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DEC	Websites, patent fillings, videos, etc.	☐			
OTHER		☒			

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1 Publishable executive summary

CREA activities in the Magic project are mainly concentrated in task 5.1: harvesting systems and post-harvest handling. The goal of this task is to spread knowledge on harvest systems for industrial crops to be cultivated on marginal lands and in different zones of Europe. To achieve the task objectives, the first activities performed by CREA is the creation of an inventory in form of deliverable (D 5.1) on the currently available harvesting technologies for the twenty crops that have been selected from the magic crop database. The inventory that is presented in this document gathers information obtained from direct data collection in previous projects, scientific literature review and market analysis on the current existing technologies used to harvest non-food crops in marginal lands. The document is organized in fact-sheets representing an "easy-to-find" and "easy-to-use" instrument for final users (e.g. farmers, industries), providing a rapid identification of the principal mechanized harvesting solutions for a specific crop, according to the final use of the biomass. For each crop a traffic light is included in the general information to provide indications about the status of knowledge on harvest technologies: green light - high level of knowledge on mechanical harvesting, based on scientific evidences; yellow light - medium level of knowledge on mechanical harvesting, based on practical evidences but not yet scientifically proven; red light - low level of knowledge on mechanical harvesting, based mainly on market analysis and manufacturer assumptions.

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2 Introduction

The currently available harvesting systems as well as post-harvest handling play a quite important role in the profitability of industrial crops, especially when those are grown on marginal land. Even if appropriate harvesting systems for industrial crops exist on the market, they are insufficiently known to relevant stakeholders (e.g., farmers, industry) due to small size of the factories producing machineries, language barriers, no appropriate advertisement, etc.

This apparent lack of appropriate machinery significantly affects farmers' perception of the possibility to cultivate these industrial crops. Thus, the development of a comprehensive inventory on currently available harvesting systems of industrial crops on marginal land has been considered as a need in the MAGIC project.

The inventory presented in this deliverable gather information obtained from direct data collection in previous projects, scientific literature review and market analysis on the current existing technologies used to harvest non-food crops to be grown in marginal lands and included in the MAGIC CROPS database. The document is organized in fact-sheets representing an “easy-to-find” and “easy-to-use” instrument for final users, providing a rapid identification of the principal mechanized harvesting solutions for a specific crop according to the final use of the biomass.

For each crop a traffic light is included in the general information to provide indications about the status of knowledge on harvest technologies: green light - high level of knowledge on mechanical harvesting, based on scientific evidences; yellow light - medium level of knowledge on mechanical harvesting, based on practical evidences but not yet scientifically proven; red light - low level of knowledge on mechanical harvesting, based mainly on market analysis and manufacturer assumptions or interpretation made by researchers according to plant characteristics and uses.

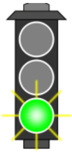
Crop n.1	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Sweet and Fibre sorghum *Sorghum bicolor* L. Poaceae	Northern Africa	South (S), Central (C)	High drought resistant crop, deep rooting system, can be grown on toxic soils.	Carbohydrate, Lignocellulosic (annual)	Bioethanol production (1st generation and advanced biofuels), biogas production, animal feed, human feed.

Figure 1.1 – Sweet sorghum

Figure 1.2 – Cressoni header

Fiber Sorghum (bioenergy from combustion, advanced bio-fuels):

The harvest period is late summer when the plants reach the maximum accumulation of dry matter. The harvest system should allow the dehydratation in the field, reducing the plant humidity from 75% to 25 % in order to bale the products and storage it. To let the water to evaporate the pith as to be putted in contact with the air, thus an excellent conditioning phase have to be performed; otherwise, the drying time of whole plants in open field would be too long, exposing the mowed biomass to adverse climatic conditions that may determine losses of dry matter and negatively affect the success of baling. Several experimental tests were conducted in Italy where the performances of different forage mower conditioner were verified in the last decade [1.1, 1.2]. By 2015 a final commercial version of Fibre Sorghum mower-conditioner developed by Cressoni company and CREA is on the market. The machine has a modular structure with seven elements mounted on the main frame, designed to work on 7 rows, with the cutting system hidden underneath. Upon cutting, the single stems are conditioned by counter-rotating toothed rollers arranged in pairs of 76 mm sections. The mechanical action of the conditioning apparatus determines deep cracking along the stem. As a result, the time required to reach the minimum moisture threshold (30%) for baling was reduced to 72 h after mowing. After just 5 days from conditioning, the moisture content reach around 20%. The advantage of this system is given by the possibility to store the product for longer time with a reduced risk of fermentation. Another advantage is the possibility to exploit part of the machines and equipment of the traditional forage harvest lines; Disadvantages can be related to the logistic that requires several passages after baling such as the loading, the transport and the preprocessing of the material according to final use.

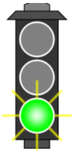
Figure 1.3 – Class Jaguar SPFH with kemper type header

Figure 1.4 – sugarcane harvester on sweet sorghum

Sweet Sorghum (human feed, forage, biogas and 1st generation bio-ethanol)

The most important aspect of the harvest of sweet sorghum is the preservation of the sugar in the biomass until the final use. Therefore, harvest solution and logistic must be searched to limit as much as possible the sugar losses in the phase going from the moment of harvest to the conversion process.

1) **Forage harvesters**: As for other annual or perennial herbaceous crops, sweet sorghum can be harvest with SPFH equipped with maize headers and loaded onto a trailer (project MULTISORGO - http://www.enea.it/it/seguici/events/multisorgo_29mag13/MULTISORGO_libro.pdf).
   In this case the fresh product formed by very fine fractions start fermenting immediately after the chopping, and loose 50% of sugar in the first 24 hours so a rapid transport to processing facility or silage site (forage production) is required.
2) **Sugar cane harvesters**: another way to harvest sweet sorghum is with sugar cane machines; this solution is widely adopted in locations where also sugar cane is cultivated as logistic and final uses can be considered similar. The machine cut the plant at the base, defoliates the stems and produce billets of variable size (10-25 cm) that are directly loaded laterally into trailer. Even if not rapid as the chipped product, also in this case sugar fermentation is fast, as studies confirmed that 20 cm billets stored in piles for 6 days under covering lost 35% of the total sugar content [1.3, 1.4] (BIOSEA - http://biosea-project.eu/). Indeed, rapid transport and conversion would be mandatory to avoid high sugar losses.

Crop n.2	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Camelina *Camelina sativa L.* Brassicaceae	Southern Europe	South (S), Central (C), North (N)	It exists both winter and spring varieties, winter camelina can resist up to -20°C.	Oilseed (annual)	Its oil seeds characterized by high content of erucic acid. Its oil has a large variety of high-added value bioproducts (chemical industry). The cake of the seeds has high protein content and is a valuable source for animal feeding.

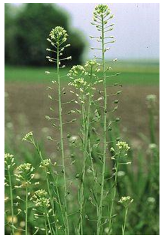


Figure 2.1 - Camelina

Figure 2.2 – camelina combine with wheat header

Figure 2.3 – header with stripping rotor

Seed harvest:

Camelina can be harvested using regular combine with grain header. Harvesting should be done early when the plants reach physiological maturity. This is usually when 50-75% of the silicles are brown in color. Delaying harvest could cause seed yield loss due to pod shattering, which is reported to be as high as 11% when camelina is directly combined [2.1]. Losses can occur also for wrong combine settings. In any case, in the event of uneven maturity, swathing the crop at earlier stage and collection with pickup header should be considered.

In direct combining, the header must be set as high as possible to minimize the amount of green material going through the combine. Appropriate adjustment to airflow (generally low speeds) of the harvester should be done to reduce seeds been blown away. Reducing airflow of the harvester camelina seeds may be collected with high percentage of plant material and seed cleaning may be needed. Installing a 0.35 cm screen over the lower sieves in the harvester will provide good separation of the seeds from stem [2.2]. Additionally, excessive combine travel speed could lead to significant yield losses). Combine settings successfully tested are the following:

Ground speed: 6 kmh; Fan speed: 500 – 800 RPM; Cylinder speed: 800 – 1000 RPM; Concave space: 2.4 cm; Top chaffer sieve number: 3 mm – 5 mm.

In Nevada, a header with a stripping rotor was successfully tested. The rotor run approximately at 430 rpm, leaving most of the stalk in the field; ground speed was set at 6 kmh (http://www.shelbourne.com). However, these tests were not scientifically validated and no information on seed losses were provided. To verify the feasibility of stripping, scientific testing should be carried out.

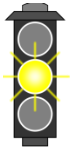
Crop n. 3	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Crambe *Crambe abyssinica* L. Brassicaceae	Eastern Africa domesticated in Mediterranean	South (S), Central (C), North (N)	Relatively drought tolerant, it tolerates soil pH from 5.0 to 7.8. It can be adapted to ***marginal land*** areas with mild winters as an autumn crop, or as a spring one in short season environments.	Oilseed (annual)	Its oil has high erucic acid and has several industrial applications, while the seed cake can be used for soil bio fumigation.

Figure 3.1 – Crambe

Figura 3.2 – crambe seeds

Figure 3.3 – combine with header for wheat used for crambe

Seed harvest:

As crambe approaches maturity, the leaves turn yellow and drop from the plant. A few days after the last leaves fell down, the seed pods and small branches turn a straw color. When this color has progressed down the stems below the last seed-bearing branches -- generally 90 to 100 days after planting - the seed should be ready to harvest [3.1].

Documented harvest tests have been performed in the past by the University of Wisconsin in 1991 and University of Nebraska in 1993 [3.1; 3.2]; these experiences were performed with traditional combines with wheat equipment. Optimal setting of harvest equipment was described as follows:

- Threshing cylinder speed: between 400 to 500 RPM; Concave clearance: 10 mm; Fan speed: 500 RPM.

Advices have been provided also for the frontal reel, which minimized seed shattering with a speed rotation slightly faster than the ground speed of the combine [3.1; 3.3]. A confirm regarding the use of traditional wheat combines on Crambe was provided also in an energy and economic assessment study on Cramble and Camelina, performed by Poland scientists which have used for the harvest a wheat equipped combine New Holland TC5070 [3.4].

Regarding combine settings other studies were performed in 2012 with a plot combine Wintersteiger, model CLASSIC (38 kW). The machine was tested using three speed of work (3.0; 5.0; 8.2 kmh) and four rotations of the threshing cylinder (400, 600, 800 and 1000 rpm) in four replicates. In general, the work suggests maintaining a field speed of 5.04 kmh and a speed rotation of the threshing cylinder of 800 rpm in order to obtain the smallest losses when fruits are completely dried [3.5].

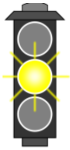
Crop n. 4	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Castor bean *Ricinus communis* L. Euphorbiaceae	Mediterranean area	South (S)	It cannot tolerate low temperatures. It can be grown on ***marginal lands*** (grows best on moderately fertile), which are not competitive with food (economic viable solution for non-productive lands). It can tolerate pH 5.5-6.5 and saline soils.	Oilseed (annual or perennial)	Source of ricin oleic acid, several chemical and medicinal applications. Its oil has international market with more than 700 uses. Castor cake can be used as nematicide

Figure 4.1 – castor bean

Figure 4.2 – combining of castor bean

Figure 4.3 – Maize header used for castor bean

The castorbean crop is ready for harvesting when all the capsules are dry and the leaves have fallen from the plants. Ideally, harvesting should begin 10 to 14 days after the first killing frost. If killing frosts will not permit completion of harvesting before winter, a chemical defoliant may be applied 10 to 15 days ahead of the desired harvest date [4.1]. Defoliants tend to reduce yields, however. Delay in harvesting after the crop is ready may result in losses from "shattering," in which the seeds pop out of the capsules.

Combine equipped with maize headers with opportune modifications such as upper frame with metal nets to prevent seed losses are currently utilized to harvest castorbeen. Since castorbeans are very susceptible to cracking and splitting during harvest, adjustment of the combine cylinder speed and cylinder-concave clearance is very important. Usually, a low cylinder speed and wide cylinder concave clearance are recommended. Combine operators should frequently inspect harvested beans for breakage. Weeds cause problems in the castorbean harvest. They may clog machinery or push in front of the harvester and cause shattering of the castorbeans.

In Israel, Evofuel Ltd., a wholly owned subsidiary of Evogene Ltd. and Fantini s.r.l announced the successful development of a mechanical harvesting solution for castor bean plants with a specific header. The solution developed has shown a significant decrease in yield losses, from up to 50% with the current solutions to as low as 5% with the combination of the harvester and Evofuel proprietary castor varieties and growth protocols in two consecutive year field trials in Israel during 2017-2018. However, details and description of the headers are not yet available (http://www.evogene.com/press_release/evofuel-fantini-s-r-l-announce-breakthrough-mechanical-harvesting-castor-bean/)

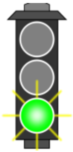
Crop n. 5	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Switchgrass *Panicum virgatum* L. Poaceae	Native of USA	South (S), Central (C), North (N)	Promising crop to be grown on ***marginal lands***. Large variety of cultivars and thus can be successfully been cultivated in all Europe.	Lignocellulosic (perennial with lifespan 10-20 years).	Solid biofuels, advanced biofuels, other industrial applications.

Figure 5.1 - Switchgrass

Figure 5.2 –mowing conditioning of Switchgrass

Switchgrass harvest and post-harvest handling operations are similar to other grasses or crop residues. The plant is well anchored to the ground by its deep root system and thus can be easily harvested by cutting devices. The trend in harvest and collection of biomass is to merge several operations within a single piece of equipment, so-called 'single-pass harvesting'. There is also a trend to make the resulting load (or package) as large as possible to reduce the number of trips to and from the field. Moisture content of biomass is a key factor affecting the feasibility of merging field operations. The main havest options are presented below [5.1]:

Mowing-conditioning and baling: The material is mowed and passes through two or more rollers to crush or crimp the plant stem. A crimped stem takes half of the time for field drying relative to conventionally mowed forage. A mower-conditioner can be run at almost the same speed of a normal mower, about 6–8 km/h. Evaporation from a freshly cut windrow occurs primarily from the windrow surface. A rake gathers the swath off the ground into a narrower windrow. The wet part of the swath is exposed for uniform drying. For a fall harvest, a simple mower (without conditioner) may be adequate to cut the crop and place it in a swath. Bales can be either round or rectangular. Round bales (1.5 m wide by 1.8 m diameter) are the most popular. Limited experiences to date with switchgrass indicate that round bales may not be suitable for large-scale biomass handling. Round bales tend to deform under static loads in a stack, and misshaped bales are difficult to secure onto trucks to form a transportable load over open roads. Experience with switchgrass harvest in US showed that variation in the density of round bales was the cause of uneven size reduction and erratic machine operation during debaling.

Figure 5.3 – self loader on Switchgrass

Figure 5.4 – forage harvester with pick-up system on Switchgrass

Figure 5.5 – tractor mounted maize silage harvester and trailer

Mowing and loading with automatic loaders: Another advanced option for collecting biomass is loading. When biomass is dry (less than 15% m.c.) a loader (or stacker) picks up the cut biomass from windrows and makes a large package of about 2.4 m wide, up to 6 m long, and 3.6 m high. The roof of the loader acts as a press, pushing the material down to increase biomass density to about 80 kg/m^3. This density gives a package roughly 4 tons in mass. Once filled, the loader transports the biomass to a storage area and unloads the stack.

Mowing and pick up of dry biomass: Forage harvesting operation follows mowing once the grass is dried to less than 15% moisture content. The self propelled forage harvester equipped with pick up harvest the biomass from windrows and chops it into smaller pieces (25–50 mm). The chopped material is blown into a forage wagon traveling alongside the forage harvester. Once filled, the self-propelled or towed wagon travels to the side of the farm where its contents are unloaded.

Single-pass harvest: the green biomass is collected in a single pass using self-propelled forage harvester or tractor mounting kemper headers. The chopped biomass is blown into a forage wagon that travels alongside the harvester or rearly attached to the tractor. Once filled, the self-propelled or towed wagon travels to the side of the farm where the biomass is unloaded into either a bunker or a silage bag. The chopped material is often compacted to ferment and produce silage.

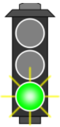
Crop n. 6	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Miscanthus *Miscanthus x giganteus* Poaceae	Native of Asia	South (S), Central (C), North (N)	promising crop to be grown on marginal lands and/or contaminated lands.	Lignocellulosic (perennial with lifespan 10-20 years).	Solid biofuels, advanced biofuels, other industrial applications

Figure 6.1 - miscanthus

Figure 6.2 – shredder attached to the front PTO of the tractor

Harvesting of Miscanthus take place during late winter and early spring following senescence, i.e. the time when the plants lose moisture and drop the leaves that have an high silica content. A variety of conventional hay forage equipment are suitable for harvesting miscanthus, the approach can change according to the logistc of biomass chain and requests of final users, i.e. the use of bales or loose material according to the energy purpose.

Shredding and baling: the crop is first shredded, the shredding breaks up the rigid stems allowing accelerated moisture loss [6.1]; the material is left in windrows or just disorderly on the ground requiring raking prior baling. Direct baling can be perfomed with the harvest yard utilized for also for Arundo and composed by frontally mounted shredder that work in combination with round or high density baler in order to reduce the number of passages and tools. This machine are generally available in reverse drive version for singular use.

There are a number of different types of balers, each producing different bales, (e.g. rectangular, round and compact rolls), suitable for different scales of energy combustion. Large rectangular and round balers are capable of producing bales with a dry matter density of between 120 and 160 kg/m3 and weighing between 250 and 600 kg. This solution, as drop the shredded material on the groung can increase the product losses and the inhert material collected in comparison with the next solutions.

Figure 6.3 – class jaguar with keper type header working on miscanthus

Figure 6.4 – tractor mounted Maize silage harvester utilized on miscanthus with unload direclty in the square baler

Single-pass harvest with self propelled forage harvesters (SPFH) or with forage mounted machines: the biomass can be collected in a single pass using self-propelled forage harvester as verified in the project OPTIMISTIC (https://cordis.europa.eu/project/rcn/101300/reporting/en) or tractor equipped with front mounted or trailed machines. In case of SPFH the chopped biomass is blown into a forage wagon towed by a tractor that travels alongside the harvester. Once filled, the towed wagon travels to the side of the farm where the material is processed or prepared for transport.

In case moisture content would not be considered acceptable, the machine can also be utilized to cut and windrow the biomass in the field to be baled in a second step. Direct chipping has been evalauted as the most time-efficient cutting method [6.2]; however, in climates with mild winters and inadequate senescence, the indirect mowing and baling methods are more scalable due to more efficient transport and storage.

In case of mounted machines, a tractor with a double (rear-front) PTO is needed. Frantally to the tractor, the machines to be mounted for miscanthus are the same utilized for maize silage (kemper type headers with chopping and unloading system)

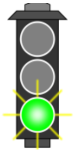
Crop n. 7	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Giant reed *Arundo donax* L. Poaceae	Mediterranean area	South (S)	promising crop to be grown on ***marginal lands***.	Lignocellulosic (perennial with lifespan 10-20 years).	Solid biofuels, advanced biofuels, other industrial applications.

Figure 7.1 – Giant reed

Lignocellulosic biomass harvest

Arundo is generally harvested once per year, during the winter season, when the aboveground organs go into a vegetative rest. The Arundo culms that remain in the field during winter reach a moisture content of about 50%, while during the pick of vegetation in early summer this parameter is close to 70%. Plantation during winter is not producing new sprouts, avoiding damages to new plants that would be provoked with the passage of harvest machines in other periods. There are three conventional systems to harvest Arundo that are described as follows:

System 1 – chipping and loading of the fresh product

This type of system involves the use of a self-propelled forage harvester (SPFH) commonly employed for the harvesting of silage maize equipped with row-independent header for maize silage harvest (kemper type). In this case, the forager is flanked by a tractor-trailer unit receiving the chopped biomass, and then delivered to a collection point [7.1]. Tractor mounted machine as that developed in the OPTIMA project can be used for the same purpose (https://cordis.europa.eu/project/rcn/101188/factsheet/en)

System 2 – Mulching and baling of the fresh biomass

The second system utilized for the harvest of Arundo consist of shredding and baling the biomass in a single pass, with the front part of the tractor equipped with the shredding/windrower machine, and the rear part equipped with the baler [7.2].

System 3 - mowing, pick up, shredding and loading of the dry product

This harvest yard requires two passes, one with a tractor equipped with mowing system and another with a SPFH equipped with a pick up system. The advantage of this systems respect the others is that the product collected is already dry and ready for conversion, while the disadvantages are undoubtedly the repeated machines passages in the field, which may increase the harvest cost and can provoke damages to the soil structure as consequence of compaction [7.3].

Figure 7.2 - System 1: Claas Jaguar 850 and Orbis RU 450XTRA

Figure 7.3 – Spapperi prototype developed within Optima project

Figure 7.4 - System 2: Nobili RM 280 BIO and Kuhn LSB1290

Figure 7.5 - System 3: Claas Jaguar 850 and PU 300 HD

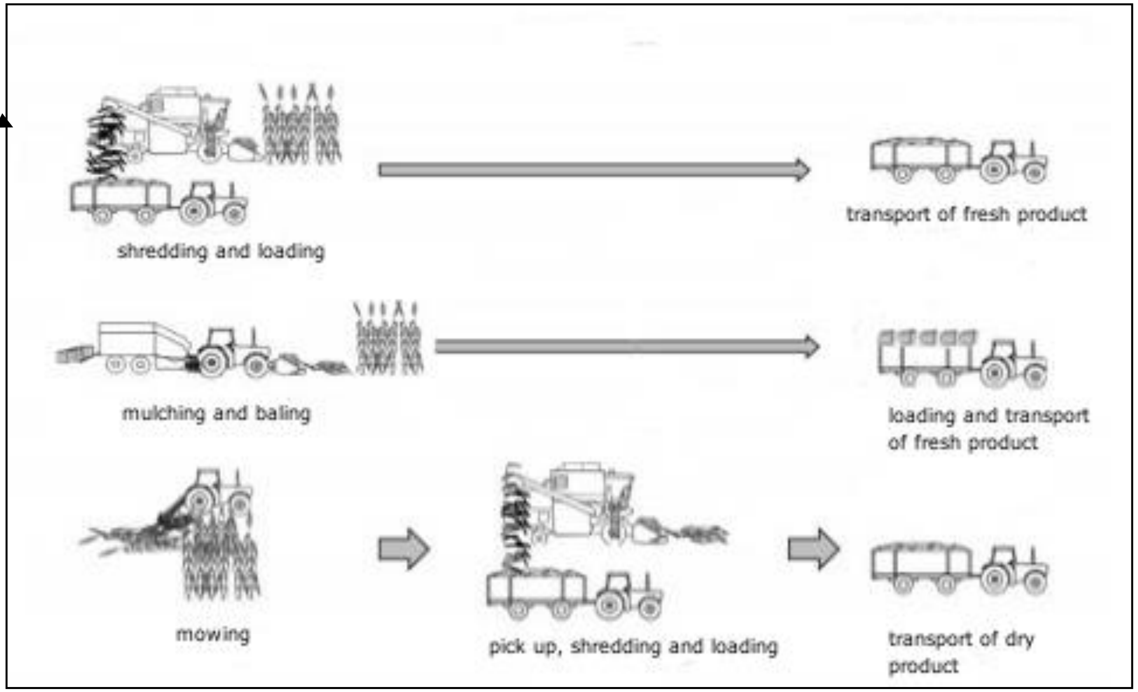


Figure 7.5 – scheme oft the three harvest systems for arundo

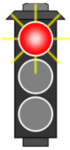
Crop n. 8	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Tall wheatgrass *Agropyron elongatum* Poaceae	Native of Eurasia	South (S)	A very tolerant plant, able to grow in a wide range of conditions. It succeeds in soils with a **pH of 5.3 - 9.0** and thrives in areas subject to ***inundation by saline water***, such as seashores and saline meadows as well as on alkaline soils.	Lignocellulosic (perennial crop)	It is used as forage and for hay in many places. Source of biomass (lignocellulose). It can be used for soil reclamation.

Figure 8.1 - tall wheatgrass

Figure 8.2 – bales of tall wheatgrass

Figure 8.3 - mowing of Tall wheatgrass with front mower

Specific harvest experiences on tall wheatgrass are still lacking, but crop charcteristics and uses lead to define the potential harvest methods to be adopted.

Mowing and baling can be identified as the most suitable option for both producing hay, or biomass addressed to combustion or production of second generation biofuels such as cellulosic ethanol. Typical haymaking machines such as mower and round/square baler can be adopted for this purpose. As perennial grass, some advices have been provided by producers in North America regarding the maintenance of the plantation. The USDA stress that 6 inches of stubble should be left at the end of the growing season and grazing the following season should be delayed until there is at least 8 inches of new growth [8.1]. Tall wheatgrass is most palatable during the early spring months and should be managed during this time. In a study to determine influence of clipping frequency on yield, Undersander and Naylor found the highest yields of tall wheatgrass were produced when clipped at 4 week intervals. If used as forage, supplemental protein must be provided.

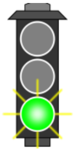
Crop n. 9	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Ethiopian mustard *Brassica carinata* L. Brassicaceae	Native of Africa (Ethiopia)	South (S)	It is considered ***drought tolerance crop***. Soils with pH 5.5-8.0.	Oilseed (annual)	Its oil has high erucic acid and has several industrial applications, while the seed cake can be used for soil bio fumigation.

Figure 9.1 - Ethiopian mustard

Figure 9.2 – wheat header utilized to harvest Ethiopian mustard

Figure 9.3 – siliqua and seeds

Seed harvest

Unless other cultivated species of Brassicaceae family, Brassica carinata L. presents the seeds contained in a siliqua that is resistant to shattering. This was verified through scientific tests performed by Pari et al. (2010) [9.1] comparing both Brassica napus and Brassica carinata. The tests revealed losses due to pre-harvest shattering equal to 7,9% in B. napus and 0,4% in B. carinata. Despite this difference, Brassica napus and Brassica carinata are very similar from a morphological point of view; in addition, the wide distribution of rapeseed cultivation for biodiesel production in the past lead to develop specific combine headers for this species, with the goal to contrast the high seed losses occurring during harvest and due to impact of the cutting bar and the dividers on rubbed plants. The modifications consist mainly in the application of vertical cutting bars to replace the dividers and on the increase of the distance between cutting bar and auger, increasing the width of the basal metal plate. Considering the morphological similarity with rapeseed, between the years 2007 and 2009 the harvest of Brassica carinata L. was tested with a combine equipped with a rapeseed header, with a modified wheat header (exchange of one divider with on vertical cutting bar) and for comparison with a traditional wheat header [9.1]. Even if limited to a few percentage points, the studies highlighted that seed losses were lower with rapeseed header and adjusted wheat header than those occurred with traditional wheat header. On total seed yield of 3 tons/ha, the use of rapeseed equipment increased the production of about 60-70 kg/ha.

Assirelli et al. (2009) [9.2] stressed that the main problem of seed losses encountered on B. carinata are mainly related to combine regulations, distance and height of the revolving ring, and limited distance between cutting blade and header auger. The best Combine regulations identified have been the following: Threshing cylinder speed: between 650 RPM; Concave clearance: 57 mm; Fan speed: 570 RPM; Upper sieve: 3mm; Lower sieve: 1,5mm.

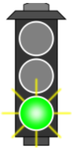
Crop n.10	Name (common & Latin) and family	To be known for harvest	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	**Industrial hemp** *Cannabis sativa* L. Cannabinaceae	- plant height: extremely variable (2-4 m) - spherical seeds 2-3 mm contained in the upper part of the plant (gradual ripening) - very strong fibers	South (S), Central (C), North (N)	Currently has been selected by **GRACE** project (BBI, Demo) as industrial crop for ***marginal lands***. It had been investigated in **MULTIHEMP** project (http://multihemp.eu). In Poland had been used for soil reclamation.	Oilseed/Fiber crop/Multipurpose (annual)	Multipurpose crop, from its stems (fibers, paper and pulp, building materials, insulation mats, etc.), from its seeds (oil, seeds…)

Figure 10.1 - hemp

Technical Fiber harvest

The production of short fiber can be achieved with different machines; the most commonly used are forage harvester equipped with modified cutting drums (hemp cut system) producing windrowed pieces of 60 cm, or simple cutting bars that produce pieces generally smaller than 1 m. With the cutting bars the material is disorderly spread on the ground, requiring repeated raking (MULTIHEMP project, http://multihemp.eu/). After retting (about two weeks) the material is baled with square or round balers [10.1].

Figure 10.2 – hemp cut systems

Figure 10.3 – cutting bars systems

Seed harvest:

It is achieved using combines with traditional or axial flow system and with adjustments to lift up the header. After the passage of the combine, the long stubbles are cut down using cutting bars, then raked and baled. The material can be used as technical fiber for industrial application. An alternative way to collect seeds was recently developed by IBFMP of Poznan consisting in a frontal cutting bar with an associated belt. The panicles are cut and transported in a lateral trailer and are successively threshed using a stationary thresher. The remaining long stubble can be harvested using multiple cutting bars and round or square balers.

Figure 10.4 - Modified combine with elevation system for wheat header

Note: Industrial hemp mechanization for long fibre production for textile porpouse is not considered in this study

Figure 10.5 - Cutting bar to be used after threshing

Figure 10.7 - Cutting bar with belt for the transport of the panicles

Combined harvest of seeds and fiber

The system is named Double Cut, was tested in Romania within the goals of the FIBRA project (http://www.fibrafp7.net/); it is a modified combine is a mod. John Deere W660 (270 kW power), equipped with a wheat-head mod. John Deere 613R in the upper part and a Kemper-type head mod. John Deere 445 in the lower part. The upper header provides the cut of the upper part of the stalks (40-50 cm) including the seeds. The lower header cut the remaining stalks in pieces of 60-70 cm length with the Hempcut technology. In this system, only the upper part is going through the combine harvester, so the volume of biomass to be threshed through the machine is significantly reduced compared to other machines used for the same purpose in the past. The threshed seeds are collected in a hopper of the machine and at full charge can be successively unloaded in a trailer. The cut stem portions are unloaded posteriorly in a windrow about 1 m wide [10.2].

Figure 10.6 - Double cut system

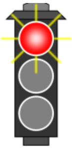
Crop n. 11	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Reed canary grass *Phalaris arundinaceae* L. Poaceae	North of Europe (perennial crop with lifespan 10-15 years)	Central (C), North (N)	It is reported as appropriate to be cultivated on ***marginal lands*** of the north (where it can grow well on both dry and wet areas), pH 4.9 to 8.2.	Lignocellulosic; 20000 ha in North of Europe.	Solid biofuels, advanced biofuels, other industrial applications.


Figure 11.1 - Reed canary grass


Figure 11.2 – mowing of reed canary grass


Figure 11.3 - baling

Reed canary grass (RCG) is harvested with disk mower equipped or not with conditioning elements in spring or fall. In spring the plants are dry (15% moisture content) and almost free of chemical elements such as chloride absorbed during the growing period [11.1]; harvest is performed with disk mowers produce windrows of biomass successively baled with round or square high density balers. The problems of the harvest are related to two main factors:

- regulation of the cutting height and plant lodging: the disc mower could not cut the lodged RCG to produce sufficiently short stubble; as consequence the long stubble in the field and are not baled. It is usual that contractors set the cutting height too high to avoid stones and rough ground that could damage the mower
- Fragility of the plant: after the mower passage the plants are fractioned in small pieces: this can determine harvest losses during baling for the reduced effectiveness of the baler pick-up and because part of the product can escape from the press chamber.

Different harvest experiments were performed in Finland, where only about 50% of the total RCG biomass was actually collected from the field for the above reasons. According to these results, harvest losses can be decreased below 20% in RCG spring harvest by appropriate adjustment of the disc mower or by using windrower equipped with a pick-up reel. Transport cost of the bales is another problem for RCG chain as the bulk denisty of the product is very low. According to the studies perfomed in Finland square balers produced higher density material respect different round balers as indicated below [11.2]:

Table 1 – densities of reed canary grass formed by different balers

	Fixed chambers round balers	Variable chamber round baler	Square bales
Bale diameter 1,2 m (kg/m^3)	130	146	
Bale diameter 1,5 m (kg/m^3)	119	130	
All sizes (kg/m^3)			148

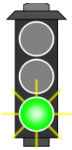
Crop n.12	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Safflower *Carthamus dictorius* L. Asteraceae	It can be found in Asia, Africa and Europe.	South (S), Central (C)	It has a ***strong taproot and thus thrives in dry climates***. It can be cultivated as both winter and spring crop.	Oilseed	Seeds (birdfeed), Oil (edible), dyes, medicines, etc.

Figure 12.1 - Safflower

Figure 12.2 – lateral view oft he combine tested in Sardinia

Figure 12.3 – combine with wheat header on work

Seed harvest

Seeds maturity generally occurs after 35-40 days after full flowering, when the plant is already dry, not brittle, and when the bracts on the head turn brown. Seed shattering is usually not a problem, but excessive moisture content can damage significantly the seeds during harvest. Preferably, the moisture level should be lower than 10%; in case it will be higher the crop windrowed and threshed after the seeds are dry enough. The harvest of safflower can be addressed with conventional combines equipped with headers for wheat.

Harvest tests were conducted in Sardinia (Italy) in 2015 by L. Pari using a conventional combine Laverda L524, equipped with wheat header Laverda E480 [12.1]. The combine was set utilizing in part the standard regulations for wheat, only fan speed was set lower respect wheat standards because grains specific weight.

The regulations of the combine were the following:

Fan speed: 400 RPM; Cylinder speed: 850 RPM; Concave space: 5,4 cm; Top chaffer sieve: 11 mm; Low chaffer sieve: 6 mm.

Plants were cut at 26 cm from soil level, the cut resulted very clean without defibering of stems. The field speed was set at 3,7 km/h, field capacity was quantified as 1,32 ha/h. The grains losses resulted 3,2%, probably provoked by a low specific weight of seeds which would have required a further reduction of the fan speed. In any case, seed impurities were quantified as 22,8%, while damaged seeds were the 1,66% of the total [12.1]. Experiences in North Dakota stressed that during the harvest operation white fuzz from the seed heads is abundant in the air and may clog combine radiators and air intakes, causing the combine to overheat. Small-meshed screen enclosures over these cooling mechanisms should minimize this problem and blowing out radiators with air once or twice daily may be necessary. Accumulations of this fuzz can be a fire hazard [12.2].

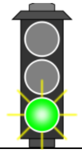
Crop n.13	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Cardoon *Cynara cardunculus* L. Asteraceae	South Europe (perennial 5-10 years; established by seeds)	South (S)	Drought resistant crop can be cultivated on ***arid marginal areas*** of south EU with the most recent example **FIRST2RUN** project (www.first2run.eu; BBI project, Flagship) and **OPTIMA** (FP7 project).	Oilseed/Lignocellulosic/Multipurpose	From its seeds: oil, protein flour, active molecules. From its stems: solid biofuels (energy), paper and pulp, other chemicals, etc. From its roots: organic substances, chemicals, etc.

Figure 13.1 - cardoon

Figure 13.2 – First prototype developed by CREA in BIOCARD Project

Seed and biomass harvest:

Seeds harvest is performed with combines that according to availability can be equipped with different header. The harvest efficiency of different combine headers was verified.

Wheat header: easy to find but the less indicated to harvest Cardoon. Frontal capitula losses occur during the cut of the plant; it is possible to reduce the losses by applying metal plates in correspondence of the cutting bar (21 metal plates where applied to a 6 m headers). Details of the modification are provided by Pari et al. (2016) [13.1]. For the the collection of the residual biomass, cut, windrowing and baling is performed with conventional forage equipment

Sunflower header*:* valid alternative to wheat headers. In case of harvest in the first year of production (no seeds), the header can be used to cut and windrow the biomass (higher attachment of the combine with no passage in the threshing system). For plantations from the second year, it can be used the classic attachment of the combine. For the the collection of the residual biomass, cut, windrowing and baling is performed with conventional forage equipment.

Maize header: better respect the other solutions because the use of the maize header has the advantage that the presence of milking rollers allows only the capitula to enter into the threshing system. Therefore, with this header it is possible to work at lower height respect the other solutions, without risking harvest losses or clogging the combine. For the the collection of the residual biomass, cut, windrowing and baling is performed with conventional forage equipment

Cardoon header (developed by CREA and Cressoni within the project BIT3G): it is a specific header developed for Cardoon with the advantage to harvest only the capitula for threshing, leaving already in windows the residual biomass (only baling is needed). The head construction followed different evolutions, the first prototype was developed in Biocard Project (https://cordis.europa.eu/project/rcn/75527/factsheet/en) in 2008, that concluded with the final version developed within the BIT3G project (https://www.novamont.it/bit3g) to exploit marginal lands with irregular surfaces (stony soils in Sardinia, Italy). The new head is designed with a specific system for cutting the biomass able to follow the soil profile, adjusting automatically the cutting height

Table 2 - Combine tested by CREA on cardoon

test	Combine	Header	Working widht (mm)	Theoretical Field capacity (ha/h)	Effective field capacity (ha/h)	Non-threshed capitula (%)
1	New Holland CS540	Wheat header	6.100	1,67	1,42	25,2%
	New Holland CS540	Wheat header modified	6.100	1,74	1,53	7,3%
2	Laverda L524	Sunflower header	4.800	1,99	1,77	5,9%
	Claas Lexion 630	Maize header Cressoni	5.250	2,65	2,41	4,0%
	Laverda L524	Cressoni BIT3G	6.000	1,72	1,20	2,2%


Figura 13.3 – wheat header


Figure 13.4 – sunflower header


Figure 13.5 – maize header


Figura 14.6 – CRESSONI bit3g header specifically designed for cardoon

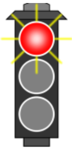
Crop n. 14	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Pennycress *Thlaspi arvense* L. Brassicaceae	Native to temperate regions of Eurasia	South (S), Central (C), North (N)	It has a short growing cycle (shorter than camelina) and it can be cultivated as a winter annual crop on ***unused land***. Low demand on soil and water nutrition and water. It is really frost tolerant (up to -20°C). Nowadays, it is been investigated as a promising oilseed crop in USA.	Oilseed	Oilseed for biodiesel production and aviation biofuels. Its seedcake has high protein content and can be used for bio fumigation.

Figure 14.1 – Pennycress

Figure 14.2 – combine with headers for wheat

Specific harvest experiences on Pennycress were not identified, but authors report that **conventional combine** equipment can be utilized to thresh the seeds [14.1]. Producers also confirmed that combine equipped with grain headers can be adopted to harvest succesfully the crop. Combining period is late spring (end May – early June) leaving to possibility to cultivate other summer crops such as Soybean [14.2].

Combine regulations should be tested in the field taking into account that seeds are very small and light; indeed, fan seed should be kept low to avoid high losses.

Some authors in Minnesota (US) verified that to maximize the seed yield and oil content in pennycress, the best harvest time should be near mid-June to reduce yield-loss through shattering, and allow for earliest planting of double-cropped soybean. However, seed moisture corresponding to optimum yield was too high at the time of harvest. For this reason future research is focusing on the evalaution of the use of desiccants to reduce the seed moisture content and breeding for reduced seed-shattering varieties.

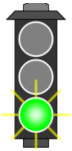
Crop n. 15	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Willow *Salix spp*. Salicaceae	Native of North Europe	Central (C), North (N)	Grows in a variety of soils with pH 5-7.5. Its roots stand highly anoxic conditions and thus can be planted in waterlogged conditions. Due to its high tolerance to soils with heavy metals it can be used for phytoremediation.	Lignocellulosic (short rotation forestry)	Solid biofuels, advanced biofuels, biobased products (construction materials, packaging materials, etc.) paper & pulp.


Figure 15.1 – Salix spp.


Figure 15.2 – whole shoots harvest


Figure 15.3 – cut and chip method

Lingo-cellulosic biomass harvest

The harvesting period occurs when stems are bare of leaves, from the end of November until April in Europe. This also tends to be the wettest period of the year, also considering the fact that willow is planted on soils which have a good supply of moisture during the summer, it means that land can be extremely wet during the harvesting period.

There are three main mechanical harvesting methods for willow SRC:

• **Whole-shoot harvesting**: this mechanical system is generally pulled by tractors which transmits the power to the cutting apparatus through the PTO. The latter is formed by two counter-rotating circular blades that perform the cut at the base of the plants. Once plants are cut they go into the transport systems formed by toothed chains and then are unloaded posterirly onto a trailer until full load. Willow stems can be stored at the field edge to allow in field drying until final usage. These types of systems can be used in 5 years old plantations, with maximum workable diameters of 8-10 cm per plant (www.nordicbiomass.dk).

• **Cut-and-chip method**: the most common system consists of adjusted self-propelled forage harvesters equipped with specific headers. These headers are formed by two circular counter-rotating blades at the base and feeding systems formed by counter rotating toothed rollers. Frontally, a fork shaped bar is used to tilt the plant and stretch the wood fibers, simplify the cut and facilitate the plant entrance in the machine [15.1].

Figure 15.4 – cut and billet method

• **Cut-and-billet method**: Machines derived from sugarcane harvesters, such as the Austoft, are also used for harvesting willow coppice, using a cut-and-billet system. They are capable of producing much coarser chips or even chunks. The normal setting of the machine produces 5 cm chips, but by removing some of the knives and lowering the drum speed, 10 cm chip or even 20 cm billets can be produced. The advantage of the larger particle size is that the material is easier to store and dry, because the piles are much more open to natural ventilation. On the other hand, the fuel is generally not suited for small-scale boilers. The 20 cm billets have to be re-chipped before they can be used as fuel. The 10 cm wood chip could perhaps be used in large installations, if they are able to handle such fuel [15.1].

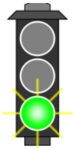
Crop n. 16	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Poplar *Populus* spp. Salicaceae	Native to most of the northern Hemisphere	South (S), Central (C), North (N)	In **multibiopro** project (www.multibiopro.eu) poplar had been selected as non-food crop that can be grown on ***marginal lands***. Currently, poplar has been selected by **Dendromas4Europe** project (BBI, Demo).	Lignocellulosic (short rotation forestry)	Solid biofuels, advanced biofuels, biobased products (construction materials, packaging materials, etc.) paper & pulp.

Figure 16.1 - Poplar

Ligno-cellulosic biomass harvest

Single-pass harvest:

The harvesting of SRC in a single-pass is preferentially performed with large-size modified foragers equipped with specific headers for woody biomass. The use of self-propelled forage harvesters (SPFH) in a single-pass is a high throughput system and the same type of mechanization can operate also in industrial crops, allowing the full integration of the SRC in traditional cropping systems. However, the harvesting period is limited to the winter months when the moisture content of wood chips is very high (50–60% on wet weight basis).

Even if conditions are carefully controlled, the storage presents some risks of significant dry matter losses. The main component characterizing the SRC harvester is the cutting head. The most important versions developed till now are Claas HS1, HS2 and GB-1, Kemper and Krone headers and GBE1 and GBE2 produced by the Italian GBE company. Various factors (soil conditions, state of the plants, wood characteristics, and plant density) affect the performance and accordingly several authors reported variable results. If the harvesting conditions are appropriate, modified foragers may allow a yield ranging (on fresh basis) from 25 to 50 tfm ha^{-1} [16.1].

Figure 16.2 – single pass, cut and chip method

Figure 16.3 – header GBE for the cut and chip method

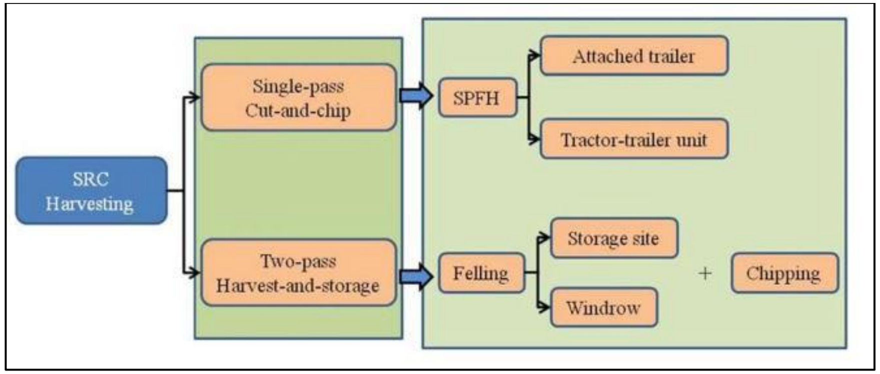


Figure 16.4 – scheme of harvesting solutions for poplar SRC

Figure 16.5 – cut- windrower for small plants (2 years old)

Figure 16.6 – pick-up chipper for small plants (2 years old)

Figure 16.7 – cut windrower for large plants (5 years old)

Figure 16.8 – pick up chipper for large plants (5 years old)

Two-passes harvest:

Succesfull experiences where also obtained with the two-pass system, in which the phases of cut and chipping are physically and temporarily separated: the plants are firstly felled (loose or tied in bundles) and transported to a storage site or left in the windrow. After a period of drying, the stems are chipped. Up to now few prototypes have been built, often intended for willow but suitable for poplar too. The expected benefits of the two-pass system are the following:

- the felling is concentrated within a short period thus exploiting the available time window;
- when the stem are stored in the windrow, there is no need for additional storage space and the restarting of the operations in late spring avoids the trafficking on heavy soil and their compaction;
- the double-pass favors the natural drying and the chipping is postponed until the moisture content of wood is lower.

Harvest experience with this type of harvest systems where perfomed in Italy on 2 years and 5 years old poplar plantations with different prototypes developed by the company Spapperi within the goals of SUSCACE and FAESI project (http://www.gruppo-panacea.it/biomasse/progetti/suscace) (http://www.gruppo-panacea.it/biomasse/progetto-faesi) [16.2].

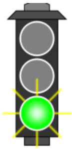
Crop n.17	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Black locust *Robinia pseudoacacia* L. Fabaceae	Native to eastern USA	South (S), Central (C)	It has high drought resistance and is nitrogen fixing. It is suitable for soil regeneration and reclaiming former mining sites. It has high ability to be grown on ***marginal lands***.	Lignocellulosic (short rotation forestry)	Solid biofuels, advanced biofuels, biobased products (furniture, construction materials, packaging materials, etc.) paper & pulp.

Figure 17.1 - Robinia

Figure 17.2 – cut and chipping with Claas jaguar 880 and GBE1 header

Figure 17.3 – JD 7400 with biopoplar header

Ligno-cellulosic biomass harvest

Mechanical harvest experiences on Robinia have been performed on biennial, triennial and quadrennial plantations. The mostly diffused practice is the single pass cut-and-chip technique. Its enduring popularity is due to its operational flexibility with regards to plant species, shoot age and diameter, planting density and field stocking. With the cut-and-chip technique stems are cut, instantly chipped and blown into an accompanying trailer [17.1]. The major advantage of this technique is that all the work is done in a single pass with only one machine operation planning and reduces relocation, machine rental and operator's costs. The cut-and-store method or two-passes harvest is another approach scarcely applied that incorporates two steps: first, stems are cut and deposited in windrows – or mowed to a central location - for air drying; second, they are chipped in a later time. Harvest test with this methodology were performed in 1996 on quadrennial Robinia [17.2].

The table below displays the most conventional harvest system tested on Robinia according to plantation age:

Tabele 1 – header tested on Robinia

Biennial	References
Biopoplar header + JD 7400	[17.3]
HTM 1500 header + Krone Bigx	[17.3]
Triennial	
GBE1 header + Claas Jaguar 880	[17.4]
New Holland 130 FB header + New Holland FR 9060	[17.5]

Figure 17.4 – chips produced with the Class jaguar 880

In 2014 the Claas Jaguar 880 (370 kW power) equipped with the GBE-1 header was tested in Southern Italy on a triennial Robinia plantation. The number of the knives in the chipping apparatus was reduced to 12 instead of 24. The modification had the purpose to increase the chip size produced to improve the storability of the product. The field capacity of the machine was 0,77 ha h^{-1} and a material capacity of 38-ton h^{-1}, similar performances were displayed in the same test on other species as Poplar and willow [17.4].

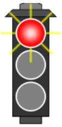
Crop n. 18	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Siberian elm *Ulmus pumila* L. Ulmaceae	Native to central Asia	South (S), Central (C), North (N)	Ulmus pumila is often found in ***abundance along railroads*** and in abandoned lots and on disturbed ground.	Lignocellulosic (perennial crop)	Solid biofuels, advanced biofuels, biobased products paper & pulp.

Figure 18.1 – Siberian elm

Figure 18.2 – tractor mounted maize header use on SRC

Figure 18.3 – self propelled forage harvester equipped with SRC header

No information are availble on harvest solutions for Siberian elm, but studies perfemed on planting systems and biomass production rate show results that can be compared with those of other broadleaves used in SRC such as poplar and willow. For instance, authors observed that after three year cycle the number of stems per stump in differnet field conditions (soil type and water stress vs. irrigated) was between 1.6 and 3.2, while mean diameter of stems ranged from 3.5 to 5.5 cm [18.1]. The greatest diameter observed was 10.24 cm. Similar results were also observed in other studies [18.2, 18.3]. Consequently, scientists affirm that the harvest of Siberian elm can be addressed with typical machineries utilized for other SRF species [18.1].

Details of harvest test on Siberian elm were not identified, but it can be assumed that **conventional self-propelled forage harvester equipped with specific head** could be adopted to harvest three-year cycle plants of Siberian elm. On the market, there are many high efficiency energy-crop harvesting systems for SRC used for cut and storage. Furthermore, SRC are commonly harvested in a combined cut and chip system with modified forage harvesters used for maize and other crops. They are either self-propelled or tractor mounted. Class Jaguar forage harvesters with different cutting heads dominate in the European. The most important versionrs developed till now are Claas HS1, HS2 and GB-1, Kemper and Krone headers and GBE1 and GBE2 produced by the Italian GBE company.

Various factors (soil conditions, state of the plants, wood characteristics, plant density) affect the performance and accordingly several authors reported variable results. The applicability of these technologies should be verified with scientific testing and eventual modifications or adjustments of mechanical parts should be taken into account.

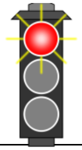
Crop n. 19	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Wild sugarcane *Saccharum spontaneum* L. Poaceae	Native to Indian subcontinent	South (S), Central (C)	It had been tested in **OPTIMA** project (www.optimafp7.eu) as a native perennial grass that can be grown on marginal lands in the Mediterranean region.	Lignocellulosic	Solid biofuels, advanced biofuels, other industrial applications

Figure 19.1 – wild sugar

Figure 19.2 – shredding and baling

Figure 19.3 – single pass harvest

Specific experiences on mechanization of wild sugarcane are still lacking, but literature shows that plant characteristics are similar to other perennial grasses such as Miscanthus [19.1]. Authors stress that several mulching techniques were proven to be successful on *Saccarhum spontaneum*, but these technologies were mainly applied as techniques for weed removal [19.2]. Plant is harvested during winter when it is completely dry, as studies displayed moisture conent is close to 5% [19.1. The uses of the crop include the production of lignocellulosic biomass as solid biofuel or advanced biofuels such as second generation bioethanol. Considering the uses and the plant morphology, the mechanization that is potentially applicable is similar to that applied to miscanthus and can be described as follow:

Shredding and baling: the plant can be shredded and baled with technologies simliar to those applied for miscanthus and arundo. The low moisture content allows direct baling that can be perfomed with the harvest yard utilized for Arundo, composed by frontally mounted shredder that work in combination with round or high density baler in order to reduce the number of passages and tools.

Single-pass harvest with self propelled forage harvesters (SPFH): plants can be potentially collected in a single pass using also self-propelled forage harvester. As for Arundo and Miscanthus chopped biomass is blown into a forage wagon that travels alongside the harvester. Once filled, the self-propelled or towed wagon travels to the side of the farm where the material is processed or prepared for transport. The possibility to use tractor mounter machines should be evalaued using tractors with a double (rear-front) PTO. Frontally, the tractor can be equipped with kemper type headers with chopping and unloading system such as tractor mounted maize chopper. The machine could eventually work in combination with round or high density baler in order to reduce the number of passages and tools.

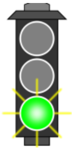
Crop n. 20	Name (common & Latin) and family	Origin	Where can be grown in Europe	References about its suitability to be grown on marginal lands	Category	Products and markets
	Lupin *Lupinus mutabilis* Fabaceae	Native of Andean region of Ecuador, Peru and Bolivia.	South (S), Central (C)	It has been selected by **LIBBIO project** as an industrial crop that can be grown on ***marginal lands*** (www.libbio.net). It tolerates the acid soils and it is considered drought tolerance.	Oilseed/Multipurpose	Oil (20%) and protein (40%) can be obtained from lupin seeds.

Figure 20.1 - Lupin

Figure 20.2 – combine with wheat header utilized on lupin

Figure 20.3 – traditional reel replaced with air reel

Lupin is harvested in mid summer (July-August). The harvest is performed with combine equipped with header for wheat. Delays can result in significant loss of yield due to lodging, pod shattering and pod drop. Harvest losses can be substantially reduced by harvesting when humidity is high, for this reason it is suggested to perform the harvest early morning to limit the pods opening. In cooler southern environments, daytime temperatures often do not become warm enough to cause major problems for harvest. In these areas it may be better to harvest the crop as quickly as possible rather than swapping between lupin and cereals.

For the combine regulation is is suggested to set the harvester drum or rotor speed to a minimum and the concave opened fairly wide. The following suggestions may help reduce harvesting losses on conventional auger:

- Use a finger or tine reel because they feed the lupin plants more gently into the front compared with batt reels
- Extend the table and knife forward by up to 300 mm to allow the crop to come under the auger, depending on the crop density.
- Use air reels, particularly if you have a light crop. Air reels direct a blast of air into the front and are very good for blowing shed seed into the table. There are two types of air reels: manifold and full-width fan. Both work well depending on power available.

3 Conclusion

The inventory presented in this deliverable gather information obtained from Authors direct data collection in previous projects, scientific literature review and market analysis on the current existing technologies used to harvest non-food crops to be grown in marginal lands and included in the MAGIC CROPS database. The structure and the contents of the document have been developed in way to represent an “easy-to-find” and “easy-to-use” instrument for final users (e.g. farmers, industries), providing a rapid way for the identification of the principal mechanized harvesting solutions for a specific crop, according to the final use of the biomass. Detailed references have been provided below for each harvest system and crop described.

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