4FCROPS

Future Crops for Food, Feed, Fiber and Fuel

Task 2.3 “Yields”

Task 2.4 “Raw material characteristics”

Tables of contents

1. INTRODUCTION

The work in work package 2 entitled "Cropping possibilities" started with the categorization of the non-food crops into five categories according to the main product. The five categories are: crops for oil production, crops for fiber, crops for short rotation forestry, lignocellulosic crops and crops for sugar production (bioethanol production). In task 2.1 a selection was carried by University of Catania and the selected the crops for each category (end use and climatic area) presented in Table 1.

Table 1. Proposed non-food crops for each climatic area and product.

	MAIN PRODUCT				
Climatic area	**Oil**	**Fiber**	**SRF**	**Lignocellulosic**	**Sugar**
Nemoral	Rapeseed	Hemp	Poplar	Reed canary grass	-
Continental	Rapeseed	Flax	Willow	Miscanthus	Sugar beets
Atlantic central	Rapeseed	Flax	Poplar	Miscanthus Switchgrass	Sugar beets
Atlantic north	Rapeseed	Hemp	Willow	Miscanthus Switchgrass	-
Lusitanian	Rapeseed	Hemp	Willow Eucalyptus	Miscanthus	Sweet sorghum
Mediterranean North	Sunflower	Hemp	Poplar	Giant reed	Sweet sorghum
Mediterranean South	Ethiopian mustard	Flax	Eucalyptus	Cardoon	Sweet sorghum

INF and MP had to work for Task 2.3 (yields) and 2.4 (raw material characteristics) on the selected fiber crops (flax and hemp). INF and MP added cotton in both tasks due to its high importance of the crop for Europe. CRES as task leader in both tasks (2.3 and 2.4) worked for all the other crops listed in the table above.

Area of cultivation of energy crops in EU27

It is reported (EnCrop Project) that in EU27 a total area between 50,000 and 60,000 ha occupied with energy crops for solid biofuels. At the same time the cultivation area for energy crops for liquid biofuels is quite bigger and came up to 2.5 million ha. This area is mainly referring to cereals and rapeseed. The need of producing 5.75% biofuels (of the total liquid fuels) was the main reason for the cultivation of the crops for liquid biofuels in 2.5 million ha.

According to *Handbook that was complied in the framework of the EnCrop project* the largest areas of energy crops for solid biofuels located in the following countries (Table 2). Statistics of energy crop plantations for solid biofuels are almost inexistent in many European countries (EnCrop project).

Table 2. Countries that energy crops cultivated in large areas in EU27 (Source: EnCrop project)

Country	**UK**	**Sweden**	**Finland**	**Germany**	**Spain and Italy**
Crop	Miscanthus Willow	Willow Reed canary grass	Reed canary grass	Miscanthus Willow	Miscanthus Poplar

2. OIL CROPS FOR BIODIESEL PRODUCTION

Biodiesel is a renewable fuel that can be produced from: vegetable oils (from rapeseed, sunflower, soybean, ricinus, jatropha, etc), palm oils (from coconut and oil palm fruit), waste oils (frying oils and animal fats) and agrae (microalgae) (*WIP, 2007*).

In the European Union biodiesel is mainly produced from vegetable oils (rapeseed and sunflower) and waste oils, while a small quality of palm oils are imported. Recently, a lot of research on producing biodiesel from microalgae is being conducted, even at demonstrative scale. It is reported that the average biodiesel production yield from microalgae is significantly higher compared to the recorded ones from oilseeds (*Gouveia et al. 2008*).

The choice of the dedicated feedstock is pre-determined by agricultural, geographical and climatic conditions. However, different feedstock types are characterized by different properties, like the oil saturation or the fatty acid content (*WWI, 2006*).

In Europe nearly 85% of the biodiesel comes from rapeseed, followed by sunflower seed oil, soybean oil and palm oil (*Mittelbach and Remschnidt, 2004*). In temperate regions, oilseeds crops typically produce lower yields per hectare than starchy cereal feedstock such as corn and wheat, whereas when grown in tropical areas oil crops can be very productive (*WWI, 2006*).

Besides the main crops listed above, there exist many other potential oil crops that can be used for bio oil and biodiesel production. The most important from these crops are cotton, Ethiopian mustard, castor bean, linseed and cardoon. Beyond these common plant oils, more than 100 native Brazilian species have been identified as having potential for biodiesel production. Most of them are palm tree species (*WWI, 2006*).

The EU oilseed situation continues to be largely affected by the demand for biodiesel. Rapeseed will continue to reach record levels in Europe following the overall trend for all the other major vegetable oils. With entrance of the new EU Member States, Romania and Bulgaria, sunflower seed production is also steadily increasing, with Romania to be the most important sunflower seed producer in the EU27.

In this chapter will present in detail the yields and raw material characteristics for selected oil crops (Task 2.1): rapeseed, sunflower and Ethiopian mustard, while information about cardoon will be given in the category for the Lignocellulosic crops. Cardoon is a perennial crop that considered as a very good crop for both solid biofuels as well as biodiesel for its seeds (the seeds contains 25% oil).

2.1 Rapeseed (*Brassica napus L. var. oleifera D.C.*)

Oilseed rape (*Brassica napus L. var. oleifera*) belongs to Brassicaceae family and is related to broccoli, cabbage and cauliflower (Johnson and Croissant, no 0.110). It is a very old cultivated plant originating in Asia and the Mediterranean area.

Rapeseed is an annual crop that can be cultivated as winter or spring crop. In northern Europe rapeseed is cultivated as winter oilseed rape, sown in August or/and early September. In South Europe can be cultivated either as annual or spring crop. In all cases the crop is flowering in May and the final harvest take place from June to July depends on the specific climatic conditions of the cultivated area (Figure 1).

The seeds reach the maturity almost two months from the pollination of the flowers. The crop at flowering has a height that varied from 60 cm to 150 cm depends on the variety and cultivation site. The flowers are yellow and have four petals. The pods are 2.5 to 3.8 mm long and around 30 mm wide. Rapeseed has a deep taproot and a fibrous, near surface root system.

Soon after the harvesting the seeds should carefully stored before the oil is extracted (ufop 2007). Its seeds have an oil content of 40-45%. There are two main categories of rapeseed varieties; the varieties that are for human consumption the ones that are for industrial uses. In the first category the rapeseed oil has high values of unsaturated fatty acid that are very helpful to the health, while in the oil of the industrial varieties there is high percentage of erucic acid and glucosinolates that are toxics for human and animal consumption.

Figure 1: Photos of rapeseed plantations at several stages of growth (vegetative phase, flowering and maturity phase)

The oil of oilseed rape has various food applications, including bottled oils or/and margarines where it is valued because it is high in monounsaturates (ufop 2007). The Brassica napus oilseed fatty acid profiles are presented in Table 3.

Canola and rapeseed are the most important oilseed crops in the world. Until the early 1970s both crops covered by the name "rapeseed". At that time, the Canadian scientists through its breeding programme create the "double low" varieties that had low or zero erucic acid and glucosinolates. For these varieties was adopted the name "canola". 00-rapeseed is now exclusively cultivated and used for nutritional purposes because of its excellent oil composition of unsaturated fatty acids (ufop, 2007). Canola is now more important than rapeseed in countries such as Canada mainly because it produces two acceptable products, an edible vegetable oil and a proteinaceous concentrate for feedstock. Nowadays, most of the canola varieties cultivated in Canada and USA are genetic modified ones.

Table 3. Brassica oilseed fatty acid profiles

	C16	C18	18:1	C18:2	C18:3	C20:1	C22:1
B. napus cv. Tobin	4.3	1.7	52.7	24.5	14.2	1.2	0.6
B. napus	3.8	1.6	39.2	20.5	9.2	11.7	14.9
B. napus	3.0	0.8	9.9	13.5	9.8	6.8	53.6
B. napus	10.0	1.0	51.0	19.0	13.0	1.0	trace
B. napus Stellar (lo 18:3)	5.0	2.0	64.0	24.0	<3.0	1.0	trace
B. napus VHOAR mutant	3.0	1.6	85.4	3.6	3.9	1.3	0.0
B. napus Tobin	3.8	1.2	58.3	24.0	10.3	1.0	0.3
B. napus Echo	2.5	1.0	32.5	18.8	8.9	12.0	23.5
B. napus R-500	2.5	1.0	13.0	13.5	10.1	5.5	51.1

Source: Carruthers S P, et al., 1995; www.ienica.net

Worldwide rapeseed occupies the third rank on the world oilseed production after soybean and palm oil. Vegetables oils are primary used in the food industry. According to UFOP (Extracts from the 2008/9 UFOP report) 83% of the worldwide vegetable oils production (127 million tons) is used for foodstuff, 10% in industry and 7% for biodiesel. In 2007/2008 173 millions tons of rapeseed production (worldwide) is for feedstuff utilization, 14 million tons for foodstuff and 6 million tons for industry (4.1 million tons for biodiesel production).

Today, winter oilseed rape is the most important oil crop in northern Europe. In 2007 the harvested area in EU27 was 6.501 million ha. The largest harvested area was for the first time in France (1.577 million ha) and the second largest in Germany (1.548 million ha). Until 2006 the largest area for rapeseed was located always in Germany. Quite big harvested area was also measured in Poland (0.797 million ha) and in UK (0.681 million ha) (Table 4). The yields (kg/ha) in the countries belongs to EU27 presented in Table 4. The variation in yields is quite big; from 1178 kg/ha (Romania) to 3890 kg/ha (Ireland). The mean seed yields for EU-27 (in 2007) was 2539 kg seeds/ha. It should be mentioned that in France that the largest area of rapeseed was established the seed yields were lower compared to the corresponding value in Germany (2888 kg/ha versus 3437 kg/ha). In Figure 2 presented the harvested area for ten most important countries for rapeseed in 2007 by descending order.

In Germany in 2007 the harvested area for rapeseed cultivation was two times higher compared to the area recorded 15 years ago (1.5 millions ha). Over a period of years, rapeseed is always cultivated in rotation with cereals and other crops and this fact is that rapeseed can be characterized anything but monocrop plant.

According to IENICA report for rapeseed the yields were 2.71 t/ha in Austria, 2.69 t/ha in Belgium, 5.27 t/ha in Denmark, 1.38 in Finland, 2.92 in France, 3.31 t/ha in Germany, 1.92 t/ha in Ireland, 0.96 t/ha in Italy, 4 t/ha in the Netherlands, 1.58 t/ha in Spain, 2.45 t/ha in Sweden and 2.81 in UK.

Table 4 - Area harvested (ha), yields (kg/ha), production quantity (tones) and seed yields (tn) in the EU-27 countries for rapeseed (source: FAOSTAT).

Country	Area harvested (ha)	Yields (kg/ha)	Production quantity (tones)	Seed yields (tones)
Austria	48509	2983	144706	269
Belgium	10776	3570	38470	
Bulgaria	53999	1723	93018	1137
Croatia	13069	3009	39330	130
Czech Republic	337571	3057	1031920	3569
Denmark	179200	3328	596300	8960
Estonia	74000	1805	133600	
Finland	89500	1268	113500	
France	1577000	2888	4554000	7885
Germany	1548177	3437	5320518	6000
Greece	4000	1500	6000*	
Hungary	223000	2234	498200	2000
Ireland	8200	3890	31900	50
Italy	7200	2078	14962	100
Latvia	99200	1985	196900	750
Lithuania	174400	1788	311900	26700
Luxembourg	5394	3393	18302	
Netherlands	4000	3250	13000	56
Poland	796751	2673	2129873	77106
Romania	306771	1178	361500	3574
Slovakia	153830	2087	321100	54
Slovenia	5400	2722	14700	
Spain	16800	1935	32500	235
Sweden	83310	2594	216100	
United Kingdom	681000	3096	2108000	7776
EU-27	6501057	**2539**	**18334299**	**8131**

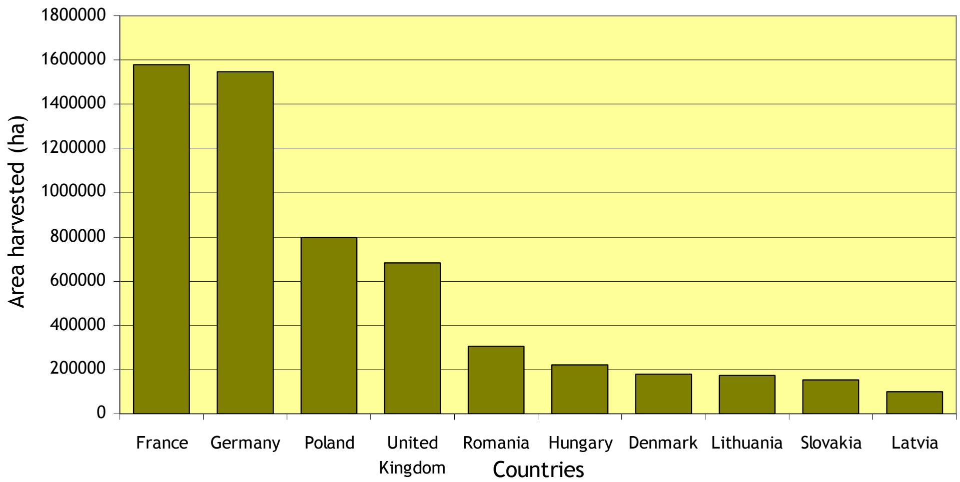

Figure 2. Area of harvested (ha) for rapeseed in 2007 for the main ten EU27 rapeseed producers

2.2 Ethiopian mustard (*Brassica carinata L. Braun*)

Brassica carinata L. Braun (Ethiopian mustard) is an annual crop, which is mainly grown in warm tropical regions. It belongs to the genus Brassica, of the large family of plants known as mustard (*Brassicaceae*). *Brassica carinata* is derived from a cross between *Brassica oleracea* and *Brassica nigra* L. Kock. It is related to rapeseed (*Brassica napus* L.).

It is originated from Ethiopia and its cultivation is limited to the Ethiopian Plateau and Kenya. Even though it is originated from Ethiopia, records from the Greek experiments and other Mediterranean countries indicated that, selected varieties can adapt well resulting to satisfactory yields in the Mediterranean soil- climatic conditions (final report of the project FAIR CT96 1946) (Figure 3).

It is a tall, leafy plant (Getinet, 1987), well adapted in the Mediterranean climate. It can be grown either as winter or spring annual crop. Vulnerability to cold temperatures at the initial growing stages has been observed, thus its cultivation is recommended only to those areas free of severe winter conditions (FAIR CT96 1946). Several studies have shown that the seed-yield potential of different “genotype” of *B. carinata* is superior to that of rapeseed in Mediterranean and dry climates (FAIR CT96 1946; Prakash et al. 1984; Fernandez-Martinez and Dominguez, 1982; Knowles et al. 1981).

B. carinata presents certain agronomic characteristics which make it suitable as a winter crop, alternative to cereals, in the Mediterranean countries. The most important are: 1) its well - developed root system, which is mainly the reason for its natural drought tolerance (Kumar et al. 1984), 2) its high natural resistance to most of the prevailing diseases and pests, compared to other Brassica species, 3) low fertilisation requirements compared to conventional crops, d) non-dehiscent siliques, a fact which is very important since it is harvested under dry conditions (FAIR CT96 1946), e) It’s fast and exuberant growth allows the efficient interception of solar light (Ferreres et al. 1983) and f) the flower disposition in *B. carinata* does not shade the leaves as in other Brassica species. Thus, the photosynthesis continues during flowering and leaf senescence is not induced by shading.

The crop is at an experimental stage. There are two major types of ethiopean mustard: edible and industrial. *Brassica carinata* is widely used as food (especially the leaf) and edible oil. The industrial type contains both high erucic acid and glucosinolates unacceptable as a food or edible product.

Generally, Brassica varieties have a relatively small seed that varies widely in purity, colour & germination. The seeds of *Brassica carinata* as the other brassica genus are very small and contain about 40% oil which is extracted by crushing to leave a high protein containing meal. The meal is used as animal feed as well as fertilization.

Cultural practices are similar to conventional crops (winter cereals). Special attention should be given to the applied herbicides (pre-emergence and post-emergence) since the crop is very sensitive to weeds. This species may be treated as rapeseed. i.e., the tradition rapeseed techniques can be applied. As a general guide these are the general recommendation: a) planting rate about 200 seed/m^2; i.e., about 8 kg/ha, b) the soil depth should be 1 to 2 cm and c) the row spacing usually should be 30 cm and d) and should be planting either in autumn (first half of October in cold areas and second half of October or early November in mind areas) or in spring.

Brassica carinata can be grown on soils which vary from pH 5.5 to 8.0. Good drainage is essential. Winter sown in particular has a little tolerance for heavy, wet soils and a high water table. Wet soils can significantly reduce winter survival and contribute to root disease. Rape grows best in sandy loams, loams with high organic matter, and loam sands. Light soils are acceptable and even ideal when adequate moisture and nutrients are available.

Harvest is a critical operation and losses can be heavy due to the small seeds and because the growth habit prevents all seeds in a crop maturing at the same time. Furthermore, early harvesting can reduce seed quality and late harvesting can enhance pod shuttering. The moisture content of *Brassica carinata* at harvest time of the seed must be around 7-9% and it's recommended for safe storage of rapeseed to be dried to less than 9% (FAIR CT96 1946).

In Greece, experimental data indicate that fresh and dry seed yields could reach up to 1.42 t/ha and 1.21 t/ha, respectively (Fereres, et al. 1983). Concerning solid biomass production, dry matter yields ranged from 3 t/ha to 8 t/ha were recorded in central Greece, in fertile soils. In the view of the Brassica carinata project a large number of lines were tested and the biomass yields found to be 16t/ha in the wet areas and 10t/ha in the dry areas. It was found that it was not possible to obtain lines with low erucic acid and with oil content similar to rapeseed.

The Spanish Centre of Energy, Environment and Technology Research (CIEMAT) have compiled agricultural production data for Brassica carinata from 160 ha. The agricultural fields where B. carinata has been cultivated have been monitored using current agricultural productions procedures. As a consequence, the final results of the environmental and energetic performance can be extrapolated to other southern European regions with similar soil and climate conditions (Gasol et al., 2007).

It was found that the maximum seed and biomass yields for Brassica carinata when it was cultivated in the Mediterranean countries recorded when the sowing took place from middle of September to the middle of October. At sowing 8 kg/ha of seeds are needed for the good crop establishment and for yields maximisation. It was not found to be particular demanded crop in nitrogen, sulphur, due to its tap root that makes good uses of fertiliser remaining from previous crops. It was found that is a very interesting preceding crop for a cropping system of cereal, well adapted to soil with lower nutritional levels (final report of FAIR CT96 1946).

In comparison to Canola (zero erucic, low glucosinolates cultivars of Brassica spp.) oil types, present forms of zero erucic-acid Ethiopian mustard (Brassica carinata A. Braun) are characterised by a seed oil relatively low in oleic acid (mono-saturated) and rich in linoleic and linolenic acids (polyunsaturated). The oil profile of zero erucic-acid Ethiopian mustard consists of 33% oleic, 37% linoleic and 21% linolenic acid (Alonso et al. 2001; Getinet et al., 1994; Fernandez-Martinez et al. 2001) compared to 61% oleic, 21% linoleic and 11% linolenic acid in Canola (Scarth and McVetty 1999). The increase of oleic acid concentration and the simultaneous reduction of polyunsaturated fatty acid levels are important breeding objectives in Ethiopian mustard.

Two types of oil from B. carinata have been studied for the production of methyl esters by transesterification. One was characterised by a high content of erucic acid (HEAR) and the other was a low erucic acid type (LEAR). The presence of unsaturated fatty acids affects negatively the oxidation stability of biodiesel. Of the two B. carinata oil samples the behaviour of the low erucic acid oil (LEAR) was significantly worse than that of the rapeseed methyl esters. In contrast, the high erucic oil (HEAR) was similar in behaviour to the rapeseed methyl ester, with a lower iodine number, despite a difference lipid profile.

Figure 3. Photos of Ethiopian mustard fields in Greece at several stages of growth (early stages of growth, flowering and harvesting time).

2.3 Sunflower (Helianthus annuus)

Sunflower is one of the most widely cultivated oil crops in the world. It belongs to Compositae family and to genus Helianthus that included 67 annual and perennial species. The crop originated in subtropical and temperate zones, but though selective breeding has been made highly adaptable, especially to warm temperate regions.

It is an annual spring crop with a plant height from 1.5 to 2.5 m at the flowering and has strong taproots, from which deeply-penetrating lateral roots develop. In each stem a total number of leaves between 20 and 30 developed. The flower is a typical head that develops in the top of each stem with a diameter 15-30 cm. The flowers tend to cross pollinating and the best temperature range for the production of seed is 20-25^{0}C. Seed and oil yields are reduced under conditions of stress. Oilseed producing varieties have a 1000 seed weight of 40 to 60 g and non-oilseed varieties have a 1000 seed weight of sometimes over 100 g (www.ienica.net).

Sunflower is adapted to a wide range of soil conditions, but grows best on well-drained, high water-holding capacity soils with near neutral pH (6.5-7.5). Production on high-stress soils such as those affected by drought, salinity or wetness is not exceptional but compares favorably with other commonly grown commercial crops. Having a well-developed root system is considered as one of the most drought resistant crops suitable for the southern semi-arid EU countries. However, oil yields are sustainable reduced if plants are allowed to become stressed during the main growth period and at flowering. Under moisture stress conditions the number and the size of the leaves are reduced. One of mechanisms employed by sunflower to resist moisture stress is by willing, since it has been shown in controlled experiments that in limp leaves water loss was reduced to a greater extend than photosynthesis. A satisfactory crop can be produced, without irrigation, even in winter rainfall regions of approximately 300mm.

Native sunflower and the early varieties were self incompatible and required insect pollination for economic seed set and yields. However, because the number of pollinators was often too low current hybrid varieties have been selected for and possess high levels of self compatibility. Modern hybrids still benefit from insect pollination.

One of the main characteristics that determine the quality of the produced biodiesel is the fatty acid composition of the sunflower oil. It is varied according to the cultivation site, the sowing dates and the years. This is because the oleic/linoleic ratio depends on the temperature during the early stages of oil synthesis in the seeds (Izquierdo et al. 2002). Moreover, the effect of temperature can be different according to the genotype (Izquierdo and Aguirrezaba, 2008).

Several quality parameters of biodiesel (e.g. density, kinematic viscosity, heating value, cetane number and iodine value) are highly dependent on fatty acid composition.

Table 5 - Area harvested (ha), yields (kg/ha), production quantity (tones) and seed yields (tn) in the EU-27 countries for sunflower.

Country	Area harvested (ha)	Yields (kg/ha)	Production quantity (tones)	Seed yields (tones)
Austria	26446	2251	59527	267
Bulgaria	602398	937	564447	21650
Croatia	20615	2634	54303	247
Czech Republic	24426	2129	52000	293
France	534000	2577	1376000	5340
Germany	19161	2655	50862	0
Greece	12100	1593	19273	363
Hungary	504900	2045	1032300	5000
Italy	127329	2129	271090	1500
Poland	3243	1746	5662	
Portugal	9000	1833	16500	100
Romania	748545	731	546922	5661
Slovakia	64746	2049	132656	2248
Slovenia	200	2000	400	2
Spain	601000	1170	703000	3000
EU-27	**3298109**	**1899**	**4884942**	**45671**

The harvested area of sunflower in EU27 is presented in Table 5. The total harvested area in EU-27 in 2007 was 3.298 million ha. The top five EU countries in terms of harvested area are: Romania 0.749 million ha, Bulgaria 0.602 ha, Spain 0.601 million ha, France 0.534 million ha and Hungary 0.504 million ha (Table 5, Figure 4). The yields varied from 731 kg/ha (Romania) to 2655 kg/ha (Germany), while the mean seed yields in the cultivated countries of the EU-27 is 1899 kg seeds/ha.

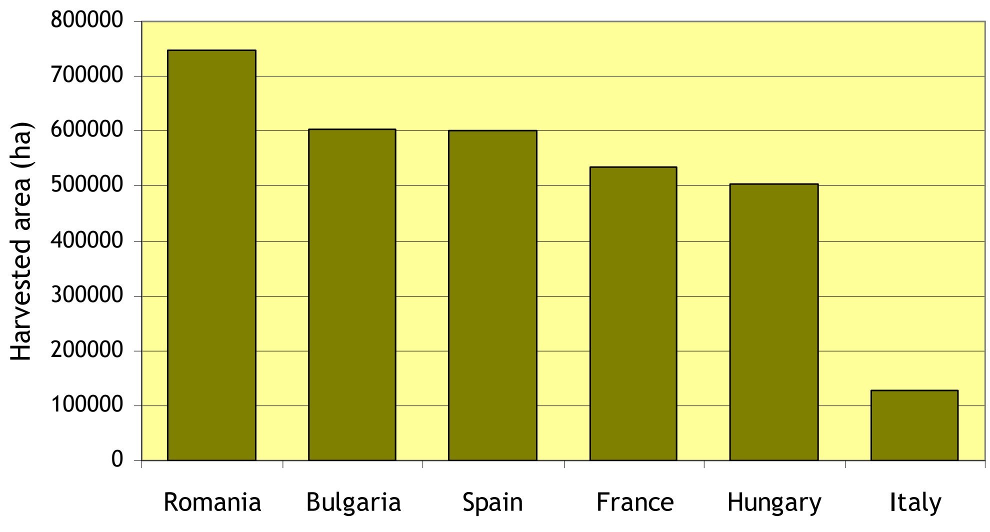

Figure 4. Harvested area (ha) in six most important EU countries for sunflower cultivation

The sunflower oil is considered as high quality oil since it has low percentage of saturated fatty acids and high percentage of unsaturated fatty acids.

Figure 5. Photos of sunflower at several stages of growth (vegetative phase, flowering phase and maturity phase) (Source: CRES)

According to the results of the Probiodiesel (www.probiodiesel.com) project the oils of rapeseed, soybean, sunflower and palm are suitable for the production of biodiesel in the process of ACCIONA production plant (Spain). The only raw material that can be used neat and is in accordance EN14214 specification parameters is rapeseed. When biodiesel is produced from sunflower, soybean and palm it is necessary to blend them or use additives to comply with the iodine index specification (for sunflower and soybean) and to improve the cold flow properties (for palm).

In Table 6 presented the results on oils of rapeseed and sunflower (and the biodiesel that were produced from them) carried out by ACCIONA in the framework of the probiodiesel project.

Table 6. Results from two oils (rapeseed, sunflower) -source Probiodiesel (D2.1, www.probiodiesel.com)

	Rapeseed	Sunflower
Non-soluble in ether	Oil:<0.01%	Oil:<0.01%
Iodine number	Oil/biodiesel: 111 g/100 g fat	Oil/biodiesel: 131 g/100 g fat
Unsaponifiable content	Oil: 1.02%	Oil: 0.75%
Acidity	Oil: 0.08% Biodiesel: 0.38 mgKOH/g sample	Oil: 0.05% Biodiesel: 0.41 mgKOH/g sample
Stability to oxidation	Oil:10.1 hours Biodiesel: 8.3 hours	Oil:5.1 hours Biodiesel: 2 hours
Ester content	Biodiesel: 99.9%	Biodiesel: 98.8%
Density at 15^0 C	Biodiesel: 883 kg/m^3	Biodiesel: 881 kg/m^3
Viscosity at 40^0 C	Biodiesel: 4.44 mm^2/s	Biodiesel: 4.13 mm^2/s
Ignition index	Biodiesel: 183 ^{0} C	Biodiesel: 165 ^{0} C
Sulphur content	Biodiesel: 0.5 mg/kg	Biodiesel: 0.5 mg/kg
Carbon residue-Micro Method (in 10% of distillation residue)	Biodiesel: 0.07% (m/m)	Biodiesel:<0.30% (m/m)
Content in sulphated ashes	Biodiesel: <0.01%	Biodiesel: 0.01%
Water content	Oil: 0.04% Biodiesel: 64 mg/kg	Oil: 0.1% Biodiesel: 334 mg/kg
Total contamination	Biodiesel: 14 mg/kg	Biodiesel: 5 mg/kg
Corrosion in copper sheet	Biodiesel: class 1A	Biodiesel: class 1A
Methyl ester of linoleic acid	Biodiesel: 9.1% (m/m)	Biodiesel: 0.1 % (m/m)
Methyl esters of poliinasaturated acids	Biodiesel: <0.01% (m/m)	Biodiesel: <0.01% (m/m)
Content in methanol	Biodiesel:<0.01% (m/m)	Biodiesel:0.10 % (m/m)
Content in mono-, di- and triglycerids, free glycerine and total glycerol	Biodiesel: Cont. monoglycerids: 0.43 % Cont. diglycerids: 0.08% Cont. triglycerids: 0.01% Free glycerin: 0.01% Total glycerin: 0.13 %	Biodiesel: Cont.monoglycerids: 0.62 % Cont. diglycerids: 0.05% Cont. triglycerids: < 0.01% Free glycerin: <0.01% Total glycerin: 0.18 %
Content in Na, K, Ca and Mn	Biodiesel: Metals of group I (Na+K): 3.9 mg/kg Metals of group II (Ca+Mg): Ca:< 1 mg/kg Mg: < 1 mg/kg	Biodiesel: Metals of group I (Na+K): Na <0.1 mg/kg, K: 0.4 Metals of group II (Ca+Mg): Ca: 0.3 mg/kg Mg: 0.1 mg/kg
Phosphorus content	Biodiesel: <1 mg/kg	Biodiesel: 0.8 mg/kg
Cold Filter Plugging Point (CFPP)	Biodiesel: -12 ^{0}C	Biodiesel: -5^{0}C

3. Short Rotation Forestry

Short rotation forestry can be expected to play an important role in the production of biomass for bioenergy. Biomass produced in short-rotation forestry can play an important role in the substitution part of the fossil fuels that will reduce the emissions of the greenhouse gases. The short rotation forestry can contribute to the carbon uptake from the atmosphere.

In EU27 as the most promising crops for short rotation forestry considered willow, poplar and eucalyptus. The first two options cultivated in some sites in EU for energy production while Eucalyptus is being cultivated in south Europe for paper pulp production.

3.1 Willow (Salix spp.)

Willow (Salix spp.) includes several trees and shrub species, native to the temperate and subtropical zones, is fast growing and ease to propagate vegetatively. Many of the species are adapted to a wide range of climatic and soil conditions, from the heat of the Chinese desert to the cold, windy conditions of the South American Andes (www.fao.org).

Some willow species have been cultivated for energy generation "energy forests" in Sweden since the first oil crisis in 1970s. Clones of Salix viminalis are mainly used in the energy forests. Other species such as Salix dasyclados have also been cultivated, but to a much more limited extent.

Willow due to its high production potential (Christersson, 1986) became the major energy crop in Sweden. Full scale willow plantations for energy use were established at the late of 1990s. The lower harvests that the ones expected as well as the water availability were the two main factors limiting the willow production in Sweden. It is reported that frequent dry spells may cause significant losses in biomass production (Niemcynowicz et al. 1993).

Willow is mostly cultivated in the fields of southern Sweden, where about 1250 farmers work with commercial plantation currently totalling about 13500 hectares. It worth mentioning that in Sweden farmers can get subsidies of about 500 Euros from the government to establish willow plantations. The establishment period and intervals between harvests are 3-5 years and the yield can reach about 8-10 tonnes dry matter per hectare per annum, but significant variation occurs according to region and year. Willow chips for direct combustion are the most commonly used products on the market. In Belgium reported dry matter yields of 3.5 tn/ha/year when willow was grown in experimental fields (Walle et al. 2007).

In Poland (2005) the cultivation area of willow was 6000 ha (Stolarski et al. 2008). Willow can be grown on polluted areas where traditional food crops should not be grown. In the result to willow growing polluted soils of good fertility can be returned into production because willow has a good phytoremediation potential combined with high productivity (Pulford et al. 2002).

The establishment of willow plantations made with cuttings in spring. Willow is usually supplied as 2-3 meter long branches that are cut between December and March when the buds are fully dormant. These can be planted immediately or carefully stored in cool conditions (-2 - -4^{0}C) until they are used. For the establishment of a willow plantation 13,000 cuttings per ha are needed. The weed control is necessary during the first year of the willow establishment.

Willow plantations are very demanding of water and nutrients, generally requiring 3-5 mm of water per day during the growing season. The demand for nutrients varies according to age of the plantation and stage of crop development. In Sweden during the establishment year no nitrogen was applied, in the second year 45 kg N/ha use to be added, in the third 100-150 kg N/ha.

Since the willow plantations are demanding to water and the irrigation is not economically viable in short rotation forests the water availability should be considered before the plantation establishment. It has been found that the biomass production and the water use of willow are strongly affected by the selection of the clonal material.

Willow is preferably harvested during the winter when the ground is frozen and the moisture content is the biomass is at its lowest (ca. 50%). Willow is harvested after 3-5 years of growth.

Willow has almost the same net heating value as the wood fuels, approximately 18.6 MJ/kg_{dm}. In Belgium reported calorific value of 19.92 MJ/kg_{dm} (Walle et al. 2007).

In a study that was carried out in Poland (Ericsson et al. 2006) it was found that willow can be an economically viable crop for relatively large fields. With the current price of wood chips (on average 33 PLN/MWh), wheat is the most viable of the three crops that were compared and willow had the same economic viability with barley.

3.2 Poplar (Populus spp.)

Poplar (Populus spp.) is a tree belonging to the Salicaceae family widely used in traditional arboriculture and forestry. It is tolerant to a wide range of soil conditions, but generally grows in deep fertile soils and it is best suited to the Mediterranean climate since it is very sensitive to frost. Poplar has fast growth; high biomass yields and good frost hardiness render poplars suitable for planting on agricultural land in temperate and boreal climates (Weih, 2004). Under optimal conditions SRF poplar plantations can reach a productivity level of about 20t_{dm}/ha/yaer. Poplar plantations could be managed to produce biomass for bioenergy and pulpwood fibre, as well as for environmental control (phytoremediation) (Karacic et al. 2003).

The advantages of the crop are: it is a crop with a known tradition in the area analysed (south Europe), high yields, high ecological interest in terms of biodiversity and low fertilizer doses are required and comparatively low biomass production costs. The disadvantages of the crop are: high requirement for water that restricts the natural distribution of the poplar (Imbert et al. 2003).

Poplar is currently the most important species for SRF in Italy. All the existing plantations are based on poplar clones grown in the northern regions of Italy and to a less extent in central Italy with a total estimated harvested area of about 5,700 ha. In Spain it is reported (www.oncultivos.es) a total area of 18,000 ha have been established.

In Italy poplar is being investigated as bioenergy crop focused on genetic improvement and clone selection, optimised cultivation techniques, harvesting and mechanisation and storage and logistics of biomass production. The work that had been carried out resulted in establishment of the crop with stem cutting 20-30 cm in length in spring. At the crop establishment 35,000 cuttings per day can be established. At the establishment 10,000 to 15,000 plants/ha are being established. In Italy the crop used to be harvested every two years but in some cases the harvesting carried out every 3-5 years.

Table 7. Comparison of the fuel characteristics among willow, poplar, reed canary grass and soft wood (EnCrop, Handbook)

	Willow	RCG (spring)	Poplar	Soft wood
Water content at harvest (%)	50	10-15	50-55	50
Dry matter yields (th/ha/year)	6-10	4-10	10-20	3-5
Ash content (%)	2.9	1-8	0.5-1.9	1-2
Gross calorific value (MJ/kg)	19.97	19.20	19.43	20.3
Net calorific value (MJ/kg)	18.62	17.28-18.72	18.10	18.97
Carboon (C), %DM	49.8	48.6	39.7	50.6
Hydrogen (H), %DM	6.26	6.1	7.7	6.24
Sulphur (S), %DM	0.03	0.04-0.17	0.2	0.03
Nitrogen (N), %DM	0.39	0.3-2.0	0.9	0.1
Chlorine (Cl), %DM	0.03	0.01-0.09	0.04	0.01
Aluminium (Al), g/kg of ash	2.2	2.8	16.7	16.0
Calcium (Ca), g/kg of ash	243.0	66.5	189.3	238.8
Potassium (K), g/kg of ash	123.3	129.5	28.6	80.7
Magnesium (Mg), g/kg of ash	23.4	21.7	42.9	31.4
Sodium (Na), g/kg of ash	2.5	7.0	3.6	4.6
Phosphorus (P), g/kg of ash g/kg of ash	36.9	32.3	17.9	12.4
Silicon (Si),	93.3	218.3	178	73.9
Ash melting point (DT/A, ^{0}C)	1490	~1400	1160	1200

Poplar is currently investigating under a European project entitled ENERGYPOPLAR (www.energypoplar.eu). The project started in 2008 and will last four years. The main objective of this project is to develop energy poplars with both desirable cell-wall traits and high biomass yield under sustainable low-input conditions to be used as a source of cellulosic feedstock for bioethanol production.

Figure 6. Source: www.4fcrops.eu Presentation of the Energypoplar poplar by Gail TAYLOR in the second project workshop in Madrid (24/3/09).

3.3 Eucalyptus

Eucalyptus genus belongs to Myrtaceae family and has more than 550 species. Although several Eucalyptus species adapted in the Mediterranean countries two are the most important: E. camaldulensis and E. globulus.

E. camaldulensis is the most widespread in Australia as well as on several Mediterranean countries. It able to produce acceptable yields on relatively poor soils with a prolonged dry season, exhibits some frost resistance, tolerates periodic water logging and some soil salinity and becomes chlorotic on highly calcareous soils. It is a drought resistance species and grows in areas receiving 200 mm rainfall per annum although growth is better where the annual rainfall exceeds 400 mm (Turnbull and Pryor, 1984).

E. globulus species includes four subspecies and the most widely spread in the Mediterranean countries is Eucalyptus globulus Labill. subsp. globulus. This species is widely cultivated in the Iberia Peninsula and other parts of the world. It is well adapted in mild, temperate climates and at high elevation in cool tropical regions. Ideal conditions in EU are along the north-western coasts of Spain and Portugal, where the annual precipitation is above 900 mm, the dry season is not severe and minimum temperature above -7^{0}C. It is considered very sensitive to moisture stress. In south-western Spain with 465 mm annual precipitation and about four months dry season grows on deep soils with available soil moisture. On drier and shallower soils E. camaldulensis is superior.

Eucalyptus and robinia are the most important candidates for SRC in Southern EU. In the framework of the European project AIR CT93 1678 Eucalyptus was investigated in south Europe for energy production. The plant density was 20,000 plants/ha and the obtained yields were 32 t/ha/year. Calorific values of 18.94 MJ/kg for wood and 16.46 MJ/kg for bark have been reported. For both species the ash content in the stems were between 2 and 3%, in the branches were between 4.4 and 4.6%, and while in the leaves were quite higher and were 5.6% for camaldulensis and 8.2% for globulus. In Ethiopia reported calorific values for E. globulus from 18.77 to 19.36 MJ/kg (Lemenih and Bekele, 2004) and for E. camandulensis 18.46 MJ/kg.

Eucalyptus is the most valuable and widely planted hardwood in the world. According to FAO (2005) the cultivation area in 90 countries was 18 million ha. In 2008 the reported area of cultivation of eucalyptus worldwide was 19 million ha (GIT Forestry consulting, 2008). It should be noted that 15 years earlier the cultivation area worldwide was half of the one reported in 2008 (Pantley, 1995). Brown (2000) reported that with an annual growth rate 10m3/ha or even more eucalyptus plantations have an enormous potential as a source for pulp, wood chips and wood fuel.

In Europe eucalyptus is mainly cultivated in Portugal and Spain and is used for paper pulp production. In 2000 eucalyptus stands supplied 10 million m^3 of wood per year to pulp factories located in southern Europe (DIEF, 2000). In Italy, in the view of afforestation projects, 70.000 ha of eucalyptus plantations were established (Saporito, 2001).

E. globulus is well adapted on a wide range of soil types. Although the best development is on deep, sandy clay soils, good growth is also attained on clay-loams and clay soils, provided they are well drained. Insufficient depth, poor drainage and salinity are limiting factors.

It is considered as one of the best eucalypt species for paper-making. It is also highly regarded for high and heavy construction, poles, piles, railway sleepers and as fuel.

The fast growth rates of eucalyptus under appropriate conditions, the good tree form characteristics combined with adequate wood properties make some eucalypt species suitable for pulp production (Pereira, 1992).

Solid energy crops such as willow, poplar and eucalyptus can be utilized whole to produce heat and electricity directly through combustion or indirectly through conversion for use as biofuels like methanol and ethanol.

Eucalyptus is widely planted and produces abundant biomass. Many conversion technologies are well understood, and several are being developed. Biomass characteristics, difficulty in securing adequate and cost effective supplies early in project development, and planning constraints currently prevent Eucalyptus bioenergy from reaching its full potential. However, increased biomass productivity and quality, prospects for carbon trading, distributed energy systems and hydrogen, multiple products from biorefinery, and government incentives should foster Eucalyptus biomass use for bioenergy (Rockwood et al, 2008).

Figure 7. Eucalyptus plantation in Greece (source CRES)

4. Lignocellulosic crops

The best energy crops are perennial, their dry matter yields are high and constant and their production costs are low. A perennial growth habit, low agrochemical requirements, effective conversion of solar energy to biomass and ease of conversion back to useful energy guarantee that energy efficiency of production is high and environmental impacts are low. For combustion it is practical the crops can be harvested when it is dry. Transportation, storage and combustion are easier and heating value is high. It is advantageous is an energy crop is suited to existing power plants and is co-combustible. This keeps investment cost low, requiring for example, only crushing and feeding lines for biomass bales. Ash content should be low and ash melting point should be high enough and combustion should occur without production of harmful elements such as chlorine content and heavy metals.

4.1 Reed canary grass (*Phalaris arundinacea*)

Reed canary grass is a robust coarse perennial, widely distributed across temperate regions of Europe, Asia and North America. The plant is a C3 pathway species. The last fifteen years the crops is being evaluated for fibre and energy production in Sweden and Finland.

It has a plant height varied from 60 cm to 2 m and has hairless light green or whitish green leaves 10-35 cm long and 6-18 cm wide. Flowering is take place in June and seeds are ready in August. Reed canary grass spreads naturally by creeping rhizomes, but plants can be raised from seed. The plant frequently occurs in wet places, along the margins of rivers, streams, lakes and pools (www.ienica.net).

It is established by seed and according to field trials that have been conducted in Finland can be productive after 15 years. The first harvest of the crop takes place two years after sowing and its root system needs two growing period to be developed. According to the trials the crop gives the best yields from the third growing period.

It grows best in soils with soil type from moist mold to fine sand soils. Reed canary grass is sown like forage grasses and can not compete well the weeds. The crops should be fertilized each spring after harvest (60-80 kg N/ha).

The chemical composition of the reed canary grass is 28% cellulose, 22% hemicellulose, 14% lignin, 8% ash (of which a high% is silica), 28% other. According to Anthony et al. 1993 its fibre length is 0.67 mm, the coarseness is 0.082 mg/m and the water retention 200. The crop removes nitrogen from the soil more efficiently than any other cool-season grasses and often analyses highest in percentage crude protein among grasses at similar stages of maturity (Anthony et al. 1993).

In Finland and Sweden reed canary grass is harvested in spring after the snow melts because then the crop is dry and the fuel quality of the raw material is high. When the crop is harvested in spring the ash content is lower and the ash melting point is higher compared to the autumn-harvested crop. Also Cl, K, Ca, N and P contents have decreased during the winter. The ask content at harvest ranged from 2 to 10% depending on the fertilization and the soils. The ash content is lower in the stems compared to the leaves and at spring harvest the stems are the 70% of the harvested material.

The harvesting takes places at a stem height of 15 cm and the moisture content of the harvested material is 10-15%.

In Finland the production of reed canary grass has increased rapidly the last decade. In 2008 the production area of reed canary grass was about 20,000 ha in Finland, while in Sweden was under 1,000 ha. In the other EU countries is not cultivated with the exception of small experimental plots. It is a crop suitable in Nordic countries, where the winter is cold. In Finland the Ministry of Agricultural and Forestry has set a target to increase the field area of energy crops to 100,000 ha before 2016. The realistic yields of the crop in Finland varied from 4 to 7 dry tones/ha. The crop is mixed with peat or wood chips (Figure 9).

It is reported yields of 11 t/ha in USA when the crop is harvested three times per year and 4.4 to 8.6 t/ha in USA when the crop is harvested one time. In Canada with three cuts the yields are 9.5 – 12 t/ha, in Sweden with two cuts 10 t/ha and in UK 4tn/ha for one harvest (Chisholm, 1994).

Reed canary grass has been exploited in EU projects such as AIR 3 CT94 2465 "Reed canary grass (*Phalaris arundinacea*). Development of a new crop production system based on delayed harvesting and a system for its combined processing to chemical pulp and biofuel powder"

Figure 8. View of the reed canary grass at flowering phase and at harvesting (Source: Presentation of Dr. Pahkala in the second 4FCROPS workshop in Madrid – 24/3/09 – www.4fcrops.eu).

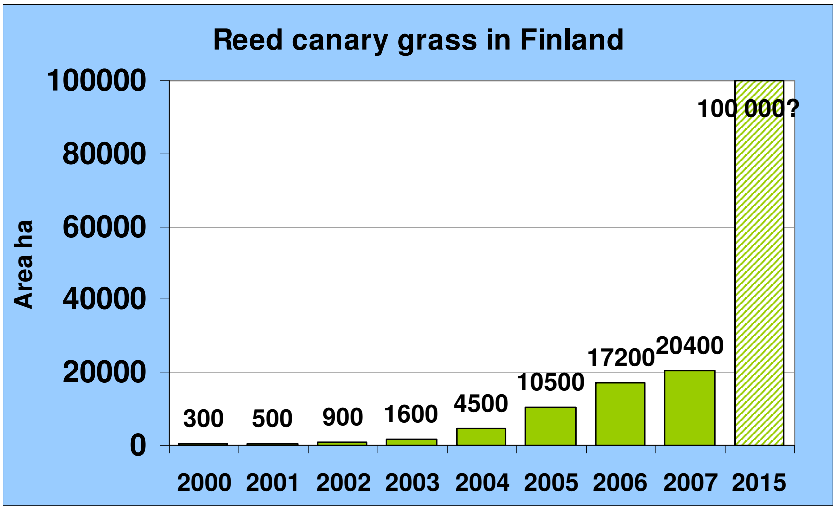

Figure 9. Area of cultivation of reed canary grass in Finland
(Source: Presentation of Dr. Pahkala in the second 4FCROPS workshop in Madrid – 24/3/09 – www.4fcrops.eu).

4.2 Miscanthus (*Miscanthus giganteus*)

Miscanthus is a woody rhizomatous C4 grass species belonging to the Andropogoneae tribe (Poaceae family) in the Graminaceae Order (McCarthy & Walsh, 1996). Originated from Asiatic countries and firstly introduced in Europe in the 1930's as an ornamental plant, it has been spread out mainly throughout Europe due to some species better adapted to cooler conditions (Scurlock, 1998).

Miscanthus x giganteus is a sterile (3n) naturally occurring interspecific hybrid which remains an unimproved plant like all *Miscanthus* species. It was collected in Japan, introduced in Denmark in 1935 and then distributed throughout Europe (McCarthy & Walsh, 1996). Firstly studied in Denmark in the 1960's for its considerable cellulose fibre yield potential under European conditions, *Miscanthus x giganteus* is, from the 1980's on, also studied for energy production by diverse European countries.

Miscanthus is a monocotyledonous Poaceae looking like a bamboo or a reed. Stems are constituted of several strong ligno-cellulosic units (such as sugar cane). They are characterized by a rapid growth up to 3 meters during the third or fourth year of production (Walsh, 1997); Scurlock (1998) found the typical maximum canopy height at about 4 m or 2.5-3 m after over-wintering and leaf drop. Inflorescences are from panicle type where male and female flowers are disposed in spikes. Blossoming is quiet rare in Europe and if it does, the seeds produced are not fertile.

Despite the fact that C4 species are best suited to tropical and subtropical climates where their growth rate is high and winter temperatures not freezing, some *Miscanthus* species naturally occur in a temperate climate. The results of the *Miscanthus* Productivity Network showed that their yields were nevertheless limited by low temperatures in Northern country (decreasing in rates of leaf expansion, canopy development, dry matter yields and length of *Miscanthus* growing season defined by the latest spring frost and the first autumn frost). Most of the yields were situated between 11 and 18.3t/ha while those obtained in South European countries were recorded at 24t/ha where water was not a limiting factor (Jones & Walsh, 2001).

Miscanthus is relatively tolerant to different types of soil (pH between 5.5-7.5) (McCarthy & Walsh, 1996). The form of soil aggregate seems to have a more significant effect on productivity than soil type or pH (Jones & Walsh, 2001).

At a practice level, *Miscanthus* technical management should start with the following land preparation: soil should be tilled in winter then mechanically cleaned at the end of winter using a cultivator-harrow in order to ensure a good soil physical structure and to enhance tap roots and rhizome development.

The crop is established by rhizomes or rhizomes cuttings. Thus better results should be obtained with large pieces of rhizomes (>200mm length) which have not been stored before being planted at 200mm depth.

Miscanthus has a high water use efficiency (272 L/kg DM) compared to the C3 species but also high water requirements due to its high productivity (between 750 and 800 mm). During the *Miscanthus* Productivity Network (McCarthy & Walsh, 1996), best yields were achieved with the highest irrigation treatment. Growth characteristics such as plant height, number of leaves, leaf area index and yield were found to be dependent on irrigation rates when *Miscanthus* was grown up in sites with low water table. Newly planted rhizomes establishment rates also appeared to be improved by irrigation under drier conditions (rhizomes were found to be less sensitive than micro propagated plants to summer drought) (Schwarz et al, 1998).

Water requirements can be provided by rain falls, irrigation or underground reserves (McCarthy & Walsh, 1996). Irrigation is usually required in Southern EU sites (Walsh & McCarthy, 1998) but it can eventually be avoided if the water holding capacity of the soil is high (McCarthy & Walsh, 1996).

It is worth noting that despite the high water requirements of the crop, doubling irrigation rates may increase dry matter yields by only 10%; then, it may be more economical and environmentally friendly to grow *Miscanthus* using moderate irrigation rates without dramatically reducing yields (Jones & Walsh-2001).

Miscanthus rhizomes act as storage organs for nutrients which allow a rapid growth in spring by re-translocation processes; the nutrient store built up during the vegetative period and filled in at the beginning of autumn (Sept/Oct), is depleted during spring for the production of the above-ground biomass. The remaining nutrients are retranslocated to the rhizome at the end of the growing period (McCarthy & Walsh, 1996). Thus, on 4-9 year-old *Miscanthus* stands in Germany, the nutrient concentrations in the harvested biomass were found to be only 61% (N), 64% (P), 55% (K) and 50% (Mg) of the initial concentration at the end of the vegetation period (harvest period : February/March). It is explained by translocation of nutrients to the below-ground plant part and the nutrient losses due to pre-harvest losses (fallen leaves, shoot-tips) (Kahle *et al,* 2001).

No clear conclusion can be made from the results of several trials on the interaction between N fertilization and yield: trials of the *Miscanthus* Productivity Network have revealed that the effect of nitrogen fertilization rates on biomass yield was generally small whereas some trials showed that plants were demanding more during the first year (60 to 120kg N/ha, 15 to 100kg P_2O_5/ha and 70 to 140kg K_2O/ha). Other Austrian trials have recorded significant effects of nitrogen fertilization rate on biomass yield in years 4^{th} and 5^{th} as yield increases (Schwarz and Liebhard, 1995). With regard to this wide range of observation, McCarthy & Walsh (1996) have concluded that responses to fertiliser applications appear to vary according to soil type and nutrient supply capacity ; N fertilization will be necessary on soils with low N contents and be avoided or limited to 50-70kg/ha/yr on soils with sufficient N mineralization (Lewandowski et al, 2003). Once the plants established, their ability to acquire and conserve large quantities of nutrients imply relatively low fertilizer applications to support growth.

The amount of P and K exported in the biomass at harvest (i.e. 7.4 and 94.3kg/ha respectively in the third year) can be replaced by fertilizer applied at compensatory rates but with adjustments to support increased growth as the crop increases in maturity (Jones & Walsh, 2001).

Thus, the internal cycling of nutrients allows harvesting *Miscanthus* with low nutrient contents but complicates the quantification and the optimisation of fertilizer applications (Jones & Walsh, 2001). Research is at present going on especially on interaction between N fertilization rates and irrigation rates because high yields were recorded in several trials (Austria, Greece, Italy) at sites receiving the highest N fertilization rates combined with the highest irrigation level (Schwarz and Liebhard, 1995).

In literature harvesting dates range from autumn to spring, depending on local conditions. Winter and early spring (before shoot regrowth) offer good harvest conditions and especially during a frost period: firm soil, homogenous harvest after leaves fell (better quality of product), low moisture of plants. In addition, the later the harvest can be performed, the more the combustion quality improves since the moisture content and the mineral contents decrease. However there is a trade-off since the biomass yield and the bioenergy yield decrease as well ; the biomass yield loss is about 30 to 50% of the standing biomass (Lewandowsky et al, 2003; Scurlock, 1998) and the bioenergy yield recorded as 187-528 GJ/ha for a harvest in December decreases with a delayed harvest by 14-15% between December and February and by a further additional 13% between February and March (but reduced total SO equivalent emissions of an energetic use of *Miscanthus* (LCA results) (Lewandowski & Heinz, 2003).

In autumn, dry matter content is maximized but moisture content remains quite high (*Miscanthus* is a hygroscopic crop; its inner moisture is directly linked to the atmospheric moisture). Moisture content at autumn harvest was found to range from 25-40% in Southern European countries to 30-60% in more Northern countries and was also found to vary between genotypes (*M. x giganteus* moisture content was about 44-50%).

Then, Jones and Walsh (2001) advise to harvest in early spring in Northern regions when the moisture content of the harvested material is lowest and in late autumn in Southern countries to avoid biomass losses caused by the adverse climatic conditions during winter. In any case, for economic reasons, a late harvest with moisture content lower than 30% is recommended because harvesting and drying costs increase with water content (Huisman, 1998).

Miscanthus estimate productive time life is about 10-15 years. The results of the main European trials have shown ceiling yields ranging from 15 to 25 t/ha at the end of the growing season in northern Europe. In central and southern Europe a higher productivity has been recorded (from 25 to 40 t/ha) but irrigation was required (Jones & Walsh – 2001). Nevertheless, according to Scurlock (1998), large-scale semicommercial trials suggest that a yield above 7-9t/ha (dry weight) is a more reasonable estimate over large areas.

Their first results suggest that yields of up to 25t/ha /year (DW) may be obtained at the time of harvest (February) under conditions from central Germany (lat. 50 N) to Southern Italy (lat. 37 N).

One of the potential end uses is as a fuel energy production by combustion in farm heating plants or co –combustion with coal for example. In this last case, Miscanthus is comparable to straw (18.2MJ/kg) (McCarthy & Walsh, 1996). This energy can then is transformed in electricity, heat, etc. (Walsh & McCarthy, 1998).

20t *Miscanthus* is equivalent to 12t of hard coal or 8,000 litters of oil on an energy basis (Lewandowski *et al*, 1995). The quantification of avoided fossil fuel-derived energy depends on several factors such as the cultivation method, biomass yield, biomass water content, biomass loss in storage and the electricity generating technology (Bijl, 1996 ; Kaltschmitt et al, 1996). *Miscanthus* is reported to have a high net energy balance compared with other energy crops (Karltsmitt et al., 1996).

Mis*canthus* has a low impact on soil and water quality due to its low requirements of pesticide and fertilizer and also on soil erosion. It may have a beneficial impact on wildlife and biodiversity compared to other high input arable crop. (Walsh & McCarthy, 1998) ; Jodl *et al* (1998) found that *Miscanthus* stands contains more large animals than other herbaceous crops (corn or reeds) probably because of the greater diversity of canopy structure providing greater range of ecological niches.

It is worth noting that these environmental benefits will only occur if production and conversion processes are carefully managed and guidelines are fully adhered to (James & Walsh, 2001).

Miscanthus has been investigated in several EU projects such as: FAIR CT97 1707, FAIR 1392, AIR1 CT92 0294, etc.

Figure 10. View of miscanthus at early stages and at harvesting time (source: CRES).

4.3 Giant reed (*Arundo donax* L.)

Arundo donax is a tall, perennial C_3 grass that belongs to the subfamily *Arundinoideae* of the *Gramineae* family (Perdue 1958, Tucker 1990). *A. donax* is thought to be originated from Asia (Boose 1999, Rossa et al. 1998) but also considered as a native species to the countries surrounding the Mediterranean Sea. It is currently found growing in India, Burma, China, Southern Africa, Australia, America, and regions adjoining the Nile River and in the Mediterranean area (Veselack and Lisbet, 1981).

It grows in dense clumps; the stems can reach a height up to 8-9 m, exhibiting growth rates of 0.3 to 0.7 m per week over a period of several months during the vegetative stage when conditions are favourable (Perdue, 1958). Stems are arising during the whole growing period from the large knotty rhizomes. They do not all emerge at the same time and later emerging shoots fail to grow well and often die off, probably due to shading.

The fleshy, almost bulbous, creeping rootstocks (rhizomes) form compact masses from which develop tough fibrous roots that penetrates deeply into soil. The rhizomes usually lie close to the soil surface (5-15 cm deep, maximum 50 cm), while the roots are more than 100 cm long (Sharma et al. 1998). The root system has two functions: to hold the plant in a stationary position and to absorb the water and nutrients from the soil.

The culms reach a diameter of 1-4 cm and are commonly branched in plantations that are two years or older. They are upright, stout, glabrous, and hollow, with walls 2-7 mm thick and divided by partitions at the nodes. The nodes vary in length reaching up to 30 cm. The outer tissue of the stem is of a siliceous nature, very hard and brittle with a smooth glossy surface that turns plane golden yellow when the culm is fully mature (Duke, 1983; Tucker, 1990). Inflorescence appears from August to November but not all shoots flower in the same year.

A. donax tolerates a wide variety of ecological conditions. It prefers well-drained soils with abundant soil moisture. It can withstand to a wide variety of climatic conditions and soils from heavy clays to loose sands and gravelly soils (Perdue, 1996) and tolerates soils of low quality such as saline ones, too (Singh et al. 1997). *A. donax* is a warm-temperate or subtropical species, but it is able to survive frost. When frosts occur after the initiation of spring growth it is subject to serious damage. It has a broad photosynthetic temperature optimum between 24^{o} and 30^{o}C.

The establishment is the most critical point of *A. donax* cultivation and has strong influences on productivity and economical viability. The two main factors determining establishment success and costs are the propagation material and the planting density. Because of seed sterility only vegetative propagation is foreseen for the commercial production of *A. donax*. Planting of rhizomes, whole stems and stem cuttings have been tested but appropriate machinery for these operations is not yet available (Pari, 1996; Veccheit et al. 1996). In the tests done so far the rhizome establishment turned out most promising. The planting of large rhizome pieces with well-developed buds directly into the field early in spring in Southern European areas had nearly 100% success (Christou et al. 1995). However, this is a very costly labor-intensive method as this includes digging the rhizomes, transporting them to the site, keeping them wet for a certain period, cutting them in smaller pieces and then planting them in the new field.

Arundo donax can be harvested each year or every second year, depending on its use. Two harvests per growing period are feasible but repeated clipping could not sustain high growth rates and the total production declined (Sharma et al. 1998).

For energy production purposes, in southern EU regions harvesting is recommended to be carried out in late winter in order to reduce the moisture content of the stems.

The production potential of *Arundo donax* can reach up to 100t fresh matter year^{-1} ha^{-1} in the second or third growing period under optimal conditions in a warm climate and by supplying it with sufficient water (Shatalov and Pereira, 2001). According to Morgana and Sardo (1995) in Sicily a mature plantation of giant reed yielded over 40 t DM ha^{-1} indicating that this high potential for dry matter production brings promise of even higher production if cultivation's limitations would be overcome.

Yields reported in Spain showed 45.9 t DM ha^{-1} on average, ranging from 29.6 to 63.1 t (Hidalgo and Fernadez, 2001). In Greece, the recorded average DM yields, estimated from 40 giant reed populations, for the first, second third and fourth growing periods were 15, 20, 30 and 39t ha^{-1}, respectively, on irrigated small plots. Stems constituted the largest part of the harvested material and amounted, on average, for 67, 87, 83 and 86% of the DM, for the first, second third and fourth growing periods, respectively. The results show increasing yields from the first to the third year. Since from the third year on stable, increasing and decreasing yields were measured no clear conclusion can be drawn on when the maximum yields of giant reed are achieved.

Because high yields were obtained from unimproved wild populations and by using conventional cultivation methods future breeding efforts and optimized production methods will probably lead to an increase in biomass yields from *A. donax*.

The calorific value of different aerial parts, for a number of *A. donax* populations grown in Greece, ranged from 17.3 to 18.8 MJ (stem) and 14.8 to 18.2 kg^{-1} DM (leaves) depending on the population and the growing periods. Leaf samples of plants grown without irrigation had statistically higher calorific value (17.2 MJ kg^{-1} DM) in comparison to the irrigated treatments (16.1 MJ kg^{-1} DM). Because of lower ash contents of the biomass irrigation slightly increased the contents of volatiles in stems, too; they ranged from 75-77 % of DM.

The contents of ash and fixed carbon contents ranged, in dependence of the population and the growing period, from 4.8 to 7.4 % and 17.7 to 19.4 % of DM, respectively. Apart from the physical attributes of stems the high measured values for ash should be attributed to the contribution of sheath as well as of impurities such as sand, which raise the ash content.

At the February harvest the N content in stems ranged from 0.2-0.4% and reached 1 % of DM in the leaves.

Compared to the plants that received 60 kg N ha^{-1}, the highly fertilized plants (120 kg of N ha^{-1}) had significantly higher nitrogen content in stems 94 days after fertilization and in leaves 30 and 60 days after fertilization. The higher nitrogen content in stems and leaves of the highly fertilized plants remained until the end of the growing season, though it was not statistically significant.

The fuel characteristics of Arundo such as calorific value (4119-4489 and 3526-4346kcal/kg odm for stems and leaves, respectively), nitrogen (0.2-0.4 and 1% on odm for stems and leaves, respectively), volatiles (75-77% on odm), ash (4.8-7.4% on odm) and fixed carbon (17.7-19.4% on odm) content of stems can be considered satisfactory for energy production. The rather high ash content found in giant reed samples indicates the probable need for automatic ash removal equipment in combustion systems. Calorific value has been estimated to 18.27 MJ/kg on dry basis, which is considered as quite high.

Giant reed has been investigated in two EU projects: a) FAIR CT86 2028 “Giant reed” and b) ENK CT 2001 00524 “Perennial chains”.

Figure 11. Arundo donax plantations at early stages of growth and at flowering stage (source: CRES).

4.4 Switchgrass (*Panicum virgatum* L.)

Switchgrass (*Panicum virgatum* L.) is a tall rhizomatous high producing warm-season grass native to central and eastern United States well adapted to the region's hot dry summer. Its photosynthesis pathway is C4. Natural habitat of switchgrass occurs from 55^0 north latitude to deep into Mexico. It is also spread in Asia, Africa and South America mainly as a forage crop.

Considering habitat preferences, morphological features, ploidy level, and molecular makers, switchgrass ecotypes are clustered into two types: **"lowland"** and **"upland".**

Lowlands are generally taller, with a faster average growth rate and a more bunch habit than uplands. However, from the emergence to the early jointing growth rate of lowlands is commonly much slower that of uplands. For this reason southern ecotypes moved to north will often fail to mature (seed production and biomass drying). This may reduce winter survival and quality of biomass for energy conservation. In fact biomass may be not dry enough and with high ash content due to the partially translocation of nutrients to the sink organs (rhizomes).

Lowlands are commonly tetraploid with a basic chromosome number of 9, while upland types are octaploid or hexaploid. Because of their elevated crown they could show cold injury problems. Morphological differences between the two ecotypes may be represented above all by larger stems and leaf of lowlands.

Lowland ecotypes may also have a lower nitrogen requirement than upland ones. It is reported that the lowland cultivars produced greater yields (Hulquist et al. 1996) than upland varieties under high and low nitrogen fertilization in well-watered or water stressed conditions. It is reported that the varieties Alamo and Kanlow (lowland varieties usually gave higher dry matter yields compared to upland varieties (Parrish et al. 1997). Lowland types usually maintain higher average leaf photosynthesis rates than upland types under both high and low nitrogen and water conditions. The main effect of the low nitrogen level was to reduce single-leaf photosynthesis. This was more evident in lowland than upland ecotypes.

Usually switchgrass cultivated for forage production (Stritzler et al., 1996) but the last two decades it has become an important crop for energy production through gasification and combustion (Samson and Omelian, 1992; Thurnhollow, 1991). Recently switchgrass is very appreciated for paper pulp and fibre reinforced composite materials (Girouard and Samson, 1998).

Many reasons are given for using switchgrass as a biomass crop for energy and fibre production. The most important reasons summarised below: high net energy production per ha, low production costs, low nutrient requirements low ash content, high water use efficiency, large range of geographic adaptation, ease of establishment by seed and adaptation to marginal soils and potential for carbon storage in soil.

In Europe the research for switchgrass as a biomass crop for energy and fibre has started in 1998 in the framework of a European network (FAIR 5 CT97 3701). In the framework of this work, experimental fields of switchgrass have been established in five European countries, two in the south Europe (Greece and Italy) and three in the north (Germany, Netherlands and UK). Before that, some research work on switchgrass had been conducted in UK and Germany. It is estimated that in Europe some 20 ha of experimental switchgrass fields exist, the 2.5 ha of them have been established and funded in the frame of the switchgrass productivity network and at least 14 ha were established in the view of the project ENK CT2001 0512 “Perennial chains”.

As well as above ground biomass root biomass and storage carbon in the soil can play an important role to the total contribution of switchgrass to the CO_2 balance. Zan et al. (1997) found that switchgrass produced a lower biomass yield than corn but the first had a clearly higher below ground biomass (7.2 Mg ha^{-1} vs. 1.6 Mg ha^{-1} respectively). Ocumpaugh et al. (1997) found that the average soil carbon levels increased from 10 to more than 12 g kg^{-1} after 3 years of switchgrass cover.

A good stand of switchgrass will last for more than 20 years (Mayers and Dickerson, 1984). Usually varieties are propagated by seed and seedling establishment is the most critical stage to reach an early maximum potential yield (Christian and Elbersen, 1998). A recommended seeding rates is between 200 and 800 PLS m^{-2} that amount to about 3 – 10 kg ha^{-1} of seeds (depending on dormancy, seed size etc.).

Row distance may influence switchgrass productivity. In literature a row space of 15-20 cm is usually recommended. Narrow rows will quicken canopy closure thus increasing light interception. However Ocumpaugh et al. (1997) found that 50 cm of row spacing compared to 15 and 30 cm will enhance the dry matter yields in dry conditions. Bransby et al. (1997) pointed out how a row distance of 80 cm (compared to 20 cm) positively affected productivity from the second year on.

Switchgrass will tolerate a soil pH of 4.9 up to 7.6 (Moser and Vogel, 1995). pH values above 6.5 should be preferred (Teel, 1997).

Since weeds are detrimental to switchgrass seedling establishment, nitrogen fertilization or manure during the first year is not recommended. For the following year it has been estimated that 50-100 kg ha^{-1} of N are sufficient for biomass production with a yearly 450-750 mm of precipitation (Turnhollow et al., 1991; Moser and Vogel, 1995).

Switchgrass production seems to be not affected by phosphate fertilisation (Jung et al., 1988 and 1990; Ocumpaugh et al., 1997). During the growing season Ca and Mg content don't change much, while K, P and total ash will decline to a minimum value when maturity is reached. This enhances the quality of biomass for industrial uses (combustion, gasification etc.).

In Europe switchgrass can be harvested from autumn to the early spring before new tillers are visible on soil surface. The thin woody stems of switchgrass allow a good dry down during the autumn-winter period. This may increase the harvest window of switchgrass compared to other perennial crops like arundo or cardoon whose have a ticker stem with a probably slower drying down.

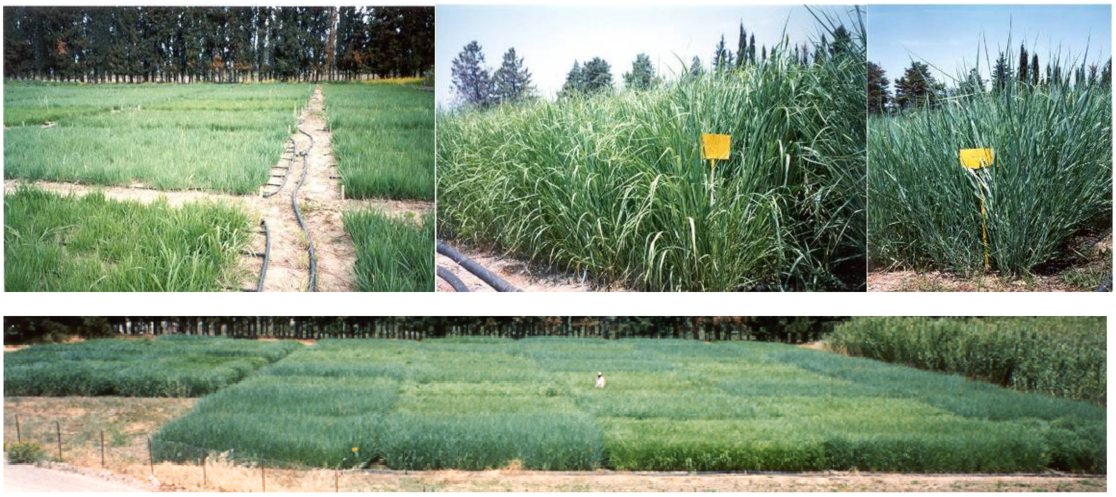

Figure 12. Switchgrass plantations at early stages of growth and at flowering stage (source: CRES).

Harvest could be done with traditional grass harvesting machines (Christian and Elbersen, 1998). Bad harvest and storage operations may strongly reduce the energy conversion quality of switchgrass. For example the contamination with dirt may increase alkali and ash content (McLaughlin et al., 1996). At the harvest the biomass moisture content should be lower than 30%; this allows baling and storing the straw for a short period before burning without the need for drying (Christian and Elbersen, 1998).

The crop was investigated in two European projects: a) FAIR CT97 3701 "Switchgrass for Energy", www.switchgrass.nl and b) ENK CT 2001 00524 "Perennial chains, www.cres.gr/bioenergy_chains.

4.5 Cardoon *(Cynara cardunculus L.)*

The distribution of the genus *Cynara* is mainly Mediterranean. Presently, the only accepted specific name for both artichoke and cardoon is *C. cardunculus* (see Hanelt and IPK, 2001).

The cultivated cardoon and artichoke have originated from the Mediterranean westerly distributed *C. cardunculus* subsp. *flavescens*. Outside the Mediterranean region, there are also some naturalized cultivars -similar to *C. cardunculus* subsp. *flavescens*- in America (California, Mexico, and Argentina) and Australia (Perennial chains project).

The cultivation of the cardoon as a vegetable (blanched petioles and young stems) dates back to the ancient Mediterranean cultures (Greece, Rome, Egypt) and hence, it has been a traditional crop in the Mediterranean region since then. In spite of its old origin and its good flavour the cardoon has never become a widespread crop. For instance Spain, that is one of the countries that most cultivates cardoon, has only 1000 ha (96% irrigated lands) for this crop. Named varieties are difficult to find outside the Mediterranean region. Current catalogs report the following cultivars for the horticultural application of cardoon: *ardo LLeno Blanco, Cardo LLeno de España, Bianco Avorio, Bianco Avorio Gigante, Gigante de Lucca, Gigante Inerme, Gigante de Romagna, Large Smooth, White Improved*. These cultivars have been selected for the horticultural application of the crop. For this application, the crop is grown as a vegetable for only one season (May-December, in Spain). The cultivation of cardoon is usually carried out in irrigated conditions and it requires intensive crop management techniques.

Cardoon, also known as cynara in the field of the energy crops, has been recently proposed as an energy crop and for this application the name 'cynara' is usually preferable. For this new application the species is grown as a crop field in rainfed conditions and the whole aboveground biomass produced by the crop over the full development cycle is used for energy purposes. Although much effort has been made for the past 20 years, the research and development of the crop for this new application is still under way. Screeening of cynara genotypes for biomass production has been performed (see Fernández 1993 & 1998, Piscioneri et al 2000, and Foti et al. 1999). Over 40 different genotypes –wild genotypes, locally cultivated genotypes, mass seed selections- have been experimented for biomass production in the framework of several european projects. The prospects and experiments carried out suggest the good performance of the Spanish seed selection 'ETSIA' and so it is has been recognised by some authors (Gherbin et al. 2001 and Piscionery et al 2000).

Cynara is a perennial herb, often richly branched with tap root. Its stems have a height of 20-180 cm and 17 mm wide.

Fernandez et al. (1998) studied the expression of different characters in a collection of 18 populations of *C. cardunculus* selected for biomass production. The achenes produced were larger, 6.5-8.1 x 2.8-3.5mm, than previously reported by Wiklund. Other characters studied by the authors (unpublished data) showed that cynara may reach heights of up to 3 m and that leaf segment shape is the most variable character; rosulate leaves of those populations exhibit leaf segment of up to 24-36 cm length and 10-19 cm wide. Most populations were spineless, and when any, they were very short and located on the intersection of the leaf segments. The central capitulum of the inflorescence (corymb-like) was generally larger than reported by Wiklund, about 9 x 11 cm average.

Figure 13. Cardoon plantations at early stages of growth and at flowering stage (source: CRES).

Cynara is a perennial herb with a development cycle fully adapted to Mediterranean climate conditions. It is well known that the main characteristics of the Mediterranean climates are the rainfall regime -low annual rainfall irregularly distributed- and the long-lasting dry period -dry and hot summers-; furthermore, in some of these climates the winter is rather cold. In rainfed conditions the unfavourable season for plant growth in Mediterranean climates is the summer, in which the high temperatures coincide with the dry season. The way in which the cynara manages to survive summertime is the drought-escape strategy: cynara has an annual development cycle and completes its reproductive cycle before the dry season begins. Aboveground plant parts dry off in summertime but the underground plant part remains alive. When the climate conditions become more favourable the perennating buds on the underground parts of the plant sprout and a new development cycle starts.

The first growth cycle starts with the seed germination, commonly in early autumn. Firstly two freshly cotyledons emerge and soon after, several leaves grow gradually resulting in a leaf rosette. Plant growth is very dependent on the hardiness of the climate conditions. The leaf rosette usually grows in a rather slowly but steady way. At the rosette stage the plant passes through winter and early spring. By late spring the plant develops a leaf-branched floral scape which eventually bears several heads. After full blossoming the fruits ripen and the aerial biomass dries up. A new plant growth cycle starts with the growth of several sprouts from the perennating buds on the underground plant organs. The main phenological stages of the development cycle are: emergence/sprouting, rosette, stem (floral scape) elongation, blossom and ripeness.

As a perennial herb the shape of the plant changes as the development cycle advances. Leaf morphology depends on the position of the leaf. Leaves arising from the rosette are much larger than the leaves arising from the floral scape. Besides, the scape leaves are usually decurrent and tend to have less leaf segments.

Cynara will germinate whenever the soil moisture and temperature are favorable. Hence, the sowing time can be autumn or spring in the Mediterranean climates. If an autumn sowing is wanted, it should be done as soon as the sowing conditions allow it so that the plant can develop a leaf rosette large and strong enough to pass wintertime. At the end of this first cycle of growth the biomass production is usually low but in the next cycles the crop yield usually increases, depending mainly on the climate conditions. In case of a cold autumn (early frosts) the spring sowing is recommended. It is advisable to accomplish the spring sowing as soon as period of frosts is over. In most cases, plants will reach summertime at the rosette stage; some leaves can be dried up as a result of the drought and the high temperatures. When the climate conditions are more favorable for the plant growth, the plant resumes their vegetative growth and the size of the leaf rosette increases. Plants complete the development cycle in the next summer; soon after the cycle is completed, the first harvest can be carried out.

Studies conducted within the framework of R&D European projects showed that the biomass production of cynara ranges between 10 and 20 t dm ha^{-1} year^{-1} if the crop is well established and rainfall is about 500 mm year^{-1} (Fernández, 1993 & 1998). In some cases, productions of over 30 t dm ha^{-1} year^{-1} have also been reported (Dalianis et al., 1996 and Foti et al., 1999). However, the irregular distribution of the rainfall that characterizes the Mediterranean climates is a limiting factor. As it usually happens for any other crop grown in rainfed conditions, the aerial biomass production of the cynara is strictly dependent on the water regime of the productive season. In a ten-year experiment carried out in central Spain in rainfed conditions, the biomass yield ranged between 3.4 t dm ha^{-1} year^{-1} (280 mm rainfall) and 25.2 t dm ha^{-1} year^{-1} (765 mm rainfall), and the 10-year mean, 14 t dm ha^{-1} year^{-1}(470 mm rainfall) (Fernández et al. 2000). The effect of the water regime is also noticed in the partitioning of the yield components. As an average, the aerial biomass (dry matter) is 92% lignocellulosic-type and 8% seeds (sensu stricto, achenes).

The potential of the cynara as an energy crop mainly lies in its application as solid biofuel. The main characteristics of the crop that suggest this application are: (i) relatively low crop inputs (Gominho et al 2000), (ii) large biomass productivity: about 14-20 t dm ha^{-1} year^{-1} depending on the climate conditions, (iii) low moisture content (14%) of the biomass at harvest: 14-50%, it varies with the particular conditions of harvesting, (iv) biomass composition mainly lignocellulosic: values depends on the biomass partitioning into the different plant organs; the ranges of variation are approximately,16-27% hemicellulose, 24-60% cellulose and 3-13% lignin (Gominho et al 2000) and (v) high higher heating value: about 15 MJ kg^{-1} at equilibrium moisture. The potential of cynara as solid biofuel has been studied for several years (EU Projects) and pilot-scale experiments are under way (Dahl, Graz-Austria).

The main characteristics of the crop that suggest this application are: (i) seed productivity of cynara: about 1100 kg ha^{-1} $year^{-1}$ as average (Fernández, 2002) (ii) seed oil content: 25% as average; 33% oil was the maximum figure reported by Curt et al (2002) (iii)oil composition similar to sunflower: 11% palmitic, 4% stearic, 25% oleic, 60% linoleic, as main fatty acids of the cynara oil and (iv) higher heating value: 22 MJ kg^{-1} at equilibrium moisture.

The oil from cynara seeds can be easily expelled by cool pressing (20/25 ºC) so that its composition does not be modified and is useful for food applications. Furthermore, another possible aplication of the oil is the production of biodiesel. Biodiesel production from cynara oil has been presented by several authors (Encinar et al. 1999 & 2002). The most significant characteristics of the cynara oil for its application as biofuel are its high cetane number (≈51) and the low freezing point (≈-21ºC).

Cardoon has been investigated in European level in the following projects: AIR CT92 1089 (Cynara carduculus L. as a new crop for marginal and set-aside lands), ENK CT2001 00524 (Perennial chains) and recently in the BIOCARD project (just completed).

5. Sugar Crops for bioethanol

Bioethanol is the ethanol that produced from biomass, while synthetic ethanol produced from fossil feedstocks. The production volume of synthetic ethanol is small compared to the amount of bioethanol produced. Generally the term bioethanol is applied specifically for ethanol used as (a component in) transportation fuel.

In 2005, the total worldwide production of bioethanol, for fuel and non-fuel applications was 46 billion litres. In South America produced 38%, in North-Central America 38%, in Asia 14%, in Europe 9% and in Africa 1%. In EU the production of fuel ethanol will expand substantially in the coming years due to the European Commission policies. Various EU countries will either expand existing production capacity (Spain, France, and Sweden) or implement new production facilities (e.g. UK, Germany, The Netherlands, Belgium Poland).

Bioethanol is the most produced biofuel worldwide with over 65 billion litres in 2008 (Biofuels Platform). This figure is mainly due to the United States (52%) and Brazil (37%). In USA the bioethanol production in 2008 estimated to be over 34 billion mostly from corn. In Brazil was estimated to be 24.5 obtained mainly from sugarcane. With a production of 28.16 billion l in 2008 EU ranks third behind the two majors. The bioethanol production was increased 56% in 2008 compared to 2007. In 2008 France is the leader bioethanol producer in EU27, followed by Germany and Spain.

Bioethanol is currently mostly used in transportation fuels blended with petrol in various percentages (B5, B10, B85), or as a component for production of the oxygenate ETBE, which is synthesized from bioethanol and isobutylene, a refinery by product.

In Brazil, sugar and bioethanol is produced from sugar cane, a crop with high yields, but only suitable for the tropical climate. Sugar beets are more versatile sugar crops, because they can tolerate a wide range of soil and climatic conditions and consequently that can be produced in most European countries. Sugar beets are used for ethanol production only in Europe. The sucrose content of the sugar beets is typically 15-20% wt% of the dry weight. In the United States and Europe bioethanol is mostly produced from starch crops. In the US this is mainly corn (maize). In Europe wheat, rye, barley and potatoes are the most widely used starch source. Wheat, rye and barley grains typically contain 60-70% wt%, 15%wt water.

For the production of the “conventional” bioethanol the bioethanol costs is strongly dependent on the feedstock costs, which make up to 50-70% of the overall costs. Thus, for a large plant with a capacity of ca 240.000 m3 bioethanol/year the production cost for sugar based processes are estimated at 0.50-0.5 euro/l, for grain based process 0.50-0.60 euro/l, 0.85-0.90 euro/l for potato based process and 0.45-0.55 euro/l for processes using residual starch streams.

In Europe the main crops for the production of bioethanol are starch crops (such as common wheat) and sugar beet. Sugar beet crops are grown in most of the EU-25 countries, and yield substantially more ethanol per hectare than wheat.

Table 8. Evolution of fuel bioethanol production in the EU (2002-8)

Country	2002	2003	2004	2005	2006	2007	2008
France	114	103	101	144	293	539	950
Germany	0	0	25	165	431	394	581
Spain	222	201	254	303	402	348	346
Poland	83	76	48	64	120	155	200
Hungary	0	0	0	35	34	30	150
Slovalia	0	0	0	0	0	30	94
Austria	0	0	0	0	0	15	89
Sweden	63	65	71	153	140	120	78
Czech Republic	6	0	0	0	15	33	76
United Kingdom	0	0	0	0	0	20	75
Others	0	0	29	49	173	119	216
UEU27	488	446	528	913	1608	1803	2855

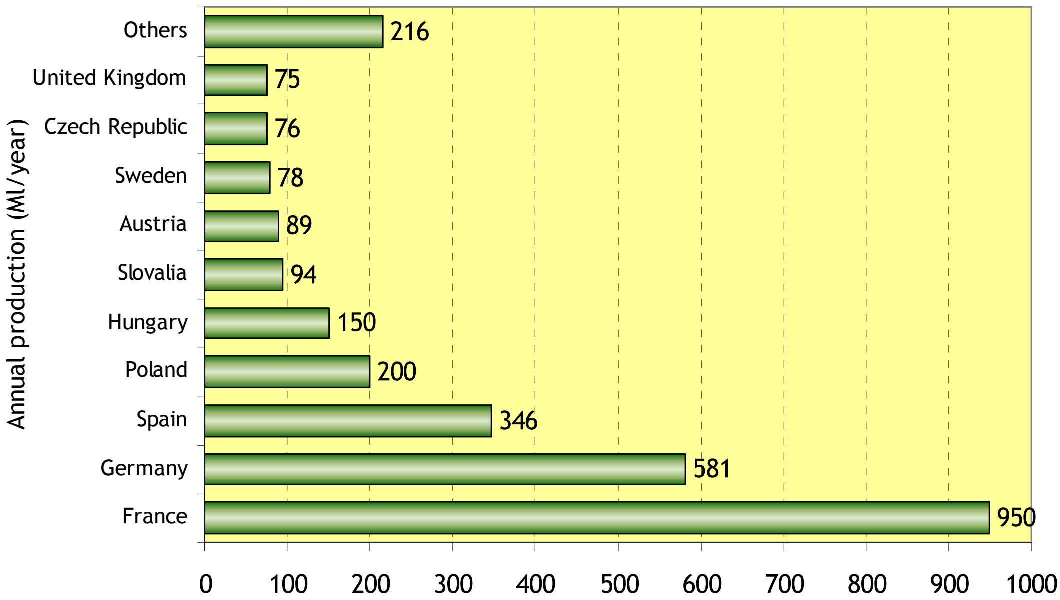

Figure 14. Annual production of bioethanol (Ml/year) in 2008

5.1 Sweet sorghum

Sorghum is an annual spring crop suitable for environments where sugar cane and maize cannot be grown successfully. Sorghum is native of central-eastern Africa and belongs to the family Graminaneae. Sorghum is grown due to its tropical origin it is mainly cultivated in the semi-arid areas of the tropics and subtropics but adapted to other climates.

It is a C4 plant characterized by a high photosynthetic efficiency. It is a high biomass yield crop and compared to other species, has one of the highest dry matter accumulation rates on a daily basis. In terms of water requirements Sorghum shows an ET coefficient lower than maize, and its resistance to water stress can be accompanied by a quite good resistance to high humidity conditions. The crop shows a good adaptability to many types of soil, sandy or clay, even with low pH and is resistant to saline soils.

In Sorghum bicolour two important types have been selected: a) the “sorgos” characterised by sweet stalks and used as source syrup or forage and b) the fibre Sorghum characterised by particular length of the fibre in the stalks which could assure high resistance to lodging.

According to Gosse (1996) sweet sorghum out of many “new crops” that are being investigated as potential raw materials for energy and industry seems to be the most promising one.

Sweet sorghum is a potential energy crop for Europe for three main reasons: a) it is already a high yielding biomass crop, up to 40 tn/ha dry matter, under certain EU environmental conditions and management practices, b) it has relatively low production inputs since it is an arable mechanised crop, with low nitrogen requirements, c) if sweet sorghum is directed towards ethanol production it has a high output/input ratio, since during the conversion phase a large amount of bagasse is left, sufficient enough to cover all the energy needs from production to distillation.

The genus Sorghum is characterised by a vastly diverse germ plasm in terms of phenotypic and morphological traits. Many of these have been exploited to give genotypes suitable for grain and forage production, as well as, alternative uses, such as energy, pulp for paper, food products, high grade chemicals and building products (Duncan et al. 1991).

Much of the research work related to non-food agricultural production of sorghum has been conducted on sweet sorghum because of the increased interest in sugar crops as potential renewable resources that can be converted into ethanol. It has a shorter growing season than sugarcane, and is therefore suitable to be grown in geographical areas with a temperate climate. It has a rapid rate of growth. In several studies, sweet types have been evaluated for fermentable sugar production and theoretical ethanol yields (Copani et al. 1989).

Sweet sorghum is highly productive crop in terms of biomass; it is a high drought and water logging resistance and salinity tolerance. For these reasons it is considered as the “camel” (Li, 1997). In the Mediterranean regions, previous studies on sweet sorghum have been conducted to assess its potential productivity and water requirement under non-limiting conditions (Mastrorilli et al. 1995, 1996). However, since water resources in the Mediterranean region are limited, the success of sweet sorghum in this area depends upon the optimisation of water supplied by irrigation.

Sorghum can have two energy destinations: the production of electricity or heat through direct combustion of biomass or indirect by from gas and oils derived from it, and, for the sweet types with a high yield of fermentable carbohydrates, the production of ethanol (Gosse, 1996). In the latter case, the use of the by-products (bagasse) would lead to an increase in the energy efficiency of the production chain.

Sweet sorghum has been investigated in several EU projects. The most important projects are: AIR CT92 0041 (completed), FAIR CT96 1913 (completed) and FP7 227422 – Sweetfuel (on going, www.sweetfuel-project.eu).

In the project FAIR CT96 1913 sweet sorghum was cultivated in Italy, France, Spain, Portugal and Greece in order to qualify the potential yield of this crop in different European conditions. It was found that in all these sites the biomass yields could be higher than 20 t/ha with maximum yields around 40 t/ha in South Italy and Greece. In the same project the water balance was examined and it was found that by reducing irrigation volume by about 40% the final yield decreased by about 30%. In comparison with a crop well-watered during the whole cycle (31.6 t/ha above ground dry biomass), sweet sorghum biomass production was reduced (36% less).

According to Cosentino et al (1997) in Sicily sweet sorghum is able to sustain extremely high yields. It was found in experimental fields that in well watered conditions (656 to 868 mm) dry matter yields from 30.3 to 45 t/ha can be produced.

Figure 15. Sweet sorghum fields at several stages of growth (source: CRES)

It is reported that in Greece c.v. Keller has produced fresh biomass yields ranging from 114.9 t/ha to 141 t/ha and dry matter yields from 30.4 t/ha to 45 t/ha, depending on the site, variety and the cultivation techniques. Moreover, it is reported that cv. Keller when grown in the pedoclimatic conditions of northern Greece (Komotini) produced fresh biomass yields varied from 114.9 to 119.6 t/ha with corresponding dry matter yields from 30.42 to 39.04 t/ha.

5.2 Sugar beet

Sugar beet (Beta vulgaris L.) belongs to Chemopodiaceae subfamily (family Amarantaceae. It is cultivated for its root that contains high concentration of sucrose. It is a biennial crop that can be cultivated successfully to a wide range of climates. In Europe it is planted in the spring and harvested in autumn. One kilo of seeds is enough for the establishment of 1 ha field.
From 100 kg fresh sugar beet can produced 12-15 kg sucrose and 3.5 kg molasses and 4.5 kg dried pulp.

Table 9 - Area harvested (ha), yields (kg/ha), production quantity (tones) and seed yields (tn) in the EU-27 countries for sugar beets.

Country	Area harvested (ha)	Yields (kg/ha)	Production quantity (tones)
Austria	42270	628392	2656214
Belgium	82701	692917	5730500
Bulgaria	1284	126799	16281
Croatia	34316	461186	1582606
Czech Republic	54271	532489	2889871
Denmark	39400	572411	2255300
Estonia	0	0	0
Finland	16000	420687	673100
France	393500	844033	33212700
Germany	402697	624269	25139137
Greece	15800	539212	851956
Hungary	41200	410873	1692800
Ireland	0	0	0
Italy	85600	540876	4629900
Latvia	300	360000	10800
Lithuania	16900	473313	799900
Luxembourg	0	0	5511500
Netherlands	82100	671315	12681555
Poland	247432	512526	320000
Portugal	4300	744186	748839
Romania	28443	263277	748839
Slovakia	18857	448904	846500
Slovenia	7000	371428	260000
Spain	73900	719201	5314900
Sweden	40786	514882	2100000
United Kingdom	122000	532786	6500000
EU-27	1851057	**521998**	**117173198**

The main sugar beets producers are: EU, United States and Russia. In the following table details about the harvested area and yields for sugar beets are presented for all the countries in EU-27 (FAOSTAT, 2007). In EU27 the total harvested area in 2007 was 1.851 million ha and the top four producers countries by descending order were Germany 0.403 million ha, France 0.394 million ha, Poland 0.247 million ha and UK 0.122 million ha.

References

Alonso, L.C., Fernández-Serrano, O. and Fernández-Escobar, J. 1991. “The outset of a new oilseed crop: *Brassica carinata* with a low erucic acid content.” In: McGregor, D.I. (ed.) Preceeding of the Eighth International Rapeseed Congress, Saskatoon, Canada. Organizing Committee, Saskatoon, pp. 170-176.

Anthony, K.R.M., Meadley, J. and Robbelen, G. 1993. New crops for temperate regions, Chapman and Hall, London.

Bijl G.van der. 1996. Sustainability of production and use of biomass for European energy supply. In *Biomass for Energy and the Environment*, Proceedings of the 9th European Bioenergy Conference, Copenhagen, Denmark, June 1996. Pergamon/Elsevier Publishers, 1 : pp 387-92.

Biofuel Technology handbook, 2007, WIP.

Boose AB, Holt JS. 1999. Environmental effects on asexual reproduction in *Arundo donax*. Weed Research. 39: 117-127.

Bransby, D. I., McLaughlin, S. B. and D. J. Parrish. 1997. A review of carbon and nitrogen balances in switchgrass grown for energy. In Biomass and Bioenergy 14: 379-384.

Brown, G. 2000. Global forest products outlook study: the future supply of wood from plantations. Rome: FAO; 2000.

Christersson, L. 1986. High technology biomass by Salix clones on a sandy soil in southern Sweden. Tree Physiology 1986; 2: 261-272.

Christian, D. C. and H. W. Elbersen.. Switchgrass (*Panicum virgatum* L.). In: N. El Bassam. Energy plant species. Their use and impact on environment and development. London: James and James publishers, 1998, p. 257-263.

Christou M, Mardikis M, Alexopoulou E. 2001. Research on the effect of irrigation and nitrogen upon growth and yields of *Arundo donax* L. in Greece. Aspects of Applied Biology 65, Biomass and energy crops. p 47-55.

Clisholm C. J. 1994. Reed canary grass. In Towards a UK Research Strategy for Alternative Crops. Silsoe Research Institute.

Dalianis C, Panoutsou C, Dercas N. (1996). Spanish thistle artichoke *Cynara cardunculus* L., under Greek conditions. In: Chartier P, Ferrero GL, Henius UM, Hultberg S, Sachau J, Wiinblad M (Eds). *Proceedings* of the 9th European Bioenergy Conference, Biomass for Energy and the Environment. Oxford: Pergamon, p. 663- 668.

DIEF. 2000. Ministry Agriculture. Informacao estatistica. 3rd revisao. Lisbon: Inventario Florestal.

Duke, J. A. 1983. Handbook of Energy Crops (http://www.hort.purde.edu)

Encinar JM, González JF, Rodriguez JJ, Tejedor A. (2002). Biodiesel fuels from vegetable oils: Transesterification of *Cynara cardunculus* L. oils with ethanol. *Energy and Fuels* 16 (2):443-450.

Encinar JM, González JF, Sabio E, Ramiro MJ.(1999). Preparation and properties of biodiesel from *Cynara cardunculus* L. oil. *Industrial and Engineering Chemistry Research* 38 (8):2927-2931.

Ericsson, K., Rosenqvist, H., Ganko, E., Pisarek, M. and L. Nilsson. 2006. An agro-economic analysis of willow cultivation in Poland. Biomass and Bioenergy 30: 16-27.

Fereres, E., Fernandez, J., Minguez, I. and J. Dominguez. 1983. Productivity of Brassica juncea and Brassica carinata in relation to rapeseed. In Proc. 6th Int. Rapeseed Con. Paris. pp 293-298.

Fernández J. 1993. Production and utilization of *Cynara cardunculus* L. biomass for energy, paper-pulp and food industry. Final Report JOUB 0030-ECCE, Commission of the European Communities, Brussels, 92 pp.

Fernandez, J. (1998).- Cardoon. En "Energy plant species" N. El Bassam (edit.) pp 113-117. James & James Sci pub. Ltd. London.

Fernandez, J. Hidalgo, M., Monte, J.P., Curt, M.D. (2000).- *Cynara cardunculus* L. as a perennial crop for non irrigated lands: yields and applications. *Int. Congress* on Artichoke. Valenzano (Bari, Italy) 17-21/10/2000.

Fernandez-Martinez J. M., Del Rio M., Velasco M., Dominguez M. and A. De Haro. 2001. Registration of zero erucic acid Ethiopean mustard genetic stock 25X-1. Crop Sci. 41: 282.

Final carinata report (http://www.biomatnet.org/secure/Fair/R1946.htm)

Foti S, Mauromicale G, Raccuia SA, Fallico B, Fanella F, Maccarone E. (1999). Possible alternative utilization of *Cynara* spp. I. Biomass, grain yield and chemical composition of grain. *Industrial Crops and Products* 10:219-228.

Gasol C. M., Gabarrell X., Anton A., Rigola M., Carrasco J., Ciria P., Solano M. L. and J. Rieradevall. 2007. Life cycle assessment of a Brassica carinata bioenergy cropping system in southern Europe. In Biomass and Bioenergy 31: 543-555.

Getinet A. 1987. “Review on breeding of Ethiopian Mustard (Brassica carinata A. Braun).” Proc. 7th Int. Raps. Congr., Poznan 11-14 May 1987, p. 593-597.

Getinet A., Rakow, G, Raney, J. P., and R. K. Downey. 1994. Development of zero erucic-acid Ethiopean mustard through an interspecific cross with zero erucic-acid Oriental mustard. Can. J. Plant Sci. 74: 793-795.

Girouard, P. and R. A. Samson. 1998. The potential role of perennial grasses in the pulp and paper industry. In: Proceedings of the 84th Annual Meeting of the Technical Section of the Canadian Pulp and Pulp Association, January 1998, Montreal, Canada, pp. 125-133.

Gominho J, Fernández J, Pereira H. *Cynara cardunculus* L. (2000). A new fiber crop for pulp and paper production. Industrial Crops and Products 13:1-10.

Gouveia L., Melo, A., Medeiros R., Marques, A., Oliveira, A.C. and F. Rosa. 2008. Microalgae: a new alternative raw material for biodiesel production. In Proceendings of the “Bioenergy: Challenges and Opportunities” (Guimaraes, Portugal, 6-9/4/08), pages: 73-77.

Hanelt P., Institute of Plant Genetics and Crop Plant Research (IPK Gatersleben) (Eds.) 2001. Mansfeld’s Encyclopedia of Agricultural and Horticultural Crops. Springer-Verlag. 1-6, 3716 pp.

Hidalgo M, Fernandez J. Biomass production of ten populations of giant reed (*Arundo donax* L.) under the environmental conditions of Madrid (Spain). 2001. In: Kyritsis S, Beenackers AACM, Helm P, Grassi A, Chiaramonti D, editors. Biomass for Energy and Industry: Proceeding of the 1st World Conference, Sevilla, Spain, 5-9 June 2000. London: James & James (Science Publishers) Ltd, p .1881-1884.

http://www.ienica.net (plant database)

http://www.probiodiesel.com (reports, deliverables)

http://www.oncultivos.es

http://www.Encrop.net (Energy from field energy crops – a handbook for energy producers)

http://www.energypoplar.eu

Huisman W. 1998. *Harvesting and Handling of PRG Crops*. In : I. Lewandowski, Editor, Production and use of perennial rhizomateous grasses (PRG) in the energy and industrial sector of Europe, Intitut fur Pflanzenbau und Grunland, Stuttgart, pp.42-47.

Hultquist, S.J., K.P. Vogel, D.J. Lee, K. Arumuganathan and S. Kaeppler. Chloroplast DNA and nuclear DNA content variations among cultivars of switchgrass, Panicum virgatum L. Crop Sci. 1996, 36: 1049-1052.

IENICA: "Agronomy Guide, Generic guidelines on the agronomy of selected industrial crops", August 2004. & www.ienica.net.

Imbert, E., Lefevre, F. 2003. Dispersal and gene flow of Populus nigra (Salicaceae) along a dynamic river system. Journal of Ecology 2003; 91 (3): 447-56.

Izquierdo, N., Aguirrezabal, L. 2008. Genetic variability of the response of fatty acid composition to temperature. Field Crops Research 106: 116-125.

Izquierdo, N., Aguirrezabal, L., Andrate F., Pereyra, V. 2002. Night temperaturas affects fatty acid composition in sunflower oil depending on the hybrid and the phenological stage. Field Crops Research 77: 115-126.

Jodl S., Eppel-Hotz A., Marzini K. – 1998 – Examination of the ecological value of M*iscanthus* expanses – faunistic studies. Pp. 778-779. In *Biomass for Energy and Industry*, Proceedings of the 10th European Biomass Conference, Würzburg, Germany, June 1998. C.A.R.M.E.N. Publishers, Rimpar, Germany.

Jones M.B. and Walsh M. 2001. *Miscanthus* for energy and fibre, James & James, 192 pp.

Jonson, D. L. and R. L. Croissant. Rapeseed/canola production. http://www.ext.colostate.edu.pubs/CROPS/00110.html.

Jung, G. A., J. A. Shaffer, W. L., Stout, and M. T. Panciera. Warm-season grass diversity in yield, plant morphology, and nitrogen concentration and removal in Northeastern USA. Agro. J., 1990, 82, 21-26.

Kahle P., Beuch S., Boelcke B., Leinweber P., Schulten HR.- 2001 – Cropping of *Miscanthus* in Central Europe : biomass production and influence on nutrients and soil organic matter – *European Journal of Agronomy* - Elsevier Sciences BV, Amsterdam.

Kaltschmitt M., Reinhardt G.A. and Stelzer T. – 1996 – LCA of biofuels under different environmental aspects. In *Biomass for Energy and the Environment*, Proceedings of the 9th European Bioenergy Conference, Copenhagen, Denmark, June 1996. Pergamon/Elsevier Publishers, 1: pp 369-86.

Karacic, A., Verwijst, T., Weih, M. 2003. Above ground woody biomass production of short-rotation populus plantations on agricultural land in Sweden. Scandinavian Journal of Forest Research 18: 427-437.

Konwles. P. F. et al, 1981. In: "New Sources of Fats and Oils." Ed. E. H. Pryde, L. H. Prince and K. D. Mukherjee.

Kumar, A., Singh, P., Singh, D.P., Singh, H. and Sharma, H.C. 1984. "Differences in osmoregulation in *Brassica* species." *Annals of Botany* 54, 537-541.

Lemenih, M. and T. Bekele. 2004. Effect of age on calorific value and some mechanical properties of three Eucalyptus species grown in Ethiopia. Biomass and Bioenergy 27: 223-232.

Lewandowski I., Heinz A. - 2003 - Delayed harvest of *Miscanthus* – influences on biomass quantity and quality and environmental impacts of energy production- *European Journal of Agronomy* - Elsevier Sciences BV, Amsterdam.

Lewandowski I., Kicherer A., and Vonier P. – 1995- CO2-balance for the cultivation and combustion of *Miscanthus*. Biomass and Bioenergy, 8 : pp 81-90

Lewandowski I., Scurlock J.M.O., Lindvall E., Christou M. – 2003- The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe. In Biomass and Bioenergy. In press (available online at www.sciencedirect.com)

Lickfett, T., Matthaus, B., Velasco, L. and C. Mossers. 1999. Seed yield, oil and phytate concentration in the seeds of two oilseed rape cultivars as affected by different phosphorus supply. In European Journal for Agronomy 11: 293-299.

McCarthy S. and Walsh M. - 1996 - *Miscanthus* Productivity Network : AIR- CT- 92-0294 final report – Hyperion :Cork.

Mittelbach M, and C. Remschmidt.2004. Biodiesel, the Comprehensive Handbook. Boersendruck Ges.m.b.H.; Vienna, Austria; 332p.

Morgana B, Sardo V. 1995. Giant reeds and C4 grasses as a source of biomass. In: Chartier P, Beenackers AACM, Grassi G, editors. Biomass for energy, environment, agriculture and industry: Proceedings of the 8th European Biomass Conference, Vienna, Austria, 3-5 October 1994. Oxford: Pergamon, p. 700-706.

Moser, L.E. and K.P.Vogel. Switchgrass, Big Bluestem, and Indiangrass. *In:* An introduction to grassland agriculture. R. F. Barnes, D. A. Miller and C. J. Nelson (eds.). Forages, 5th ed. Vol.1, Ames, IA: Iowa University Press, 1995, pp. 409-420.

Nieneynowicz, J., Linderson, M-L, Olsson, J., Barring L. 1993. Regn i Skane – Karakterisering av nederborden i Skane baserad pa 234 dygnsmatare. Report no 3163, Department of Water Resources Engineering, Lund Institute of Technology, University of Lund, Sweden.

Pantley, D. 1995. Forest plantation areas 1995-report of FAO project GGP/INT/628/UK. Rome: FAO.

Pari L. 1996. First trials on *Arundo donax* and miscanthus rhizomes harvesting. In: Chartier P., Ferrero G.L., Henius UM, Hultberg S, Sachau J, Wiinblad M, Chartier P, editors. Biomass for energy and the environment: Proceedings of the 9th European Bioenergy Conference, Copenhagen, Denmark, 24-27 June 1996. New York: Pergamon , p. 889-894.

Parrish, D. J., Wolf, D. D., and W. L. Daniels. Switchgrass as a biofuels crop for the upper Southeast: Variety trials and cultural improvement. Five year report. Oak Ridge National Laboratory, Oak Ridge, TN. 1997. Contract # 19X-SK098C.

Perdue RE. 1958. *Arundo donax* - Source of musical reeds and industrial cellulose. Economic Botany, 12: 368-404.

Pereira, H. 1992. The raw material quality of Eucalyptus globulus. In “Eucalyptus for biomass production”. Eds. Pereira and Pereira. Commission of the European Communities.

Piscioneri H, Sharma N, Baviello G, Orlandini S. (2000). Promising industrial energy crop, *Cynara cardunculus*: a potential source for biomass production and alternative energy. *Energy Conversion and Management* 41:1091-1105.

Prakash S., et al., 1984. “Cruciferae Newsletter”: 36.

Pulford, I. D., Riddell-Black D., Steward, C. 2002. Heavy metal uptake by willow clones from sewage sludge-treated soil: the potential for phytoremendiation. International Journal of Phytoremendiation 4: 59-725.

Rockwood, D. Rudie, A. W., Ralph, S. A., Zhu, J. Y. and J. E. Winandy. 2008. Energy production options for Eucalyptus species grown as short rotation woody crops. Int. J. Mol. Sci. 9: 1361-1378.

Rossa B, Tuffers AV, Naidoo G, von Willert DJ. 1998. *Arundo donax* L. (Poaceae) - a C3 species with unusually high photosynthetic capacity. Botanica Acta, 111, 216-221.

Samson R. A. and J. A. Omielan. Switchgrass: A potential biomass energy crop for ethanol production. In: The Thirteenth North American Prairie conference, Windsor, Ontario, 1992, p. 253-258.

Saporito, L. 2001. Perspective energy utilization for eucalypt biomass in Sicily, vol. 69. Sherwood; 2001. p. 1-6.

Scarth, R. and McVetty PBE. 1999. Designer oil canola. A review of food-grade Brassica oils with focus on high oleic, low linoleic types. In: Wratten N, Salisbury PA (eds.) Proc. 10th Int. Rapeseed Congress, 26-29 Sept 1999, Canberra, Australia, GCIRC, CD ROM.

Schwarz H. and Liebhard P. – 1995- Fertilization effects on production of *Miscanthus sinensis giganteus*. In Chartier Ph., Beenackers, A.A.C.M and Grassi G (eds) *Biomass for*

Energy, Environment, Agriculture and Industry – Proccedings of 8th E.C. Conference. 3-5 Octobre, 1994, Vienna, Austria Elsevier Science Ltd., Oxford, 1 : pp 523-9.

Schwarz K.U., Kjeldsen J.B., Munzer W., Junge R. – 1998- Low cost establishment and winter survival of *Miscanthus x giganteus*. Pp. 947-950. In *Biomass for Energy and Industry*, Proceedings of the 10th European Biomass Conference, Würzburg, Germany, June 1998. C.A.R.M.E.N. Publishers, Rimpar, Germany.

Scurlock J.M.O. – 1998 – Miscanthus : a review of European experience with a novel energy crop. ORNL/TM – 13732. Oak Ridge National Laboratory, Oak Ridge, Tennessee, 26 pp.

Sharma KP, Kushwaha SPS, Gopal B. 1998. A comparative study of stand structure and standing crops of two wetland species, *Arundo donax* and *Phragmites karka*, and primary production in *Arundo donax* with observations on the effect of clipping. Tropical Ecology 39(1), 39.

Shatalov AA, Pereira H. 2001. *Arundo donax* L. (giant reed) as a source of fibres for paper industry: Perspectives for modern ecologically friendly pulping technologies. In: Kyritsis S, Beenackers AACM, Helm P, Grassi A, Chiaramonti D, editors. Biomass for Energy and Industry: Proceeding of the 1st World Conference, Sevilla, Spain, 5-9 June 2000. London: James & James (Science Publishers) Ltd, p. 1183-1186.

Singh, C., Kumar, V. and Pacholi, R.K. 1997. Growth performance3 of *Arundo donax* (reed grass) under difficult site conditions of Doon valley for erosion control. Indian Forester, 73-76.

Stolarski, M., Szczukowski, S., Tworkowski and A. Klasa. 2008. Productivity od seven clones of willow coppice in annual and quatrennial cutting cycles. Biomass and Bioenergy 32: 1227-1234.

Stritzlet, N. P., Pagella, J. H., Jouve, V. V. and C. M. Ferri. 1996. Semi-arid warm-season grass yield and nutritive value in Argentina. Journal of Range Management 49:121-125.

Teel, A. 1998. Management guide for the production of switchgrass for biomass fuel production in southern Iowa. In Proc. BIOENERGY98 on Expanding Bioenergy Partnerships, October 4-8 1998, Madison, WI, pp. 1054-1057.

Turnhollow, A. F. 1991. Screening herbaceous Lignocellulosic energy crops in temperate regions of the USA. Bioresource Technology 36, 247-252.

Tucker GC. 1990. The genera of Arundinoideae (Graminae) in the southeastern United States. Journal of the Arnold Arboretum, 71(2), 145-177.

UFOP. 2007. Sustainable winter oilseed rape. (www.ufop.de).

UFOP. 2009. Biodiesel & Co. The situation and future challenges of the biodiesel sector in Germany and in the European Union 2009/2010 – the implementation of the ordinance for sustainable biofuels (www.ufop.de)

Vecchiet M, Jodice R, Pari L, Schenone G. 1996. Techniques and costs in the production of Giant reed (*Arundo donax* L.) rhizomes. In: Chartier P., Ferrero G.L., Henius UM, Hultberg S, Sachau J, Wiinblad M, Chartier P, editors. Biomass for energy and the environment: Proceedings of the 9th European Bioenergy Conference, Copenhagen, Denmark, 24-27 June 1996. New York: Pergamon, 654-659.

Veselack MS, Nisbet JJ. 1981. The distribution and uses of *Arundo donax*. Proc. Indiana Acad. Sci., 90-92.

Walle, I. V., Camp, N. V., Van de Casteele, L., Verheyen, K. and R. Lemeur. 2007. Short rotation forestry of birch, maple, poplar and willow in Flanders (Belgium) II. Energy Production and CO_2 emission reduction potential. Biomass and Bioenergy 31: 276-283.

Walsh M. - 1997 - *Miscanthus* handbook. EU project FAIR 3-CT96-1707. Hyperion: Cork.

Weih, M. 2004. Intensive short rotation forestry in boreal climates: present and future perspectives. Canadian Journal of Forest Research 34: 369-378.

WIP, 2007. Biofuel Technology Handbook *(www.marketplace.com)*

WWI (WORLDWATCH INSTITUTE), 2006. Biofuels for Transportation, Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century – Submitted report prepared for BMELV in cooperation with GTZ and FNR; 398p.

Zan, C., Fyles, J., Girouard, P., Samson, R., Doan, M.1997. Carbon storage in switchgrass and short rotation willow plantations. In: Overend RP, Chornet, E., editors. Making a business from biomass in energy, environment, chemicals, fibres and materials. Vol. 1 Oxford, UK: Elsevier. 355-361 pp.

Gosse, G. 1996. Overview of different filieres for industrial utilization of sorghum. Proc. First Seminar on sorghum for energy and industry. Toulouse, 1-3 April 1996, pp. 10-15.

Duncan R. R., Bramel-Cox P. J., and F. R. Miller. 1991. Contributions of introducing Sorghum germoplasm to hybrid development in the USA. Use of Plant Introductions in Cultivar Development. Part I, Crop Science Society of America: 69-102.

Li, D. 1997. Development sweet sorghum to accept the challenges problems on food energy and environment in 21st century. In Li, D. (eds). Proc. First Int. Sweet Sorghum Conf., Institute of Botany, Chinese Academy of Sciences, Beijing, 100093, China, 19-34.

Mastrorilli, M, Katerji, N. and G. Rana. 1995. Water efficiency and stress on grain sorghum at different reproductive stages. Agric. Water Manag. 28, 23-34.

Mastrorilli, M, Katerji, N. and G. Rana. 1996. Evaluation of the risk derived from introducing sweet sorghum in Mediterranean zone. In: First European Seminar on Energy and Industry, INRA, 323-328.

Cosentino, S. L., Riggi, E., and M. Mantineo. 1997. Sweet sorghum (Sorghum bicolor L. Moench) performance in relation to water deficit in the South of Italy. Proc. Of first international sweet sorghum conference. Li Dajue Ed., 430-442.