass yield of each plot. All the ears of each plot were weighted separately in order to study the biomass fractions of the maize crop and the ratio between ears and the total biomass. Four samples of maize cobs, of maize seeds and of leaf biomass were randomly collected in each experimental field, weighed and stored into vacuum-packs to measure the moisture content. Bulk density (kg/m^3) of the maize cob was assessed taking 10 samples of cob randomly selected from the biomass discharged by the machine.
The study of the machine performance was carried out during maize grain and cob harvesting. Maize grain and cobs harvested per each block were weighed separately in the farm scale by using different trailers.
The cob losses were estimated by gathering and weighting the material not harvested during passage of the machine, and any cob left on the ground. Five random plot of 10 m^2 were chosen per each experimental field, the cob present in each plot was collected and weighted with a portable scale.
Results of pre-harvesting sampling are described in Table 4. The values are related to the average of ten replicates of sampling plot (1 m^2) per each field, mean values are related to the mean of the three fields. The

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

average value of the stem diameter was 2.3 cm with a maximum value of 3.3 cm. The plant height showed a great variability ranging between 155 and 420 cm with an average value of 325.8 cm. The average weight of the total biomass was 50.7 t ha^{-1}, showing a great variability ranging between 42.8 to 55.1 t ha^{-1}. The ears weight was 19.5 t ha^{-1} in the average with 17.0 and 20.9 t ha^{-1} of minimum and maximum values respectively. The average value of the ears/biomass ratio was 44.0 %.

Table 4. Main crop characteristics of the experimental fields

	Stem diameter (cm)	**Plant height (cm)**	**Total biomass (t ha^{-1})**	**Ears weight (t ha^{-1})**	**Ratio ears/biomass (%)**
Mean	2.3±1.5	325.8±31.9	50.7±6.4	19.5±2.2	44.0

The average value of the leaf moisture content was 32.5%, while the stalks registered value of 72.2%. Values of grain moisture content showed value of 18.9%, and cob moisture content was 32.1%. The average bulk density resulted 132.36 kg m^{-3}.

Table 5. Means (±SD) of moisture content and bulk density of the biomass

	Leaf MC (%)	**Grain MC (%)**	**Cob MC (%)**	**Stalks (%)**	**Bulk density (kg m^{-3})**
Mean	32.5±2.9	18.9±2.2	32.1±3.4	72.2±2.8	132.36±11.58

The results of work time study are reported in table 6. The average value of effective field capacity was 1.36 ha h^{-1}. The average value of grain and cob yield was 13.12 and 1.72 t ha^{-1}, respectively. The cob losses were 0.58 (t/ha).

Table 6. Performance test, results of the combine harvesting machine

	CASE IH 7140			
	Seeds		**Cob**	
	Mean	**Dev.st.**	**Mean**	**Dev.st.**
Theor. Field Capacity	1.89	±0.29		
Eff. Field Capacity	1.36	±0.18		
Yield (t seeds ha^{-1})	**13.12**	**±0.28**		
Material capacity (t seeds h^{-1})	18.58	±0.13		
Yield (t cobs ha^{-1})			**1.72**	**±0.23**
Material capacity (t cobs h^{-1})			**2.31**	**±0.09**
	Mean		**Dev.st.**	

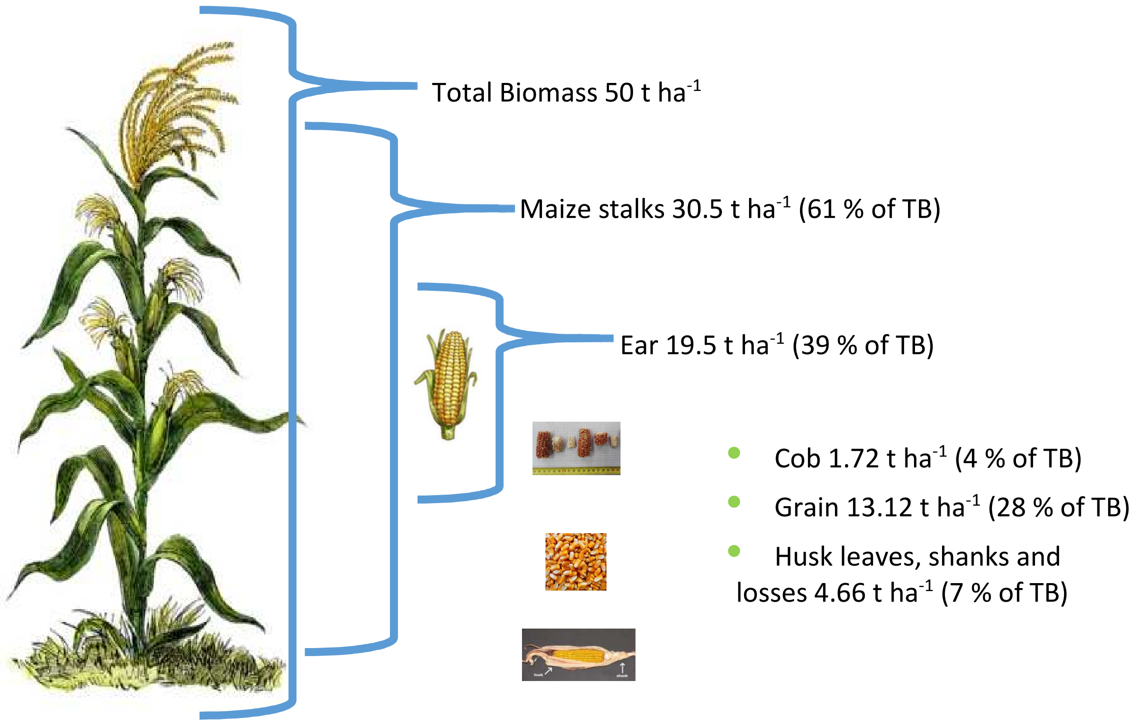
"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Fuel consumption (l ha^{-1})	27.1	±4.02
Cob losses (t ha^{-1})	0.58	±0.23

The amount of the biomass per hectare was in the average 50.7 t, as depicted in figure 7, being the amount of ear 19.5 t and the ear/biomass ratio 44 %. Considering this amount of biomass, the combine harvester machine equipped with the Harcob system, allowed to collect 13.12 t ha^{-1} of grain and 1.72 t ha^{-1} of maize cob characterized by a bulk density of 132 kg m^{-3}, with cob losses equal to 25 % (0.58 t ha^{-1}) of the total cob biomass potentially harvestable.

Because of its high moisture content after harvesting (32.1 % on average), the maize cob can be considered an appropriate biomass to be fed directly into a biogas power plant. In the case of a scope for animal bedding, natural drying could be a cost-effective option to reach lower moisture contents. Instead, it needs to be dried with a forced system if it must be used for animal feed production.

Figure 7. Biomass characterization of maize.



The aim of the work was also to investigate the potential utilization of maize cob as feedstock for advanced biofuel production in areas where these by-products are available but there is still no market. Five samples of maize cob were randomly collected by the fields of Revello (Cuneo, Italy) during field test to determine the feedstock chemical composition. The analysis were conducted according to EN ISO standards. Results of the analysis are depicted in the table 7. The proper functioning of the Harcob system and the quantity and quality of the maize cob, also considering the availability of this product in EU, makes this untapped material an attractive biomass resource that can be used for many purposes.

Table 7. Maize cob chemical composition

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Biomass	Moisture content (w%-ar)	N (%w/w)	Cl (%w/w)	S (%w/w)	Ash (%w/w)	LHV (MJ/kg_{db})
Maize cob	32.1±3.4	0.75±0.01	0.27±0.01	0.02±0.01	2.02±0.01	17.64±0.04

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

4.4 Fiber sorghum value chain

The CREA-IT within the project in collaboration with COPROB sugar beet cooperative, who has undertaken a productive strategy towards the energy production from biomass, has studied the value chain of fiber sorghum. The objective was to describe the fiber sorghum harvesting machineries and the supply chain built-up by COPROB for an energy purpose.

Among the biomass crops, fiber sorghum was selected by COPROB due to its annual cycle, the high yield and its high drought adaptability.

Figure 8 – Fiber sorghum fields.

Here below, it is summarised the storyline of the COPROB and the interesting data of the use of fiber sorghum for energy purpose.

COPROB has diversified his business from a merely sugar agro-industry to be part of a society running a biomass power plant (in 2 of their sites). In 2006, when the EU policy of sugar production changed, they decided to re-convert their activity inside the energy sector with the support of the Italian government, being part nowadays of the societies running 3 energy power plants (2 combustion, 1 biogas). Moreover, nowadays, this diversification represents an interesting complement for the COPROB farmers.

Regarding fiber sorghum, the cooperative members produce this feedstock to be used in one of the combustion power plant managed by the partnership COPROB and ENEL, being the former one of the feedstock supplier and the latter the one who manages the facility. Other materials fed in the plant are agricultural residues (wheat straw and maize stalks) and poplar wood chips.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

COPROB technicians studied in detail the different stages of the fiber sorghum cultivation process in collaboration with the farmers of the cooperative and together they organized the logistic chain.

Planting pattern of the sorghum is 70 cm between the rows and 10 cm between the plants on the row. The biomass yield can vary from around 20 to 48 t/ha of dry matter in normal conditions. Plant lodging is another plant characteristic to take in consideration when a variety should be planted. In fact, this can vary from 5 to 35%, according to the fiber sorghum variety planted, and the mechanical harvesting chain should be decided also in function of the lodging level of the crop.

Regarding the logistics, the harvesting is performed by external companies organised by COPROB. In the early stage of the conversion process, even though sorghum resulted a very interesting energy crop, harvesting was the main issue due to the lack of efficient harvesting systems. In fact, green fiber sorghum has a moisture content of 75 – 80 % (w-%, as received; wet basis used in the whole report). This value must be decreased to over 50 % in order to preserve the product during the yearly storage (meaning a reduction to minimum 30 % moisture content) and make the whole supply chain economically feasible (reduction of transport costs).

To this day, machines derived from haymaking or from mower conditioners, hay rakes and balers have been used for this purpose. However, according to various Research Institutes that have carried out fiber sorghum harvesting tests with machines for the haymaking, the conditioning resulted not always satisfactory as it extended the times required for the field drying process with the risk to postpone the harvesting and ruin the product in the case of rainfalls. In order to speed up the drying process, the spongy pith of the stems (moisture content of about 90%) must be put in contact with air in order to dry it naturally.

For this reason, today COPROB uses two different logistic chains based on two different harvesters (see Figure 9):

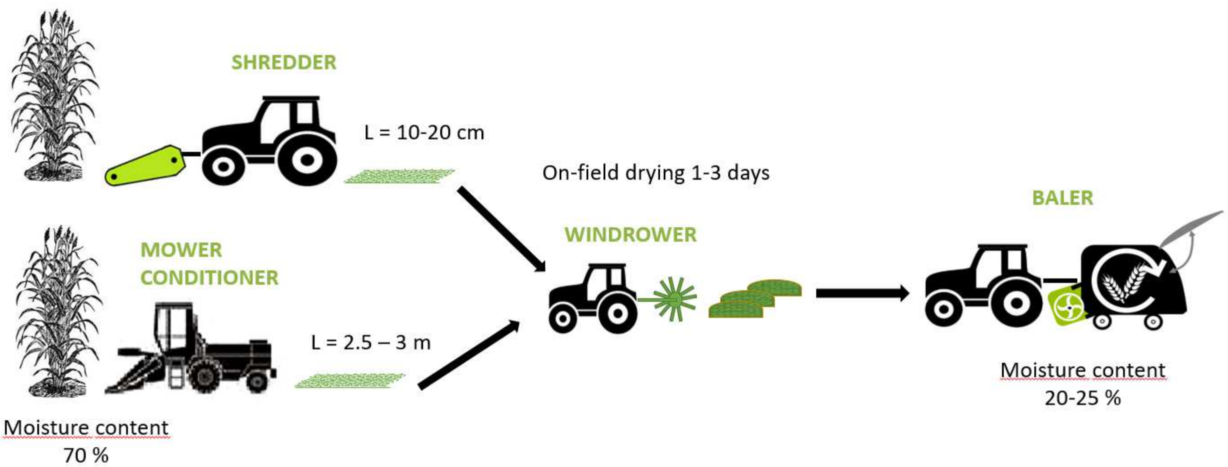


Figure 9. Steps of the logistic chain used by COPROB.

Conditioning is made with Cressoni header (Figure 10): It is a machine specifically developed for COPROB by CREA and Cressoni firm during the project Suscace (National Project funded by the Italian Ministry of Agriculture to support the conversion from sugar agro-industry to biomass power plants). The header allows to condition the plants of four rows per time, alternatively squeezing and cutting each plant stem. By this header, the crop passes from an average moisture content of 70% to 15-20% in a very small period (in

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

normal conditions about 4- 5 days) (Figure 4). The approximate fuel consumption and biomass losses are 30 l/h and 10%, respectively. Field capacity is about 1 ha/h. The price of the device is about 60,000 €.

Figure 10. Cressoni header and aspect of the conditioned plants.

Figure 11. Picture of a conditioned plant by the CRESSONI machine after the drying process on-field.

Shredding is made with Nobili WS 320 BIO machine (Figure 12): it is a commercial robust machine, with a shredding system that consists of a horizontal rotor with 64 flail blades half Y-shaped. The eight rows of flails are staggered to provide a complete cut. An idle conveyor roller (Ø 160 mm) in front of the moveable hood reduces friction with the crop and assists entry of the product into the shredding chamber. Contra knives mounted inside the shredding chamber increases the shredding action. Double auger conveyor situated in the rear of the shredding chamber allows the product to be windrowed. Rear roller allows adjustment of the working height. The fuel consumption is similar to Cressoni header (30 l/h) and biomass losses slightly higher (15 %). Field capacity is about 1 ha/h. The price of the device is about 20,000 €.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Figure 12. Nobili header and aspect of the harvested material.

After the windrowing (Figure 13), when the moisture content reaches 15-20 %, the material is baled with conventional prismatic baler (Figure 14). All the logistic chain costs represent around 30 €/t (including harvesting, windrowing, baling and transport for maximum distances of 50 km). COPROB purchases the material to the logistic operators at 50 €/t (plant gate price) considering 75 % of dry matter.

Figure 13. Before and after field drying + windrowing of the material.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Figure 14. Conventional baler used for fiber sorgum.

The Finale Emilia Power Plant (15 MWe), in operation from one year (incentives agreed for 15 years) has a proper storage area where the management of the different raw materials is operated (Figure 15).

Figure 15. Storage of baled Sorghum (right) and straw bales (left) in the power plant.

The fiber sorghum value chain represents an example of collaboration between conversion processes, farming systems and logistics. This synergy allowed to overcome problems related to the requirements of each step of the value chain and to define a strategy to cultivate, harvest, transport and store the biomass to be converted in energy in a more efficient way.

Following are summarized the value chain from cultivation to the storage (Figure 16) and its simplified cost analysis (Figure 17).

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

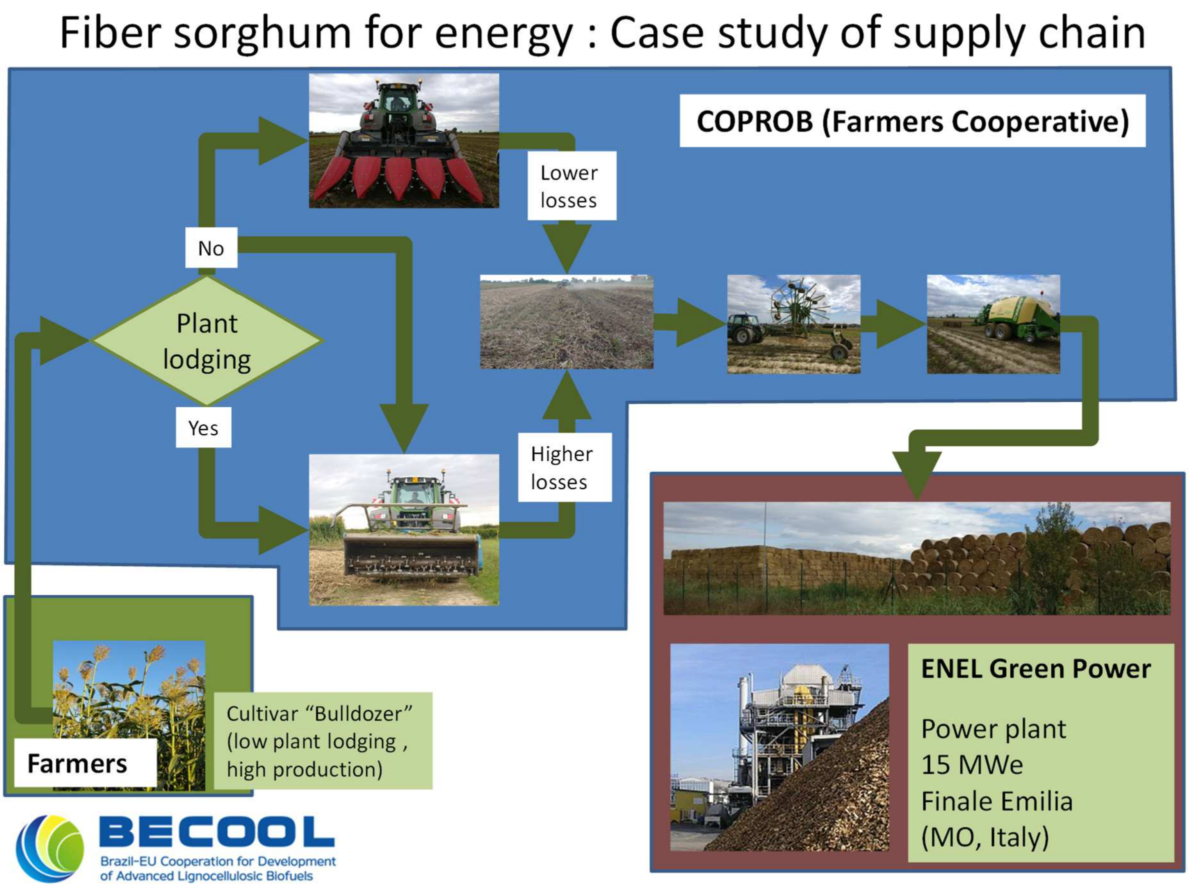


Figure 16. Value chain form cultivation to storage.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

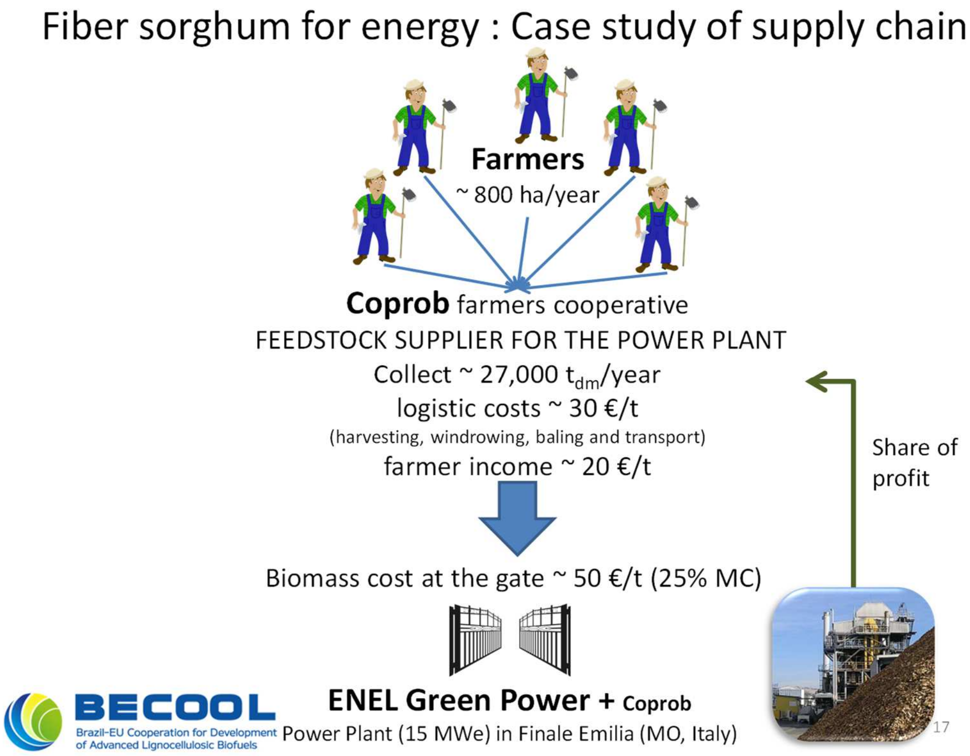


Figure 17. Simplified cost analysis of the value chain.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

4.5 Eucalyptus storage test

The goal of this subtask is to define the best logistic chain of eucalyptus on the basis of the storage performance and of the quality of the biomass according to the final use of the feedstock. For this purpose, CREA carried out storage trials of 5 years old eucalyptus plants in three different biomass formats (whole trees, chips and firewood), testing different treatments: the whole plants were stored with and without branches, the comminuted biomass was stored covered and uncovered, and the firewood was tested in outdoor and indoor conditions.

The evaluation of the storage performance was made according to the evolution of biomass quality characteristics (moisture content every sampling day, whereas ash content, heating value and chemical composition at the storage beginning; all parameters were analysed according to current ISO standards) and dry matter losses, along storage time. Climatic parameters such as precipitation, wind speed and mean air temperature were recorded during the entire test. Data were recorded using a weather cab "Davis vantage pro 2" placed approximately 200 m from the storage site. It has been the first attempt to store eucalyptus in this area. For the trials, eucalyptus from CREA were harvested by a chainsaw and treated with commercial machinery to obtain the different formats studied.
The next lines explain how the storages were built and monitored. Mean results on moisture content and dry matter losses are presented in Table 9. Additional values on biomass quality are still on processing and will complete the study to obtain final energy variation (gain or loss).
Wood stem storage with and without branches: the trial of wood stem took place outdoors during nine months, using 60 eucalyptus plants (3.5 tons). The experimental layout was composed by 4 non-covered piles of whole trees, 2 with stem-only and 2 with whole trees (leaves and branches included). Each pile of 15 plants was formed by 5 layers of plants, starting from 5 plants at ground level till one plant in the top. Each pile of trees was weighed using a dynamometer at harvesting date, every 30 days and at the end of the storage period. At the same time, 10 samples of wood stem for each pile were randomly selected to determine moisture content.

Figure 18. Wood pile for stem storage (left) and whole tree storage (right).

Comminuted biomass stored on covered and un-covered pile: around 34.6 tons of comminuted biomass was stored in a pile during nine months. Half of the pile was covered using a Toptex textile. Monitoring storage was carried out by placing pT-100 sensors and plastic net bags in 18 sampling points distributed on each

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

semi-pile. Temperature was recorded every 10 minutes in order to evaluate heat development. Each bag was weighed and moisture content was determined at the beginning and the end of the trial. Particle size distribution (ISO 17225-4:2014) of the comminuted biomass was determined before the storage in piles by analyzing 3 samples of 8 liters of volume each.

Figure 19. Covered and uncovered pile of comminuted Eucaliptus

Firewood outdoor and indoor storage: around 1.2 tons of firewood was packed into 52 net plastic bags, half of which was stored outdoor and the other half indoor (in a covered warehouse). Each net plastic bag was weighed using a dynamometer at the beginning of the storage, every 30 days and at the end of the storage period in order to calculate the mass variation due to losses of dry mass and moisture content reduction. In this regard, concurrently with the day of weighing, samples of firewood for the different treatments were randomly selected to determine the moisture content.

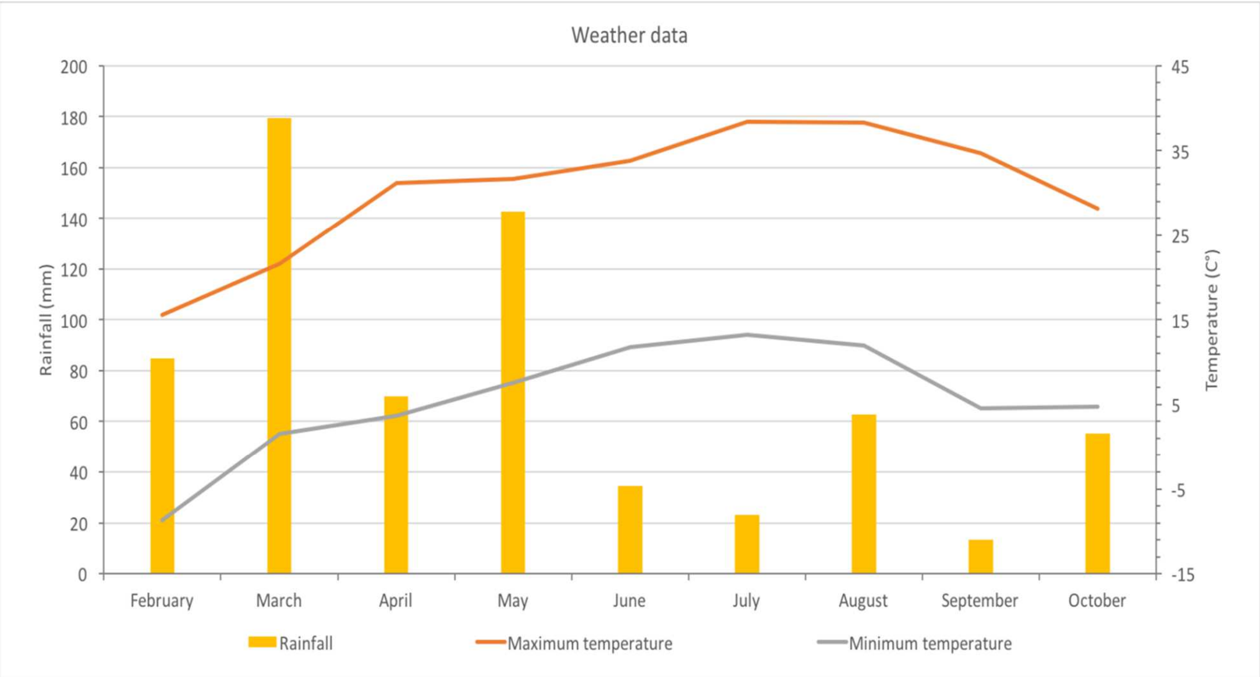
"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Figure 20. Firewood stored stored indoor (left) and outdoor (right)

During the storage period the total rainfall recorded was 665.8 mm. The mean temperature during the whole storage period was 17.97 °C, and the mean monthly rainfall was 73.98 mm. Maximum and minimum temperature were registered respectively in July (38.4 °C) and February (-8.7 °C), while the maximum amount of precipitation was recorded in March (179.4 mm) and the minimum in September (13.2 mm).

Table 8. Weather data of the storage period

Weather data	
Total rainfall	665.8 mm
Mean monthly rainfall	73.98 mm
Maximum rainfall	179.4 mm
Minimum rainfall	13.2 mm
Mean temp	17.97 °C
Maximum temp	38.4 °C
Minimum temp	-8.7°C



"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Figure 21. Weather data of the storage period

At time of harvest, after five years of cultivation, the mean height of the plants was 9.7 m and the mean diameter 13.08 cm. The total weight of the plant was 68.17 kg in the average, while the mean weight of the stem was 38.23 kg. The moisture content was 50.56 % for the stem and 49.68 % for the chipped biomass (w%-ar). In table 9 are depicted the mean results of storage performances.

Table 9. Results of storage performance

Storage type	Treatment	Initial moisture content (w%-ar)	Final moisture content (w%-ar)	Dry matter losses (%)
Whole plant (3.5 t)	Stem storage (SS)	50.56	15.01 a	-4.26 a
	Whole tree storage (WS)		12.17 b	-17.75 b
Chipped biomass (34.6 t)	Covered	49.68	24.18 a	1.24 a
	Uncovered		31.99 a	-6.65 a
Fire wood (1.2 t)	Indoor	50.56	10.50 a	2.53 a
	Outdoor		13.56 a	-3.17 b

Wood stem storage with and without branches:

The initial mean weight of the SS piles was 583.3 kg with a dry matter content of 288.41 kg, at the end of the storage period the biomass reached a mean weight of 324.7 kg and the dry matter content was reduced to 276.0 kg. The storage period caused a reduction of 44.31 % of the total weight, a loss of 83.49 kg H20 and 4.26 % of dry matter.
For what concern the WS piles the initial mean weight was 1114.3 kg with a dry matter content of 550.96 kg, at the end of the storage period the biomass reached a mean weight of 515.9 kg and the dry matter content was reduced to 453.1 kg. The storage period caused a reduction of 53.7 % of the total weight, a loss of 500.55 kg H20 and 17.75 % of dry matter.
The differences between the two treatments in terms of final moisture content and losses of dry matter were statistically significant ($P<0.05$).
In October, 52.2 mm of rainfall were recorded. This amount of precipitation caused an increase of 7 kg of total weight of the biomass due to a 4.33 % increase of the moisture content of the SS piles, while it caused an increase of 8.7 kg of total weight of the biomass due to a 1.3 % increase of the moisture content of the WS piles. Reducing the storage time until the end of September will avoid the autumnal precipitation producing a biomass with lower value of moisture content.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

Comminuted biomass stored on covered and un-covered pile:

Following are depicted the results of particle size distribution (table 10). The comminuted biomass belongs to the dimensional class P16 (ISO 17225-4:2014), it means that the dimensions of more than 60% of the chips are included between 3.15 mm and 31 mm. P16 is a type of chipped biomass of very small dimension that during storage reduces the air circulation inside the pile affecting the dehydration process.

Table 10. Results of particle size distribution of biomass after comminution

Sieve	**Fraction (mm)**	**Sample 1 (%)**	**Sample 2 (%)**	**Sample 3 (%)**	**Mean (%)**
1° sieve	**63-100**	0.0	0.0	0.0	0.0
2° sieve	**45-63**	0.0	0.0	0.0	0.0
3° sieve	**31-45**	0.0	0.0	0.0	0.0
4° sieve	**16-31**	1.4	1.5	0.9	1.3
5° sieve	**8-16**	16.5	20.3	21.0	19.2
6° sieve	**3.15-8**	59.4	58.8	53.8	57.3
Collector	**< 3.15**	22.8	19.4	24.3	22.2
	Total	100.0	100.0	100.0	100.0

Probably this situation fostered the fungi and bacteria development that, preferring wet environment and biomass, caused very high dry matter losses (6.7 %) during uncovered storage.
The moisture content was reduced till 31.99 % from an initial content of 49.68 %reduction.
Moisture content reduction of the comminuted biomass stored covered was higher reaching a final value of 24.18 %, even if no statistically significant differences were found. This result was guaranteed by the Toptex textile coverage that prevented wetting of the biomass after the rainfall.
Storage of comminuted biomass in piles confirmed what already highlighted from previous studies: the dehydration and degradation of the biomass is strongly influenced by the particle size distribution. In this study the reduced dimension of the chips, affected the air circulation inside the pile limiting the drying process.

Firewood outdoor and indoor storage:

When the trial started the average weight of each net plastic bag was 20.8 kg and the moisture content was 50.6 %, with a dry matter content of 49.4 %. Regarding the indoor storage, at the end of the storage period the firewood biomass reached a mean weight of 11.8 kg, and the moisture content was 10.5 %. The storage period caused a reduction of 44 % of the total weight, and the dry matter losses were equivalent to 0, even if resulted positive.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

For what concern the outdoor storage, at the end of the storage period the firewood biomass reached a mean weight of 11.5 kg and the moisture content was 13.56 %. The storage period caused a reduction of 45 % of the total weight, and the dry matter losses were equivalent to 3.17%
The difference in terms of dry matter losses resulted statistically significant among the two treatments (indoor and outdoor), while no statistically differences were recorded in terms of final moisture content.

The aim of the work was also to investigate the potential utilization of eucalyptus as feedstock for advanced biofuel production in areas where these by-products are available but there is still no market. Five samples of eucalyptus were randomly collected by the CREA fields during harvesting to determine the feedstock chemical composition. The analysis were conducted according to EN ISO standards. Results of the analysis are still under processing.

The storage test allowed to compare the storage performance and the quality of the biomass of three different storage methods of biomass deriving from a medium rotation forestry plant of Eucalyptus.
Storage of firewood showed highest reduction of moisture content and lowest losses of dry matter. Whole plant storage highlighted results very similar to firewood except for dry matter losses of whole tree storage that were very high (17.75 %). The comminuted biomass stored in piles highlighted a lower moisture content reduction and high dry matter losses during uncovered storage.
Final moisture content reached by firewood and whole plants could allow to use the biomass as firewood or as chipped biomass. Nevertheless, the moisture content increase of the last month of storage suggested to store the biomass until the end of the summer in order to prevent rewetting caused by autumnal rainfalls.
Future economic analysis are needed to investigate which storage system is the more sustainable in terms of costs and logistics.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

5 Conclusions

The last European directive on the promotion of the use of energy from renewable sources bind European countries to find new sources of feedstock for bioenergy. The biomass studied appeared very promising and even is some bottlenecks still exist on them value chain, these feedstocks can apparently be appropriate substitutes for the traditional energy production systems.

The activity performed by CREA-IT inside the WP 1 shown as the optimal organisation of the value chain, strictly depends on the harvesting and storage of the biomass. The harvesting test carried out on wheat chaff, maize cob, olive pruning and on the storage of eucalyptus was crucial to better understand the critical points of the value chain and fill the existent gaps.

The proper functioning of the Thievin and Racca systems and the quantity and quality of the wheat chaff and maize cob, also considering the availability of these products in EU, makes these untapped materials an attractive biomass resource that can be used for many purposes.

The results of olive pruning test demonstrated that the fuel consumption is essentially linked to the chopping phase and that harvesting in the hills does not seem to excessively influence the fuel consumption of the tractor-shredding.

The storage test of eucalyptus highlighted the importance of choosing the right period to store the biomass to limit dry matter losses and reduce the moisture content. However, the different type of storage of this biomass resulted very effective confirming that this feedstock could be used for many purposes such as fire wood, chip and logs.

The fiber sorghum value chain studied, demonstrated that the development of the harvesting system fosters the following development of the entire supply chain. In fact, this is an example of the involvement of all the stakeholders from farmers to the energy plant manager. This synergy allowed to overcome problems related to the requirements of each step of the value chain and to define a strategy to cultivate, harvest, transport and store the biomass to be converted in energy in a more efficient way.

5.1 Further steps

In the next period of BeCool project the storage test on giant reed, actually on-going, will be finalized. Furthermore, once the BioValue project will be run, some activities focusing on agricultural residues of special interest of the Brazilian counterpart will be performed. These activities will consolidate the collaboration between Europe and Brazil. Particular attention will be paid on Banana, Pineapple and Sugar cane residues. These biomasses are very important for the Brazilian agricultural sector, and even if the potential in terms of energy, fiber or pulp production is well known, the mechanization systems do not exist. Thus, can be of great interest for European agricultural machineries industries that are looking to new markets and a basis of mutual cooperation between Europe and Brazil.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

6 References

Amaducci S, Amaducci MT, Benati R, Venturi G. Crop yield and quality parameters of four annual fibre crops (hemp, kenaf, maize and sorghum) in the north of Italy. Ind Crop Prod 2000;11(2e3):179e86.

Angelini, L.G., Ceccarini, L., Bonari, E. Biomass yield and energy balance of giant reed (*Arundo donax* L.) cropped in central Italy as related to different management practices. Eur. J. Agron., 22, 2005, pp. 375-389

Assirelli, A., Pignedoli, S., 2005. Costo di esercizio delle macchine agricole. Cent. Ric. e Prod. Anim. 1–10.

Ban, J., Yu, J., Zhang, X., & Tan, T. (2008). Ethanol production from sweet sorghum residual. *Front Chem. Eng. China, 2*(4), 452-455.

Boldrin, A., Astrup, T. GHG sustainability compliance of rapeseed-based biofuels produced in a Danish multi-output biorefinery system. Biomass and Bioenergy, 75, 2015, 83-93.

Boll, T., Neubert, F. P., Zimmermann, K., Bergfeld, A., 2015. Decision criteria and implementation strategies for short rotation coppice in Germany from the perspective of stakeholders. Bioenergy from Dendromass for the Sustainable Development of Rural Areas.

Buratti, C., Barbanera, M., Fantozzi, F. A comparison of the European renewable energy directive default emission values with actual values from operating biodiesel facilities for sunflower, rape and soya oil in Italy. Biomass Bioenergy, 47 (2012), 26-36

Carriquiry, M.A., Du, X., Timilsina, G.R., 2011. Second generation biofuels: Economics and policies. Energy Policy 39, 4222–4234.

Cosentino, S.L., Copani, V., D'Agosta, G.M., Sanzone, E., Mantineo M. First results on evaluation of *Arundo donax* L. clones collected in Southern Italy. Ind. Crops Prod., 23 (2006), pp. 212-222

Davila-Gomez, F. J., Chuck-Hernandez, C., Perez-Carrillo, E., Rooney, W. L., & Serna-Saldivar, S. O. (2011). Evaluation of bioethanol production from five different varieties of sweet and forage sorghums (Sorghum bicolor (L) Moench). *Ind. Crops Prod., 33*(3), 611-616.

Dyjakon, A., den Boer, J., Bukowski, P., Europruning a new direction for energy production from biomass, Agr. Eng. 18 2014.

EC, Eurostat Database, Eur. Comm. Online Stat. Database. (2017). http://ec.europa.eu/eurostat/data/database.

Ericsson, K., Nilsson, L.J., 2006. Assessment of the potential biomass supply in Europe using a resource-focused approach. Biomass and Bioenergy 30, 1–15.

European Parliament, Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009, Off. J. Eur. Union. 140 (2009) 16–62. doi:10.3000/17252555.L_2009.140.eng.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

EU 2015/1513, ILUC Directive, Off. J. Eur. Union. (2015) 20–30. doi:http://eur-lex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf.

Faasch, R.J., Patenaude, G., The economics of short rotation coppice in Germany. Biomass and Bioenergy, 45, 27-40, 2012.

Garcìa-Galindo, D., Lopez, E., Gomez-Palmero, M.E.P., Europruning project: summary of final results, in: In Proceeding of 24th European Biomass Conference and Exhibition, June 2016 (a), pp. 6-9. Amsterdam, The Netherlands, 6-9.

Garcìa-Galindo, D., Gomez-Palmero, M.E.P., Germer, S., Pari, L., Alfano, V., et al., Agricultural pruning as biomass resource: generation, potentials and current fates. An approach to its state in Europe, in: Proceeding of 24th European Biomass Conference and Exhibition, June 2016 (b), pp. 1579-1595. Amsterdam, The Netherlands, 6-9.

Ghaderi, H., Pishvaee, M.S., Moini, A., 2016. Biomass supply chain network design: an optimization-oriented review and analysis. Ind. Crops Prod. 94, 972–1000.

Haughton, A.-J., Bohan, D.-A, Clark, S.-J., Mallott, M.-D., Mallott, V., Sage, R., Karp. A. Dedicated biomass crops can enhance biodiversity in the arable landscape, GCB Bioenergy 8 (6) 1071-1081, 2016.

Hutton, G. (2008). Increasing cow/calf profitability using chaff and chaff/straw feedstuffs. Alberta Agriculture and Forestry, Alberta Agri-facts. Agdex 420/50-2.

Iakovou, E., Karagiannidis, A., Vlachos, D., Toka, A., Malamakis, A., 2010. Waste biomass-to-energy supply chain management: a critical synthesis. Waste Manag. 30, 1860–1870.

ISO 14774-2:2009, Solid biofuels – Methods for the determination of moisture content – oven dry method

ISO 14775: 2010. Solid biofuels – Determination of ash content.

ISO 15104: 2011. Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen-Instrumental method.

ISO 16994, Solid biofuels — Determination of total content of sulfur and chlorine

ISO 17225-4:2014, Solid biofuels – Fuel specifications and classes – Part 4: Graded wood chips, (2014) 8

ISO 17828, Solid biofuels — Determination of bulk density

ISO 18125:2017, Solid biofuels -- Determination of calorific value

Jansen C, Lübberstedt T (2011) Turning maize cobs into a valuable feedstock. Bioenerg Res. doi: 10.1007/s12155-011-9158-y

Johnson, J.-F., Allmaras, R.R., Reicosky, D.C., 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. Agron. J. 98, 622–636.

“This project has received funding from the European Union’s Horizon 2020 research and innovation programme *under grant agreement No 744821”*

Khawaja, C., Janssen, C., 2015. D4.3a of the SUCELLOG project - Summary of the current situation of Tschiggerl Agrar GmbH and feasibility study. SUCELLOG project, Triggering the creation of biomass logistic centres by the agro-industry

Lenz, H., Pecenka, R., Idler, C., Dumfort, S., Whittaker, C., Ammon, C., & Hartung, E. Continuous weighing of a pile of poplar wood chips–A comparison of methods to determine the dry matter losses during storage. Biomass and Bioenergy, 96, 119-129, 2017.

Lewandowski, I., Scurlock, J.M.O., Lindvall, E., Christou, M. The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. Biomass Bioenergy, 25 (2003), pp. 335-361

Lundin, G. & Rönnbäck, M. (2010) Simultaneous harvest of straw and chaff for energy purposes - Influence of bale density, yield, field drying process and combustion characteristics. Uppsala, JTI - Swedish. Institute of Agricultural and Environmental Engineering.

Murray, D. (2005). Ethanol's potential: Looking beyond corn. *Earth Policy Institute.* Retrieved from http://www.earthpolicy.org/Updates/2005/Update49.htm.

Magar S.B., Pelkonen P., Tahvanainen L., Toivonen R., Toppinen A. Growing trade of bioenergy in the EU: public acceptability, policy harmonization, European standards and certification needs, Biomass Bioenerg. 35 (8), 2011, 3318-3327.

McCartney, D.H., Block, H.C., Dubeski, P.L., Ohama, A.J. Review: The composition and availability of straw and chaff from small grain cereals for beef cattle in western Canada, Can. J. Anim. Sci. 86 (2006) 443–455. doi:10.4141/A05-092.

Messineo, A., Volpe, R., Marvuglia, A., Ligno-cellulosic biomass exploitation for power generation: a case study in Sicily, Energy 45 (1), 2012, 613-625.

Nassi o Di Nasso, N., Angelini, L.G., Bonaria, E. Influence of fertilisation and harvest time on fuel quality of giant reed (*Arundo donax* L.) in central Italy Eur. J. Agron., 32 (2007), pp. 219-227

Nelson, R.G., 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States—rainfall and wind-induced soil erosion methodology. Biomass and Bioenergy 22, 349–363.

Onofri, A., 2007. Routine statistical analyses of field experiments by using an Excel extension, in: 6th National Conference of the Italian Biometric Society.

Paiano, A., Lagioia, G. Energy potential from residual biomass towards meeting the EU renewable energy and climate targets. The Italian case, Energy Policy. 91 (2016) 161–173. doi:10.1016/j.enpol.2015.12.039.

Palmieri, N., Forleo, M.B, Giannoccaro, G., Suardi, A. Environmental impact of cereal straw management: An on-farm assessment, J. Clean. Prod. 142 (2017). doi:10.1016/j.jclepro.2016.10.173.

Pari, L., Suardi, A., Santangelo, E., García-Galindo, D., Scarfone, A., & Alfano, V. Current and innovative technologies for pruning harvesting: A review. Biomass and bioenergy, 107, 2017, 398-410.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Patel, B. Biomass Characterization and its Use as Solid Fuel for Combustion, Iran. J. Energy Environ. 3 (2012) 123–128. doi:10.5829/idosi.ijee.2012.03.02.0071.

Pilu, R., Manca, A., Landoni, M. Arundo donax as an energy crop: pros and cons of the utilization of this perennial plant, vol. 58, Maydica Electronic Publication (2013), pp. 55-59

Pilu, R., Bucci, A., Badone, F.C., Landoni, M. Giant reed (*Arundo donax* L.): a weed plant or a promising energy crop Afr. J. Biotechnol., 11 (2012), pp. 9163-9174

Pollex, A. and T. Zeng. Initiators Handbook MIXBIOPELLS, 2012.

Ratnavathi, C. V., Suresh, K., Vijay Kumar, B. S., Pallavi, M., Komala, V. V., & Seetharama, N. (2010). Study on genotypic variation for ethanol production from sweet sorghum juice. *Biomass and Bioenergy., 34* (7), 947-952.

Romanski, L., Dyjakon, A., Adamczyk, F., Frackowiak, P., Problems with deriving the fruit tree pruned biomass for energy use, Agr. Eng. 18, 2014.

Saidur, R., Abdelaziz, E.A., Demirbas, A., Hossain, M.S., Mekhilef S. A review on biomass as a fuel for boilers, Renew. Sustain. Energy Rev. 15 (2011) 2262–2289. doi:10.1016/j.rser.2011.02.015.

Sathre, R. Comparing the heat of combustion of fossil fuels to the heat accumulated by their lifecycle greenhouse gases. Fuel, 115, 2014, 674-677.

Scarlat, N., Martinov, M., Dallemand, J.-F., 2010. Assessment of the availability of agricultural crop residues in the European Union: potential and limitations for bioenergy use. Waste Manag. 30, 1889–1897.

Scarlat, N., Dallemand, J. F., Banja M. Possible impact of 2020 bioenergy targets on European Union land use. A scenario-based assessment from national renewable energy action plans proposals. Renew Sustain Energy Rev, 18 (2013), 595-606

Sipos, B., Re´czey, J., Somorai, Z., Ka´da´, R. Z., Dienes, D., Re´czey, K. (2009). Sweet sorghum as feedstock for ethanol production: enzymatic hydrolysis of stem-pretreated bagasse. *Appl. Biochem. Biotechnol., 153*(1-3), 151-162.

Shinners KJ, Binversie BN, Muck RE, Weimer PJ (2007). Comparison of wet and dry corn stover harvest and storage. Biomass Bioe 31:211–221.

Shirtliffe, S.J., Entz, M.H. Chaff collection reduces seed dispersal of wild oat (Avena fatua) by a combine harvester, Weed Sci. 53 (2005) 465–470. doi:10.1614/WS-03-109R2.

Spinelli, R., Magagnotti, N., Nati, C., Harvesting vineyard pruning residues for energy use, Biosyst. Eng. 105 (3), 2010, 316-322.

Spinelli, R., Magagnotti, N., Nati, C., Pari, L., Vanneste, J. Recovering kiwifruit pruning residues for biomass production, Trans. ASABE 55 (1) ,2012, 21-28.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*

Trebbi G. Power-production options from biomass: the vision of a southern European utility. Bioresour Technol 1993;46(1e2):23e9.

Wiesenthal, T., Mourelatou, A., Petersen, J.E., Taylor P., How much bioenergy can Europe produce without harming the environment? EEA. No. 7 (2006).

Wilhelm, W.W., Johnson, J.M.F., Hatfield, J.L., Voorhees, W.B., Linden, D.R., 2004. Crop and soil productivity response to corn residue removal. Agron. J. 96, 1–17.

Yazan, D.M., van Duren, I., Mes, M., Kersten, S., Clancy, J., Zijm, H., 2016. Design of sustainable second-generation biomass supply chains. Biomass and Bioenergy 94, 173–186.

"This project has received funding from the European Union's Horizon 2020 research and innovation programme *under grant agreement No 744821"*