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SP2 – STUDIES ON BIOMASS FEEDSTOCK AND OPTIMISATION FOR THE SELECTED VALUE CHAIN
WP2.2 – BIOMASS SUPPLY CHAINS

Deliverable report

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Deliverable Identification	
Deliverable Number:	D2.2.2 and D2.2.3
Deliverable Title:	Optimum harvest-storage options – handling requirements
Responsible Beneficiary:	DTI
Contributing Beneficiaries:	CRES, UWM
To be Submitted to the EC:	No

History			
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V1	Jorgen Hinge	First draft	31/08/2012
Final	Myrsini Christou	Additions and merge D2.2. with D2.2.3	20/09/2012

Approval				
	Name	**Organization**	**Date**	**Visa**
Deliverable Responsible	Jorgen Hinge	DTI	31/08/2012	OK
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Dissemination level		
PU	Public	X
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Content

Executive summary

Description of the deliverable objective and content

The objective of Deliverable 2.2.2 is to present different harvesting and storage options and to discuss which are the methods that are the most reasonable in terms of costs, energy- and CO_2- balance. Collection of data for harvesting machinery and storage facilities are carried out, and results from EuroBioRef harvest and storage trials are included.

Besides the harvesting and storage information, the survey of yielding performance of high yielding species of willow and Miscanthus is included.

As there were no specific requirements regarding the handling of biomass, Deliverable 2.2.3 was added in this deliverable as chapter 3.

Brief description of the state of the art

The state of the art of harvesting equipment and storage facilities was described in M2.4 and M2.7.

In Europe, the harvesting of lignocellulosic crops (Miscanthus, Willow, Giant reed etc.) and oil crops (Rape seed etc.) is fully commercialized.

In Madagascar, harvesting of most crops is primarily done manually by hand. Mechanical harvesting is applied for some crops on commercial scale, but diffusion is often limited by infrastructural (field size, physical accessibility) and financial conditions. Whereas existing technologies for harvesting lignocellulosic crops can be applied in Madagascar wherever infrastructure and financial situation permits, (further) development of harvesting technology for oil seeds like Pongomia and Barbassu is needed.

Technologies/methods for short and long term storage of different types of feedstock are well developed and documented. However, for specific products like Castor, Jatropha and Barbassu no data is available on critical values for, e.g., moisture content before storing.

Handling of the biomass types dealt in this project can include baling or pelletizing the harvested feedstock, either it derives from the woody species of from the herbaceous crops.

Deviation from objectives and corrective actions

No deviations from the planned work has occurred

Innovation brought and technological progress

Non applicable

Analysis of the results

The results of the work in Deliverable 2.2.2 are mainly the collection of data on harvesting machinery, storage facilities and other elements in the handling/supply chains. These data sheets are essential for the further work in the WP 2.2 regarding setting up different optimized scenarios for all year supply of biomass for biorefineries.

In principle, the data sheets – providing numerous data on equipment price, capacity, energy consumption etc. – make it possible to point out the “optimum harvest and storage options” for each crop. However, the analysis reveals, that it makes no sense to talk about for instance a single optimum harvest option for willow.

Only when harvest and storage elements are integrated in total supply chains, and these chains are analysed with regard to interdependencies between the different handling operations, it is possible to make recommendations on optimum combinations of handling operations and handling chains.

Impact of the results

The conclusions of Deliverables 2.2.2 and 2.2.3 form the basis for the work in deliverable 2.2.4

Related IPR

There are no IPR considerations regarding Deliverable 2.2.2 and 2.2.3

Publishable information

No information is to be published regarding Deliverable 2.2.2 and 2.2.3, as the results of the workshop is used only for further work in SP2

Conclusion

The conclusions of the work in Deliverable 2.2.2 and 2.2.3 are as follows:

Recommending optimum harvest options is not a matter of just looking at the harvest equipment and process itself. Instead total supply chains have to be considered.

Optimization of storage operations in biomass handling chains cannot – however important it might be - be looked at in isolated terms. Instead, whole chain considerations, especially the interconnection between harvest and storages, must form the basis for conclusions and recommendations regarding the optimum storage options.

In many cases, it will not even be possible to point out one single supply chain as the most feasible ; Intstead, for all year supply to a biorefienery, two or more supply chains involving different harvesting and storage methods may very well be the best solution. The best options – that means optimum combination of supply chains – have to be determined in each case, based on the information and demands by the biorefinery with regard to:

- Type(s) of biomass
- Supply profile
- Quality demands

1. *Yield Performances*

1.1. Willow

SRC willow plantations in Europe are still marginal. Sweden is the largest operator (16.000 ha), followed by Poland (9.000 ha), UK (6.000 ha) and Germany (5.000 ha) (Faasch, 2012).

Apart from Sweden, in the rest of the countries of Northern Europe, there is not yet extensive commercial experience in growing willow plantations, so in general no reliable statistics on yields are available, although many studies and initiatives have been done. Typically, yields in field trials are higher than those in commercial plantations due among others to better management and less waste (Ericsson, 2006)

Yield levels depend on several interrelated factors such as species (clones), site-specific conditions (soil fertility, climate, water capacity, etc.), type/intensity of management (planting density, size of the plantation, rotation sequence, fertilization, weeding, harvesting, etc.) and also farmers´ engagement.

According to Mola-Yudego and Aronsson (2008) in **Sweden** an average annual growth of 10 – 20 t d.m. ha^{-1} has been observed in many experiments. In Christensson (1987) growth rates of 36 t dm. $ha^{-1}.yr^{-1}$ have been recorded in intensively irrigated and fertilized research plots of *S. dasyclados* in southern Sweden for the 3 year of cultivation. Such findings may have contributed to over optimistic predictions of the yield in commercial willow plantations. Surveys of commercial willow plantations show average yields of 3 to 5 t d.m. $ha^{-1}.yr^{-1}$. However annual average yields over 10 t d.m. $ha^{-1}.yr^{-1}$ are possible in commercial plantations fertilized and properly weeded and some plantations have reporter yields up to 11 t d.m. $ha^{-1}.yr^{-1}$ (Table 1). One reason for the low commercial plantation yields can be that the nitrogen resupply is commonly assured by sewage sludge applications but proper nitrogen fertilization is rate. Another possible important factor is the dominance of old, not especially bred short rotation varieties in the older plantations (Mola-Yudego, 2008). Newer plantations have been established with new, higher productive varieties, which are more tolerant to pests, insects and frost. Plantations with new varieties are now beginning to be harvested and there is a trend for higher average yields.Regarding to the rather wide range of harvest rates an explanation can be that some farmers established willow SRC plantations largely in response to high investment subsidies and located the plantations on more marginal soils and employed low-cost/low labour management, while other farmers establish willow SRC plantations for the purpose of generating high net revenues expecting high biomass prices and then target better soils and managed the plantations for achieving high yields (Dimitriou, 2011).

Different models estimate yields in Sweden from 2.5 t to 17 d.m. $ha^{-1}.yr^{-1}$, in function of for example the geographical situation, type of management and soil productivity (Table 1).

In Denmark **commercial plantations show yields up to 25 t d.m. $ha^{-1}.yr^{-1}$. Being the average willow yield of around 7 t d.m. $ha^{-1}.yr^{-1}$ (Table 2). In** Finland **(**
Table 3) the measured productivity from plantations managed by local farmers ranged from 0.4 to 8.4, with yields up to 11 t d.m. $ha^{-1}.yr^{-1}$ for the clone *S.viminalis 78112*. There is a big difference between North and South Finland as main consequence of the colder winters. In the North of Finland average yields have been reported less than 1 t d.m. $ha^{-1}.yr^{-1}$ in experimental plantations, being in the South of around 3 to 5 t d.m. $ha^{-1}.yr^{-1}$ (Talvanainen, 1999). In experimental trial yields from 3 to 10 t d.m. $ha^{-1}.yr^{-1}$ have been found. In **Germany** different studies show an average yield of around 6 to 8 t d.m. $ha^{-1}.yr^{-1}$; but values of around 14 t d.m. $ha^{-1}.yr^{-1}$ have also been obtained for Björn and Tora species (Table 4). **Polish** field trials present in general higher rates (Table 5). Yields of 33 t d.m. $ha^{-1}.yr^{-1}$ have been observed for *S.viminalis* 1058 (Stolarski, 2008), and yields of 15 t d.m. $ha^{-1}.yr^{-1}$ to 30 are frequent. Commercial plantations in Poland present as well lower yields than field trials. According to Stolarski (2011a) yields in commercial plantations range from 4 to 10 t d.m. $ha^{-1}.yr^{-1}$.

In **UK** special breeding test yields up to 25 t d.m. ha^{-1}.yr^{-1} have been reached, but in most of field trials yields up to 15 t d.m. ha^{-1}.yr^{-1} are obtained, being the average between 6 to 10 t d.m. ha^{-1}.yr^{-1} (Table 6). According to Bullard (2002) most frequents yield in commercial plantations are as well in the range of 6 to 10 t d.m. ha^{-1}.yr^{-1}.

Regarding to the Baltic countries yields are lower. Predictions under current agricultural practices range around 9.0, 10.1 and 9.7 t d.m. ha^{-1}.yr^{-1} for Estonia, Lithuania and Latvia, respectively, in very suitable conditions, and slightly below 5 t d.m. ha^{-1}.yr^{-1} in all three countries in moderately suitable land. In Estonia, results from experimental plantation yielded up to 10 t d.m. ha^{-1}.yr^{-1}, in the high quality soils when there was proper management practices, and 6 t d.m. ha^{-1}.yr^{-1}, in the medium quality soils (Mola-Yudego, 2010).

Table 1: Annual willow yield in Sweden

Field trials				
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})			References
10 different clones: *S. schwerinii* 77077, *S. mixture* 77082, *S. viminalis* 77683, 78003, 78021, 78090, *78183,* 78195, *S.dasyclados* 78196 and 81090.	Cutting cycle of:	Mean yield individual clones	Mean yield clone mixtures	Willebrand, 1993
	1 yr. (9 harvests):	~5	~6	
	2 yr. (4 harvests):	~6.5	~8	
	3 yr. (2 harvests):	~6.5	~9	
	5 yr. (1 harvest):	~8.5	~9.5	
	Different irrigated and fertilized field trials.			Christersson, 1987
S. dasyclados Wimm. 075	Yield range of the 3th yr. harvest (4 yr. old roots)	28 – 36		
	Yield of the 2nd yr. harvest (4 yr. old roots)	30		
S. viminalis *L.* 081	Yield range of the 2th yr. harvest (4 yr. old roots)	12 – 18		
S. viminalis 082	Yield of the 2nd yr. harvest (4 yr. old roots)	15		
Commercial plantations				
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})			References
In Swedish plantation main willow species crossings and hybrids of *S.viminalis*, *S. dasyclados* and *S. schwerinii* (Mola-Yudego, 2008)	Possible average yield in plantations fertilizer and properly weeded:	10		Mola-Yudego, 2008
	Survey of a large number of plantings suggest and achievable yield of:	7		Mitchell, 1995
	Average yield in 130 ha:	4.7		Tahvanainen, 1999
	Yield variation from:	1.2 – 11.2		
	Average yield from survey to 175 farmers in 1998. Depending on soil type from:	3 – 4.4		Dimitriou, 2011
Models and reviews				
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})			References
Model based on water availability and in experimental data from more than 40 sites part of a demonstration project	Estimated yields in:			Lindroth, 1999
	North-Eastern Sweden:	8 – 9		
	Dry Eastern Sweden:	9 – 10		
	Very South Sweden:	11 – 12		
	Belt along south-western coast:	16 – 17		
Model based on recorded yields (1989 – 2005) of 2082 commercial plantations	Mean estimated yield: (3 cutting cycle of 6, 4.5, and 4.2 yr.)	3.6		Mola-Yudego, 2008
Model based on data from 1512 commercial plantation from 1986 to 2000	Low productivity areas, 1st cutting cycle:	2.5		Mola-Yudego, 2011
	High productivity areas, 1st cutting cycle:	5.4		

Model based on same data than Mola-Yudego, 2008	Fertilizer scenario, 5 cutting cycle of 4 yr: 6.7 Non-fertilizer scenario, 5 cutting cycle of 4 yr: 4.0	Gonzalez-Garcia, 2012
Different clones, densities and cutting cycles	Average yield: 10.2	Mitchell, 1995

Table 2: Annual willow yield in Denmark

Field trials		
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
- *S.viminalis* L78183 - Bjørn	Mean yield range for different fertilization and planting tests for 4 consecutive harvests of 2 to 4 yr. cutting cycle: 7.1 – 7.3 11.3 – 14.1	Lærke, 2010
- Tora - Inge	Mean yield range for different weed treatments for 1st harvest of 1 yr. cutting cycle: 2.5 – 9.8 2.5 – 7.5	Larsen, 2012
Different varieties, not defined	Tests with different kind of harvesting machines in 3 sites with diverse types of cutting cycle: 7.2 – 9.9	Peterson J., 2011
Commercial plantations		
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
Data from 11 farmers for harvest between 2007–2010	Yield variation from: 2 – 10 Typical average yield level: 4 – 7	Pederson J.B., 2011
Data from 11 farmers for harvest in 2011. Most fields harvested at least once early	Yield variation from: 0.7 – 16.6 Typical average yield level: 2.0 – 8.0	Pederson, 2012
Data from 26 plantations with clones with root age from 2 to 6 yr. Clones type: Tordis, Sven, Tora, Gudrun, Inger and Thorhild	Yield variation from: 1 – 25 Average yield: 7.3 26% plantations mean yield: 10.0 3% plantations mean yield over: 16.0 33% plantations mean yield under: 5.0	Sevel, 2011
Reviews		
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
Field scale intensive farming plantations	Mean yield over a period of 10 yr.: 10 - 17	Jørgensen, 2008
Different clones, densities and cutting cycles	Average yield: 7	Mitchell, 1995

Table 3: Annual willow yield in Finland

Field trials		
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
10 different *S. viminalis* clones: 832502, 810217, 78112, 78183, 832803, 821624, 78021, 81110, 812509, 832501	Results from 16 experimental plantations. Average yield range of 3 consecutive harvest of 1 yr. cutting cycle for: All individual clones and plantations: 0.4 – 8.4 3 best plantations: 5.4 – 8.8 South Finland plantations: 3.1 – 5.4 North Finland plantations: 0.3 – 0.9 Best clone (78112) in the best plantation: 11	Talvanainen, 1999

7 different clones: 77908, 78090, 78021, P6009, 78146, 78183, 78105 Clone with higher yield: 78090	2, 3 and 4 yr. cutting cycle in Easter Finland: Average yield range all individual clones: 2.8 – 9.6 Average yield all individual clones: 6.7 Mean yield best clones (78090, P6009, 79090) 9.1	Toivonen, 1998
 - *S. phylicifolia* - *S. trianda*	Average yield of 19 growing seasons for 2 different fertilization trials in central Finland: 7.2 4.4	Hytönen, 2009
Reviews		
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
Different clones, densities and cutting cycles	Average yield: 2.8	Mitchell, 1995

Table 4: Annual willow yield in Germany

Field trials			
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})		References
 - Rapp - Ulf - Orm - Björn - Tora	Average yield of 5 consecutive harvests with cutting cycles of 3 yr. 8.9 9.7 10.6 13.4 14.4		Zander, 2008
	Average yield for cutting cycles of:		Boelcke, 2008
	6 yr. (2 harvests)	6 yr. (2 harvests)	
- *S. viminalis*: Zieverich	7.4	7.4	
- *S. viminalis*: Weide 10	8.5	8.5	
2 different clones: Inger and Tordis	37 field trials with 3 consecutive harvests of 1 yr. cutting cycle (ProLco project). Average yield all individual clones: 2.5 Yield range all clones in 3rd cycle: 1.9 – 8		Larsen, 2012
S. viminalis 83/21/12	Average yield range for different fertilization test with 3 consecutive harvests of 2 yr. cutting cycle: 4.3 – 6.8		Scholz, 2002
Reviews			
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})		References
Values from different studies	6 – 14		Hoffmann, 2005

Table 5: Annual willow yield in Poland

Field trials		
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
5 different clones: *S. viminalis L* UMW 046, Corda, Tur, Turbo, Duotur	1st harvest of 1, 2 and 3 yr. cutting cycle: Yield range of all individual clones: 14.0 – 24.0 Average yield of all individual clones: 19.2 Range highest yield clones (Doutur, Tur): 16 – 24 Average yield of best clones (Doutur, Tur): 21.5	Stolarski, 2011b

6 different clones: Turbo, *Tu*, Duotur, Corda, *S. viminalis L.*UMW 043 and UMW 046	1st harvest of 4 yr. cutting cycle. Trials in marginal soils with different plant densities Yield range of the different test: 4.2 – 15.5 Average yield of the different test: 7.8 Yield range best clones (Doutur, UMW046): 6.1 – 15.5	Stolarski, 2011a
2 different clones: *S.viminalis var. Gigantea* and *S.viminalis* L.	Average yield for the 2 clones for 3 harvests of 1 yr. cutting cycle from the 4th cultivation yr.: 14.5	Borkowska, 2012
6 different clones: *S. viminalis* 1023, 1033, 1037, 1054, 1056, 1058 Higher yield clone 1058	Average yield range different individual clones 1 yr. cutting cycle (4 harvests): 14 – 20 4 yr. cutting cycle (1 harvest): 14.4 – 33.2 Average range best 2 clones (1058, 1054) 1 yr. cutting cycle (4 harvests): 18 4 yr. cutting cycle (1 harvest): 32.3	Stolarski, 2008
4 different clones: *S.viminalis x S.viminalis lanceolata, S. tirandra, S.viminalis Gigantea and Regalis*	1st harvest of 1, 2, 3 and 4 yr. cutting cycle: Yield range of all clones: 5.2 – 29.6 Average yield of all clones: 16.8 Yield for best cycle and best clones (4 yr. *S.viminalisxS.viminalis lanceolata, S.regalis):* 27.4	Szczukowski, 2005
Reviews		
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
Values from different studies	Under the optimal conditions up to: 30 Average yield in experiments: 10 – 12 Yield in commercial plantations range: 4 – 10	Stolarski, 2011a

Table 6: Annual willow yield in UK

Field trials		
Specie	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
15 different clones: Bebbiana, Bjorn, *Stott10*, Dasyclados, Delameres, Ulv, Tora, Germany, Jorr, Jorum, Orm, *S.Spaethii*, Stott11, S.ST/2481/55, Q83	Results from 49. Average yield for 2 consecutives harvests of 3 yr. cutting cycle: Yield range individual clones: 7.3 – 11.3 Average yield of all the clones: 9.3 Average best clones (Tora, Jorr): 11	Aylott , 2008
4 different clones: Ashton *Stott*, Jorr, Tora, Ulv Higher yield clone Tora for 20000 plants/ha	48 field-scale experimental plots. Average range yield of all clones after 1st harvest for different plant density: 4.0 – 10.8	Wilkinson, 2007
S. viminalis *cv.* Jorunn *S. x dasyclados*	Mean yield range for 2 sites and 2 different plant densities. 1st harvest (2 and 3 yr. cycle): 9.4 – 10 6.7 – 7.1	Bullard, 2002
More than 26 clones of elite Swedish and Uk willow varieties	Results from 4 sites after the 2nd harvest. Cutting cycle of 1st and 2nd harvest were 2 and 3 yr. Yield range individual clones: 6.3 – 15.4 Average yield all clones: 9.3 Average yield best clones (Ashton Stott and Parfitt) 14.7	Lindegaard, 2001
Reviews		
Comments	Annual Yield (t d.m. ha^{-1}. yr^{-1})	References
Yields after 1st harvest	Expected to be in the range: 7 - 12	DEFRA, 2004

Commercial plantations	More frequently observed yields	6 – 10	Bullard, 2002
Different clones, densities and cutting cycles	Average yield:	8.1	Mitchell, 1995
Estimation by project partners in UK and Ireland	Average yield:	13	Ericsson, 2009
Trials data	Under certain conditions: Through specialised breeding:	15 – 18 25	Wickham, 2010

1.2 Miscanthus

Miscanthus x giganteus is the dominant commercial variety at present. Extensive field trials of *M. giganteus* have been carried out in Northern Europe since 1983 (Robbins, 2012). The high risk of plant winter losses is the main obstacle for the production of *M. giganteus* in Northern Europe. *M. sinensis* genotypes have superior survival rates to M. x giganteus (Lewandowski, 2000). According to Clifton-Brown (2001) plantations with *M. giganteus* and *M. sacchariflorus* are unlikely to be viable where winter soil temperatures fall below -3 ^{o}C at a depth of 5 cm. In a trial performed with 15 different *miscanthus* genotypes in 5 European countries in England and Germany, *M.giganteus* genotypes were among the top performers while the highest-yielding genotypes in Sweden and Denmark were *M. sinensis* hybrids (Clifton-Brown, 2001).

The full establishment of a *miscanthus* stand takes 3/5 years during which time the yield increases in each successive year. Afterwards yield is maintained. Ceiling yields are attained more rapidly in warmer climates than in cooler climates, especially when crop water supplies are not limiting. In addition to soil, climatic conditions, plant density, etc., yield varies according to the date and method of harvest (Lewandowski, 2000).

In recent years around fifteen thousand hectares of commercial *miscanthus* production have been initiated, mainly in the UK, and there is so far only limited experience with full-scale commercial harvesting and delivery for energy purposes (Jørgensen, 2011).

In table 7 a summary of *miscanthus* yields for different Northern European Countries is presented.

In **UK** average dry matter harvestable yields have been reported of between 7 and 20 t. $ha^{-1}.yr^{-1}$. Similar yields have been found in **Poland**. In **Germany** yields up to 30 t d.m. $ha^{-1}.yr^{-1}$ have been obtained. While in Denmark average yields from field trials are lower ranging from 6 to 12 t d.m. $ha^{-1}.yr^{-1}$; however yields up to 18 t d.m. $ha^{-1}.yr^{-1}$ have been observed. In Sweden yields of 24 t d.m. $ha^{-1}.yr^{-1}$ have been reached. In Finland the estimated average yield with the model Miscanmod is 13 t d.m. $ha^{-1}.yr^{-1}$.

Table 7: *Miscanthus* yield in North European countries[1,2]

Annual Yield (t d.m. ha-1. yr-1)			Comments	References
UK				
12.4 – 13.0			Average range for 14 years cultivation and 3 different fertilization tests.	Christian, 2008
7.3 – 18.5			Average range for 7 year cultivations in 3 different sites	Price, 2004
20.8			In 3th cultivation year	Beale, 1997
10 -15			In 3th cultivation year	Bullar 1996. In. Lewandowski, 2000
1st yr.	2nd yr.	3th yr.	Mean yield of 15 out of 15 surviving genotypes (*M. sacchariflorus, M. sinensis* and hybrids of both of them)	Clifton-Brown, 2001
0.6	4.0	12.1		

Annual Yield (t d.m. ha-1. yr-1)			Comments	References
0.9	5.9	18.7	Genotype with higher yield (Genotype 3). *M. giganteous*	
12			Yields routinely achieved (Review)	Powlson, 2005
18.6			Estimated yield with *model* Miscanmod	Clifton-*Brown*, 2004
Germany				
16			Central Germany, Mean yield for 2^{nd} and 3^{th} cultivation year	Himken, 1997
15 – 14 4 – 20 9 – 19			Northen Germany, 3^{th} and 4^{th} cultivation year Central Germany, 3^{th} and 4^{th} cultivation year Southern Germany, 3^{th} and 4^{th} cultivation year	Lewandowski 1997. In Lewandowski, 2000
15 - 22			Central Germany, 3^{th} and 4^{th} cultivation year	Jacks-Sterrenberg 1995. In. Lewandowski, 2000
Poor soil	Good soil		Central Germany, from 3^{th} to 8^{th} cultivation year	Hotz 1996. In. Lewandowski, 2000
5 – 10	15 – 24		*M. giganteus*	
5 – 6	10 – 19		*M. sinesis Goliath*	
2	6 – 17		*M. sin. Gracillimus*	
3 – 4	10 – 15		*M. sin. Grosse Fontaine*	
2 – 5	8 – 15		*M. sin. Silberfeder*	
4 – 6	9 – 15		*M. type Ungarn*	
8.1 – 30.5			Souther Germany, 3 sites, 3^{th} and 4^{th} cultivation year, different test regarding irrigation, fertilization.	Lewandowski, 1997
6.2 – 19.8			Central Germany, 4 sites, range average for 3 harvests in a row of 4 to 9 year old miscanthus.	Kahle, 2001
1^{st} yr.	2^{nd} yr.	3^{th} yr.		Clifton-Brown, 2001
1.9	6.2	17	Mean yield of 15 out of 15 surviving genotypes (*M. sacchariflorus, M. sinensis* and hybrids of both of them)	
3.0	8.1	29.1	Genotype with higher yield (Genotype 4). *M. giganteous*	
21.3			Estimated yield with *model* Miscanmod	Clifton-*Brown*, 2004
Denmark				
7.7			*M. giganteus* , average from 3^{th} to $5t^{h}$ cutivation year	Jørgensen, 1997
6 – 12			*M. sinensis,* average range 15 selections, from 3^{th} to $5t^{h}$ cutivation year	
1^{st} yr.	2^{nd} yr.	3^{th} yr.		Clifton-Brown, 2001
0.7	3.6	10.8	Mean yield of 11 out of 15 surviving genotypes (*M. sacchariflorus, M. sinensis* and hybrids of both of them)	
1.4	8	18	Genotype with higher yield (Genotype 4). Hybrid *between M. sacchariflorus and M. sinensis*	
8 – 12			Average yield range of 14 clones of *M. sinensis* , for 5^{th} , 6^{th} and 7^{th} cultivation year	Kjeldsen, 1999
21			Estimated yield with *model* Miscanmod	Clifton-*Brown*, 2004
Sweden				
1^{st} yr.	2^{nd} yr.	3^{th} yr.		Clifton-Brown, 2001
0.4	5.9	16.1	Mean yield of 10 out of 15 surviving genotypes (*M. sacchariflorus, M. sinensis* and hybrids of both of them)	
0.4	9.5	24.7	Genotype with higher yield (Genotype 8). Hybrid *between M. sacchariflorus and M. sinensis*	
13.2			Estimated yield with *model* Miscanmod	Clifton-*Brown*, 2004

Annual Yield (t d.m. ha-1. yr-1)	Comments	References
Poland		
17.7 – 18.7	Average yields derived from field trials established on average Polish soils (Literature review)	Krasuska, 2012
12.6 – 21.1	Average yield range. 2 sites, 15 genotypes	Borzecka-walker, 2012
Finland		
13	Estimated yield with *model* Miscanmod	Clifton-*Brown*, 2004

[1] If not indicated the specie considered is *Miscanthus giganteus*
[2] If not indicated data make reference to field trials

1.3 Giant reed

Arundo donax is a Mediterranean grass from the Poaceae family and is claimed to have very high yields of 20 – 25 t d.m. ha^{-1} yr^{-1}. (Lewandowski, 2003). Within Europe it is native to Greece and Italy and is quite common in the Mediterranean where it occurs in marshy areas by rivers. A. donax tolerates a wide variety of ecological and soil conditions. Although it prefers well-drained soils with abundant soil moisture, it can tolerate extended periods of severe drought accompanied by low atmospheric-humidity. This ability is attributed to the development of coarse drought-resistant rhizomes and deeply penetrating roots that reach deep-seated water tables. 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 (Perdue, 1958).

The establishment is the most critical point of A. donax cultivation and has strong influences on productivity and economic 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, which is through plant rhizomes, stem cuttings or tissue culture.

Planting of rhizomes, whole stems and stem cuttings have been tested but appropriate machinery for these operations is not yet available (Pari, 1996; Vecchiet et.al, 1996). Rhizome planting 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, 2001). 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.

The full establishment of a *giant reed* stand takes 2-3 years, depending on the soil conditions and water accessibility. During this time the yield increases in each successive year. Afterwards yield is maintained. Ceiling yields are attained more rapidly in warmer climates than in cooler climates, especially when crop water supplies are not limiting.

The production potential of Arundo donax can reach up to 100 t fresh matter ha^{-1} yr^{-1} in the second or third growing period under optimal conditions in a warm climate and by supplying it with sufficient water (Christou et.al, 2001). According to Morgana (Morgana & Sardo, 1995) in Sicily a mature plantation of giant reed yielded over 40 t d.m. ha^{-1} yr^{-1} indicating that this high potential for dry matter production brings promise of even higher production if cultivation's limitations would be overcome. High productivity of A. donax should be attributed to high CO2 exchange rates, foliage arrangement and turnover and patterns of resource acquisition and allocation (Rossa et.al, 1998). Yields of 45.9 t d.m. ha^{-1} yr^{-1} are reported in Spain (Hidalgo et.al. 2001), higher than 30 t d.m. ha^{-1} yr^{-1} (Christou et.al, 2002), higher than 50 t d.m. ha^{-1} yr^{-1} in France, 34 -37 t d.m. ha^{-1} yr^{-1} in Germany and UK (Christou et.al, 2005; Christou et.al, 2005). Two European research networks on giant reed were funded by the 3rd and 5th European programmes, the FAIR3 CT96 2028 'Giant reed (Arundo donax L.) network, Improvement, productivity and biomass quality' (1997-2000), and ENK6-CT2001-00524 'Bioenergy chains from perennial crops in South Europe' (2001-2005), both coordinated by CRES. In table 8 a summary of giant reed yields for different European Countries is presented.

Table 8: *Giant reed* yield in North European countries

Annual Yield (t d.m. ha-1. yr-1)			Comments	References
Greece				
1st yr. 20	2nd yr. 25	3rd yr. 19	Mean yield of 3 irrigation and nitrogen fertilisation treatments	Mardikis et.al, 2002
1st yr. 4-12	2nd yr. 18-56	3rd yr 7-18	Range of yields in field trials in North Greece, as a mean of 40 local populations and 3 irrigation and nitrogen treatments	Christou et.al. 2002
3-24	7-31	14-44	Range of yields in field trials in South Greece, as a mean of 40 local populations and 3 irrigation and nitrogen treatments	
1st yr. 1.4	2nd yr. 2.7-9	3rd yr. 6-19	Range of yields in field trials in South Greece, as a mean of 3 irrigation and nitrogen treatments, in arid conditions	Christou et.al. 2005, www.cres.gr/bioenergy_chains
Italy				
40			Mature plantations in Sicily	Morgana & Sardo,1995
1st yr. 1 – 6	2nd yr. 4-34	3rd yr. 9-66	Range of yields in field trials in North Italy, as a mean of 40 local populations and 3 irrigation and nitrogen treatments	Christou et.al. 2002
7 – 14	15-34	21-45	Range of yields in field trials in South Italy, as a mean of 40 local populations and 3 irrigation and nitrogen treatments	
1st yr. 12	2nd yr. 27	3rd yr. 25	Average yields in field trials in Bologna, North Italy	Christou et.al. 2005, www.cres.gr/bioenergy_chains
France				
1st yr. 8– 23	2nd yr. 32-74	3rd yr. 56-127	Range of yields in field trials in North France, as a mean of 10 populations	Christou et.al. 2002
5-15	6-15	10-20	Range of yields in field trials in South France, as a mean of 40 local populations	
	10		Average yields in North France after one year and a half from the establishment of the plantation	Christou et.al. 2005, www.cres.gr/bioenergy_chains
Spain				
45.9			Average yields, ranging from 29.6 to 63.1, in field trials	Hidalgo & Fernandez, 2001
1st yr. 2– 32	2nd yr. 8 –37	3th yr. 32-63	Range of yields in field trials in Spain, as a mean of 40 local populations and 3 irrigation and nitrogen treatments	Christou et.al. 2002
1st yr. 5.1	2nd yr. 7.9	3th yr. 4.4	Range of yields in field trials in Spain	Christou et.al. 2005, www.cres.gr/bioenergy_chains
Germany				
1st yr. 5 –10	2nd yr. 15-20	3th yr. 10-34	Range of yields in field trials in North France, as a mean of 10 populations	Christou et.al. 2002
UK				
1st yr. 0.2 – 8	2nd yr. 8 - 37		Range of yields in field trials in North France, as a mean of 10 populations	Christou et.al. 2002

1.4 Results from EuroBioRef trials on willow

The willow plantation has been established between the 11th and 20th of April 2010 at the Educational and Research Station in Łężany belonging to the University of Warmia and Mazury in Olsztyn. The main factor in the field experiment are three varieties and four clones of willow, all of them created by the Department of Plant Breeding and Seed Production of the University of Warmia and Mazury in Olsztyn.

1. Start – variety from the species *Salix viminalis*
2. Tur – variety from the species *Salix viminalis*
3. Turbo – variety from the species *Salix viminalis*
4. UWM 006 – clone from the species *Salix viminalis*
5. UWM 035 – clone from the species *Salix pentandra*
6. UWM 043 – clone from the species *Salix viminalis*
7. UWM 155 – clone from the species *Salix dasyclados*

After the second year of grow the yield of *Salix spp*. was assessed. The yield of fresh biomass for selected clones varied between 6.85 t ha^{-1} and 37.08 t ha^{-1} (tab.9). After moisture was taken into account, the yield of dry matter was assessed for plants after second year of growth, which amounted to 10.65 t ha^{-1} in average. Among all tested varieties the highest yield was given by clone UWM 006 (18.25 t d.m. ha^{-1}). Yields of all willow varieties are presented in Table 3. In November 2012 after end of plants' vegetation the yield if the varieties will be assessed again. Moreover in late autumn or winter 2012 the harvest trial with harvester Claas Jaguar will take place. The harvest trial will allow to collect a data about yields, energy and agricultural machinery use for willow tested in EuroBioRef Project.

Table 9: Estimated biomass yield of *Salix* spp. after the second year of vegetation

Variety or clone	Fresh biomass yield		Dry biomass yield		Dry biomass yield	
	(t/ha)	stand. dev. (±)	(t/ha)	stand. dev. (±)	(t/ha/year)	stand. dev. (±)
Start	24.91 ab	8.18	12.21 ab	4.20	6.10 ab	2.10
Tur	14.04 bc	3.78	7.05 b	1.93	3.53 b	0.96
Turbo	21.96 b	4.67	10.44 b	2.21	5.22 b	1.10
UWM 006	37.08 a	7.55	18.25 a	3.35	9.13 a	1.67
UWM 035	12.58 bc	4.29	6.10 b	2.04	3.05 b	1.02
UWM 043	35.55 a	15.60	17.31 a	7.69	8.66 a	3.84
UWM 155	6.85 c	2.21	3.20 c	0.98	1.60 c	0.49
Mean	21.85	12.89	10.65	6.32	5.33	3.16

± standard deviation
a, b, c… homogenous groups

1.5 Results from EuroBioRef trials on giant reed

Existing small scale fields with a variety of feedstock (giant reed, switchgrass, cardoon) were used to report on yielding performances over a period of 7-10 years that will be studied in the project using also pre-existing knowledge. The fields were established in spring 2002, therefore the first harvest was made in February 2003. The experimental design was a split plot design with three irrigation levels: I0: no irrigated, I1: 50% of ET, I2: 100% of ETo, and three nitrogen fertilisation rates: N0: 0 kg N/ha, N1: 40 kg N/h, N2: 120 kg N/ha.

A large scale giant reed fields has already been established in Greece since the beginning of the project.

The fields of giant reed, along with the rest of the perennial herbaceous crops, were harvested in February 2011.

Dry matter yields in 2011 final harvest ranged from 7 – 16 t/ha, with moisture content at 54% (fig 1). Giant reed tends to achieve mature yield from the 3rd growing season. All irrigation rates had a significant effect on yields, whereas only the lack of nitrogen fertilisation rate resulted in significantly lower yields.

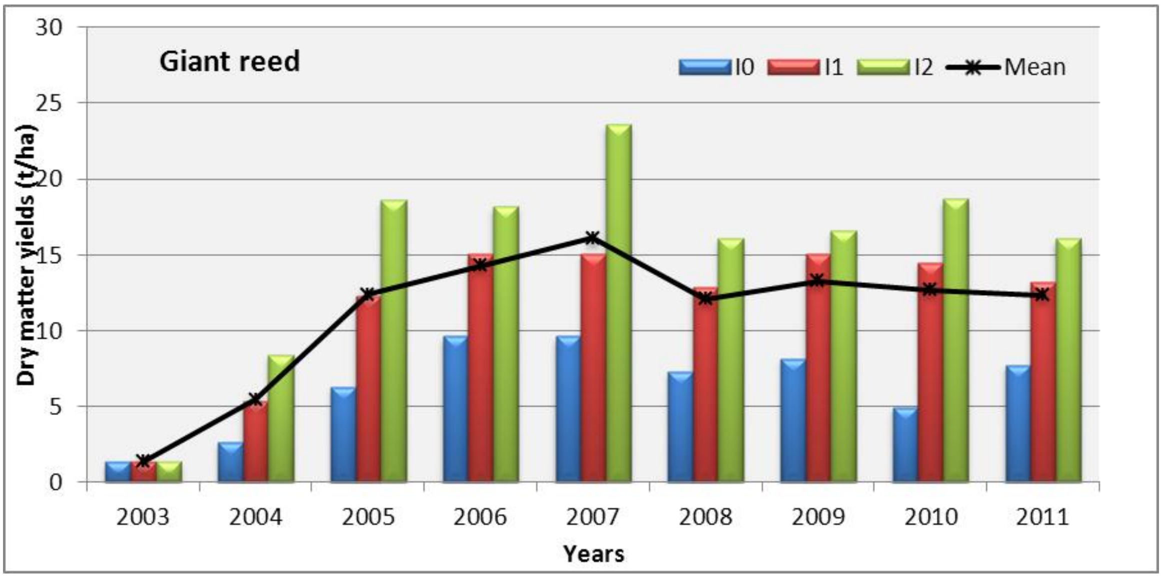

Figure 1: Dry matter yields (in t/ha) of giant reed for 9 subsequent growing periods (2003-2011) for 3 irrigation rates

2. Harvest options

Harvesting of lignocellulosic crops like willow and miscanthus is well developed in Europe and commercialized in many European countries. However, harvest still constitutes a large proportion of the costs of handling lignocellulosic crops, and thus continued work on optimizing harvesting technology and harvesting practise is crucial in the continuing efforts to increase the use of lignocellulosic biomass for biorefineries. Examples of harvesting equipment are shown in this chapter, whereas in chapter 5, advantages and disadvantages of different technologies are discussed and optimum combinations are described.

2.1. Willow

Harvest of willow is done either as whole shoots or the willow is directly chipped. Whereas the machines for direct chipping typically are modified machines originally developed for other crops like maize or sugar cane, whole shoot harvesters are typically developed especially for harvesting willow.

Figure 2: Self-propelled harvesters for direct chipping with trailer

The self propelled harvester for direct chipping has a large capacity, 15-25 tons DM/hour. Furthermore an advantage is, that it can be used for many crops like grass, corn, grain, oil crops, short rotation crops etc.

Figure 3: Self-propelled whole shoot willow harvester

The whole shoot willow harvester has a capacity of 12-50 tons DM/hour. The machine is dedicated for willow harvesting and can typically not be used for other crops.

Table 10: Comparison between direct chipping harvesters and whole shoot harvesters. It should be emphasized that figures are indicative and may vary between different machines and harvesting conditions.

	Price (Euro)	Capacity (tons DM/hour)	Applications	Harvesting costs (Euro/ton DM harvested)	CO_2-emission (kg CO_2 /ton DM harvested)
Direct chipping harvester	370.000 – 450.000	15-25	grass, corn, grain, oil crops	14-30	17-30
Whole shoot harvester	160.000	12-50	Willow (perhaps other SRC)	12,5	9,6

In the table above, a comparison is made between direct chipping harvesters and whole shoot harvesters. The figures are based upon the data sheets prepared for setting up the supply chains. It seems from these figures, that it would be most feasible - both in terms of costs and CO_2-emission – to harvest all willow crops with whole shoot harvesters. However this turns out not to be the case, when taking into account all costs/CO_2-emissions for all the handling operations included in the handling chain. The whole shoots must be chipped anyway somewhere during the supply chain, and this increases the total costs and CO_2-emissions for the biomass delivered “at the gate”, and also transport costs for whole shoots are much higher (in terms of ton DM transported) than for chipped material.

This illustrates, that recommending optimum harvest options is not a matter of just looking at the harvest equipment and process itself. Instead total supply chains has to be considered. As will be described in chapter 3, the same applies for storage options. Therefore, in chapter 4, these challenges are addressed

2.2. Mischanthus and other lignocellulosic crops

Figure 4: Direct chipping of Miscanthus with self propelled machine.

Many lignocellulosic crops like Giant Reed, Switchgrass and Cardoon can be harvested with conventional equipment, normally applied for production of hay. And straw of course is produced as a “byproduct” from combined harvesting of grain crops.

2.3. Giant reed

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.

Figure 5: Arundo donax plantation at flowering stage in September (left) and at harvest time in February (right) [Source: CRES]

Harvesting and storage techniques were addressed in North Italy, by CETA (figures below). In order to determine the suitability of common machinery for giant reed harvesting, a three rows mower- fodder-loader combining machines (HESTON 7650, 250HP) and a mower- fodder- loader combining machines (JOHN DEER 6950) with no rows cutter KEMPER, generally used for maize harvesting, were tested.

The use of a three rows mower- fodder-loader combining machines resulted in a high risk for tires to be punctured by the slanting stumps due to the cutter cut some stems obliquely [Christou et.al, 2002]. This indicated that harvesting of the giant reed stems would be best performed with larger cutter, which could cut the stems horizontally. The mower- fodder- loader combining machines with no rows cutter seemed to be more appropriate for giant reed harvesting.

Figure 6: A three rows mower- fodder-loader combining machines (HESTON 7650, 250HP) [Source: CETA].

Figure 7: A mower- fodder- loader combining machines (JOHN DEER 6950) with no rows cutter KEMPER [Source: CETA]

Under the funded by the European Union project “Bio-energy chains from perennial crops in South Europe” which was conducted by a number of countries (Austria, France, Germany, Greece, Italy, Spain, The Netherlands and UK) four selected crops (Cynara, switchgrass, miscanthus and giant reed) were studied and harvested successively. The results of the harvesting periods in SE countries was feasible because - in contrast to the northern EU countries - under South European conditions the end of growing cycle of these crops occurs from summer (cynara) to autumn switchgrass, miscanthus, giant reed) when inflorescence emerges (Bioenergy chains project). The progressive leaf senescence and simultaneous dying back of the stems until the end of February, beginning of March (switchgrass, miscanthus, giant reed), allows the lowest possible moisture content in the harvested material, a wide harvesting window, a minimization of the storage time and the relative storage costs, along with better allocation in time of the harvesting equipment use.

Harvesting of the Arundo donax large field was carried out in February by means of a six rows CLAAS Jaquar 690cl mower-fodder-loader combining machine (fig 8). The efficiency of this machine was quite high indicating that it should be regarded suitable for Arundo harvesting. No problems were faced at all during the harvest and losses of the harvested material were low.

Figure 8. Harvesting of giant reed with a six-rows CLAAS Jaguar mower-fodder-loader combining machine

3. Handling options

Baling is the typical method for handling straw and most other non-wood fiber raw materials. Straw bale piles may contain from 500 to 3,000 tons and can be either round or rectangular. Since the straw on the bottom and outside layers of the piles deteriorates with time, deterioration will be less if larger piles are used, however this depends on the locally existing baling equipment. Large straw piles are usually about 12 m high, 20-22 m wide and about 160 m in length. Piles are spaced 20 to 30 m apart to reduce the fire hazard and to permit access for fire fighting equipment (Hurter, 2007).

Another option would be to pelletize the harvested biomass. Pellets are generally made from compacted sawdust or other wastes from sawmilling and other wood products manufacture by compressing the woody material. They can also be made from agricultural residues like rice husks, etc, grasses and other non-woody biomasses, like the herbaceous perennial crops, grown in this project. Pellets are manufactured in several types and grades, depending mainly on their energy uses in the domestic and industrial sector (CHP, power plants, etc) (Alakangas, 2009). Their size is generally kept to be about 6mm diameter and 25mm length in the form of a cylinder, in order to be conveniently blown from a tanker to a storage bunker or silo.

For the biorefinery options deadly in this project, there are no specific handling requirements of the harvested biomass. The materials used in the tests were in the form of pellets or chips.

4. Storage options

Storage of the biomass may in many situations be a crucial handling element in the biorefinery supply chains, because:

- Whereas the harvest windows for some crops may be only a few months a year, the biorefinery will typically need all year supply, so after the harvest is completed the biomass will have to be stored until it is needed at the refinery.
- During storage, considerable changes in physical, chemical and biological properties of the biomass may occur, depending on the type of biomass, harvest technology, type of storage etc. If there are certain quality demands for the biomass from the biorefinery, this has to be taken into account when choosing between storage options.
- Due to biological and chemical degradation a large proportion of the biomass may be lost during storage and thereby indirectly increasing the costs of the biomass considerably. So to minimize the biomass loss during storage, it must be considered which storage options should be applied depending on the type degradability of the biomass and the storage duration.

In chapter 4, the combination/optimization of harvest technologies, biomass characteristics, storage type (and storage duration) are discussed, whereas in this chapter, examples of different storages types are described.

4.1. Storage of chipped material and whole shoots

In (Nielsen et al., 1997), a comprehensive study of different methods of storing willow chips and whole shoots was carried out. Trials with chipped material were carried out over 3 storage seasons, with several different parameters and storage types being investigated:
- Storage piles were established on concrete/asphalt bottom as well as on a field with grass in order to determine the impact on pile moisture content and loss of biomass when the piles were emptied.
- Different shapes and sizes of piles were established in order to determine the impact of pile height.
- Different chip size (2,5cm, 2,8cm, 5cm, 10cm and 20cm) were produced in order to determine differences in biological degradation between the different types of chips
- Different degrees of covering of the piles were applied, varying from uncovered piles to airtight wrapping.
- The impact of ventilation of piles of chips was determined.

Numerous parameters were monitored during the storage trials, including
- Moisture content
- Changes in pile temperatures during the storages period
- Loss of dry matter
- Lower heating value
- Fungal spores
- Bacteria
- Content of alcohols and acids, especially for airtight wrapped piles
- Also, total costs of storing willow were calculated.

The most important results of the storage trials were:
Storage for 5 months will result in a dry matter loss of 3-20% of the stored amount, whereas storage for 9 months will result in a dry matter loss of 6-30% of the stored amount. Losses during storage decreased with increasing chip size.

The most favourable – in terms of costs – method of storing willow fuel was to establish simple piles in the field. Open storage piles with small-sized chips were most competitive for short term storage (1-2 months), whereas piles of larger sized chips and whole shoots were competitive with increased storing period. With a storing period of 8-9 months airtight wrapping could be competitive.

The results from (Nielsen et al., 1997) show, that no single means of storing biomass (chip size/whole shoots, type of pile, covered/uncovered etc.) is THE optimum solution (in terms of total costs) for storing biomass for all year supply to biorefineries or other consumers. If also energy balance and CO_2-emissions have to be considered as important parameters in optimizing biomass handling chains, the picture may become even more complex.

Therefore, optimization of storage operations in biomass handling chains cannot – however important it might be - be looked at in isolated terms. Instead, whole chain considerations, especially the interconnection between harvest and storages, must form the basis for conclusions and recommendations regarding the optimum storage options. This is discussed more thoroughly in chapter 4.

Figure 9: Harvested and chopped biomass 10-15 mm of size

A significant advantage of giant reed is its good storability. It can be stored outdoors without any shelter protection with minor losses. Losses occur mainly in the leaf fraction (blades and sheaths), which represents a small percentage, about 10 to 15 %, of the total biomass production. Stems can be stored with almost no losses (Christou et.al, 2002).

The storage of the giant reed biomass in pile, covered with PVC film, allows obtaining, after one month of storage, a strong decreasing of biomass moisture content from 48% (at starting up) to 23%. The average of the water content during the storage time (from the first month to the last one) is about 19% (Christou et.al, 2002).

At the same time, due the microbial degradation of the biomass, a loss of dry matter was observed and determined. The degradation of giant reed biomass was in the range of 9%, after the first month of storage, till 18% at the last sampling, in November. The yearly average of biomass loss was about 15% (Christou et.al, 2002]). It is possible to prevent the biomass loss by anaerobic storage, during the ensilage of giant reed biomass as maize, but with this method the biomass drying does not take place.

4.2. Summary of storage trials from the EuroBioRef project.

In the frame of biomass storage experiment, in the middle of March 2011, five piles of willow chips were formed (fig. 10). In this test different methods of storage of willow chips collected in one stage technology were analysed. The willow chips were stored till middle of March 2012. In the storage period and after its end, a thermo-chemical properties and biomass losses were analysed. For comparison one piles of whole willow stems were formed. The purpose of this task is assessment of quality of biomass acquired in two stage technology (harvest of whole stems, their natural drying and chipping). Similarly as in previous experiment the biomass quality will be analysed in various sampling periods. About 2 tons fresh willow chips was stored in one pile. Three of them were covered with different materials: Toptex 200 g/m^2, Toptex, 130 g/m^2, typical foil used for roof covering one pile was uncovered and one stored inside a wooden shed.

Figure 11 presents temperatures in the piles during storing period. The graph presents that the temperatures in all piles increase rapidly in the first month of storage.

Figure 12 presents moisture of the chips. Their moisture content intensively decreased from the beginning of storage in the covered piles and under the sheltered one. The most rapidly decrease was noted under Toptex 200 fabric, from the 52% through 17% to about 13%.

Figure 13 presents moisture content of whole willow stems. Thermopsyical analysis of willow included also ash content, fixed carbon, volatile matter content and lower heating value. The ash content decreased in all piles except uncovered (fig. 14). Fixed carbon content increased during storing period in biomass in all piles (fig. 15). The volatile matter content decreased during the storage period in all piles as well till November 2011 but in pile covered with Toptex 200, Toptex 130 and pile stored in the shed started to increased again. However the volatile matter didn’t reach the initial value (fig. 16). The lower heating value, which depends closely on moisture content, increased in biomass stored under both Toptex fabrics and pile under the shed while under uncovered pile decreased significantly due to high moisture content. Lower heating value of willow chips stored under breathable foil increased during first six month but next started to decrease due to foil disintegration and moisture content increase (fig. 17).

Figure 10: Trial of five different methods of willow chips storage

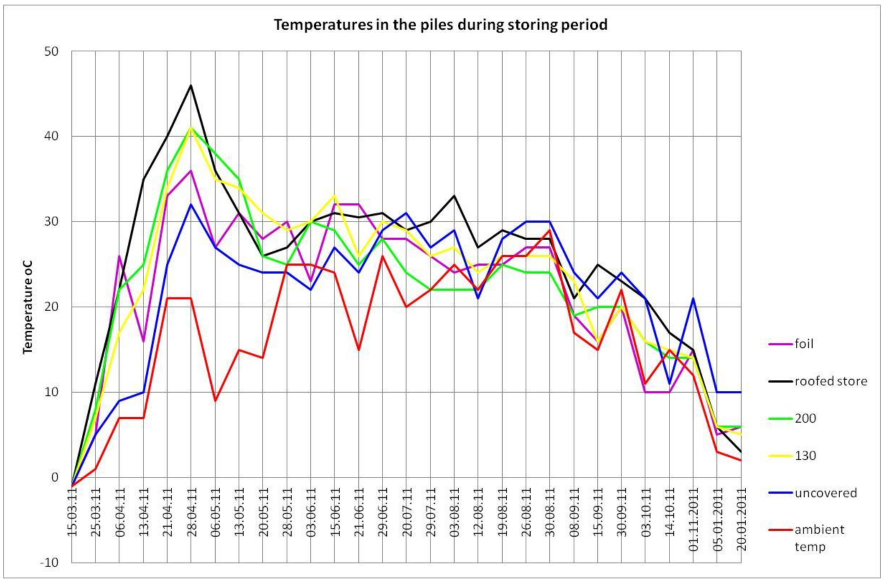

Figure 11: Temperature in the examined piles during storage

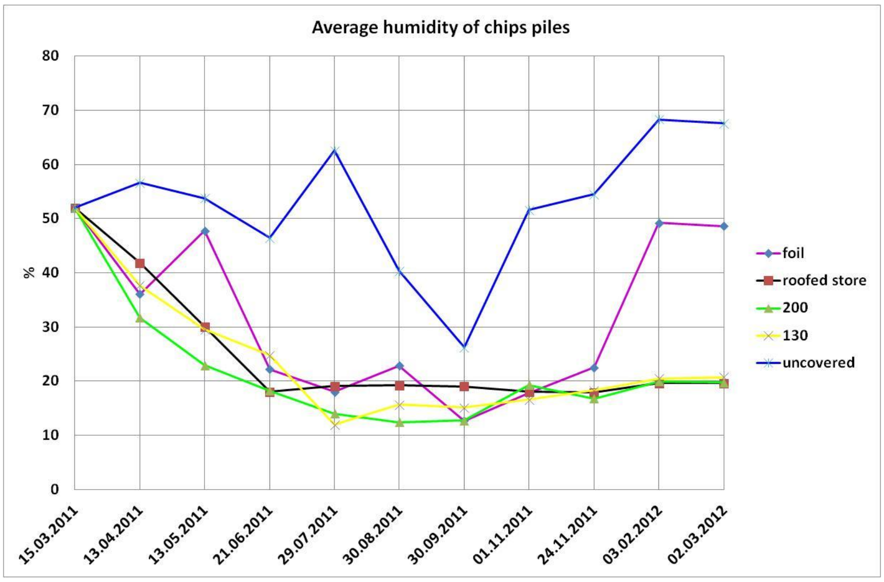

Figure 12: Moisture content in willow chips stored under different covers

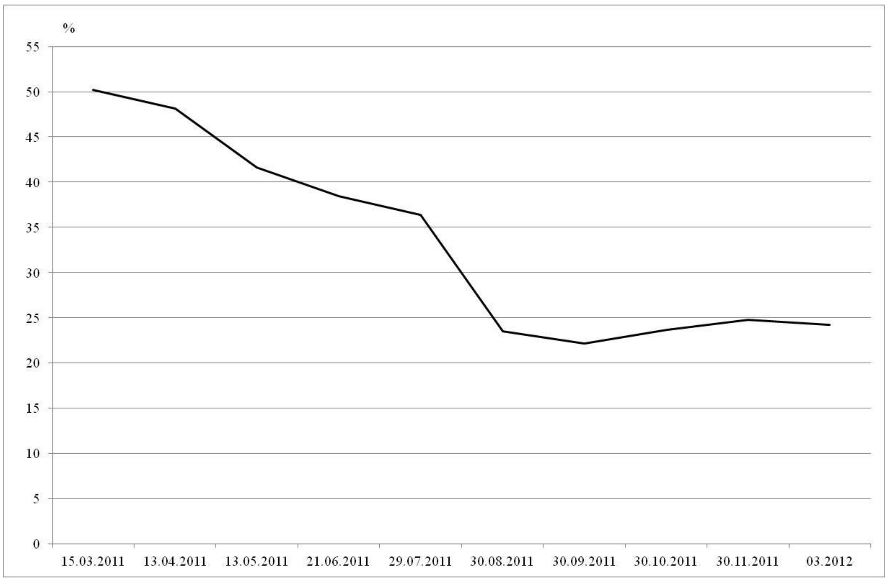

Figure 13: Moisture content of natural dried willow stems

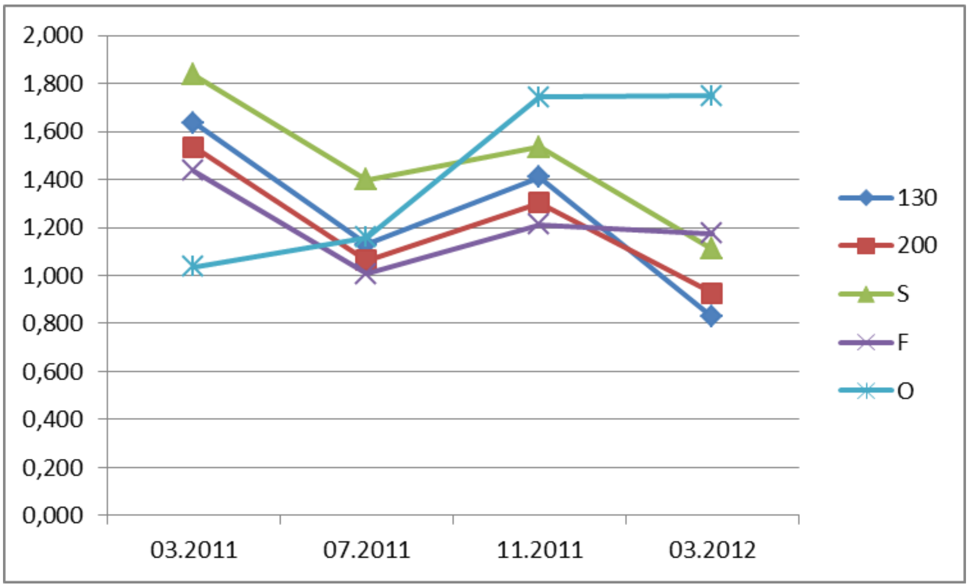

Figure 14: Ash content in willow chips stored under different covers

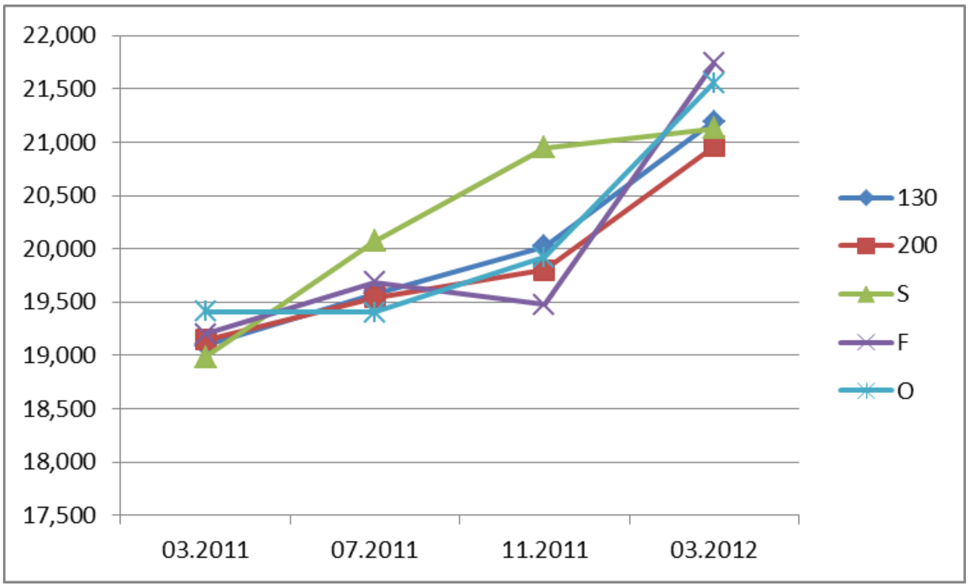

Figure 15: Fixed carbon content in willow chips stored under different covers

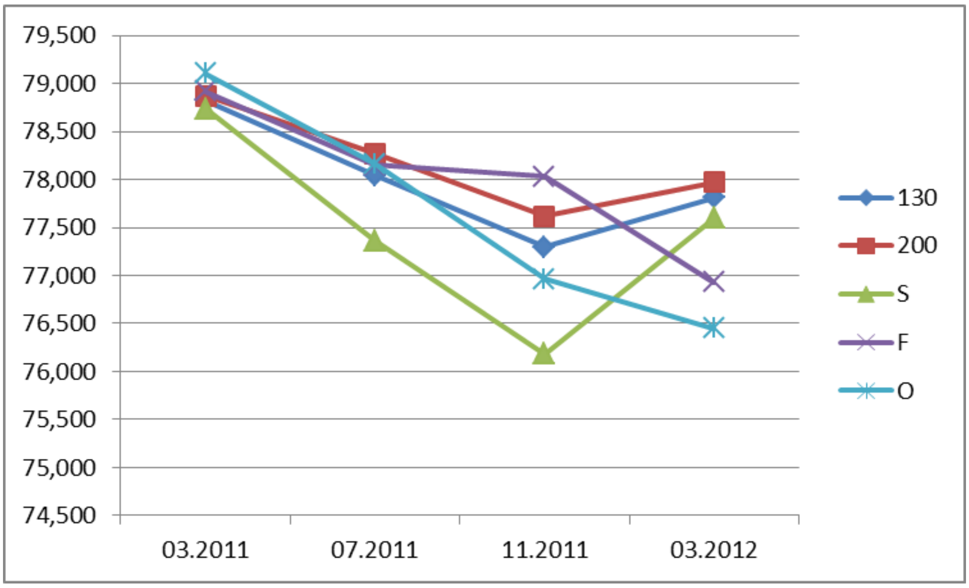

Figure 16: Volatile matter content in willow chips stored under different covers

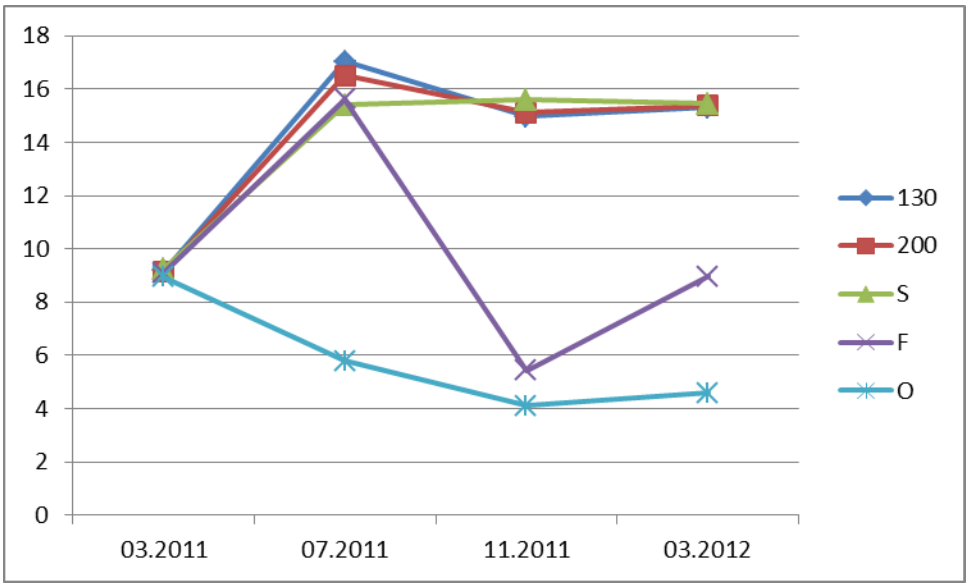

Figure 17: Lower heating value in willow chips stored under different covers

Biomass loses

An average dry biomass losses in all 5 piles amounted to 14% of initial amount. The lowest losses of dry biomass was found in piles under Toptex 130, Toptex 200 and under the shed, 5%, 4% and 7% respectively. Biomass losses under foil amounted to 13%. The highest biomass loses were found in uncovered pile (41%).

After the first storage trial we decided to test in next storage period (03.2012-03.2013) Toptex fabrics due to high quality of willow chips gained after experiment end and their durability. Next experiment started in March 2012 has been run on 3 piles: Toptex 200, Toptex 130 and uncovered pile as a reference. Approximately 10 Mg of fresh biomass has been stored in each pile. In the storage period and after its end, a thermo-chemical properties and biomass losses will be analysed as in previous trial.

5. Optimum harvest and storage options

5.1 Optimizing supply chains, not single handling elements

As discussed briefly in chapter 2 and 4 optimizing harvesting and storage options does not make sense unless you consider the total supply chain from the biomass is harvested until it is delivered at the gate of the biorefinery. And the considerations should even go beyond that as discussed in the following. Only cost considerations are discussed here, but basically, the same considerations apply for energy and CO_2-emission optimization.

We learned in chapter 2 and 4, that the cheapest harvesting method is not necessarily the method which gives the lowest total cost; it depends among many other things on storage loss of the biomass which is depending on the biomass characteristics resulting from that particular harvesting method, the density of the harvested material will influence the subsequent transportation costs etc. So for a given crop a number of handling or supply chains can be put together, including all the different handling elements, like harvest, field transport, decentral storage, conditioning, loading, road transport, sea transport, central storage etc. These single handling chains can be compared for a given crop harvested at a given time and delivered to the biorefinery at a given time; and one of the chains may prove to be the most feasible.

However, when a biorefinery will need all year supply of a biomass, which for instance only can be harvested during 2 or 3 months of the year, the situation becomes much more complex. In the example of willow, direct chipping and transport directly to the plant – perhaps with short term storage, 1 or 2 months – will probably be the most feasible during the months where willow can actually be harvested (typically November-March). But for the delivery during the months August-October, the willow obviously has to be stored somehow in the period from harvest until consumption. Because loss of biomass is much smaller in a whole shoot storage than in a pile of willow chips. A supply chain involving whole shoot harvest and storage may prove to be most feasible during those months. So for all year supply, two or more supply chains involving different harvesting and storage methods may very well be the best solution.

And if this was not enough, when the biorefinery is based on several different types of biomass, some of which may come from other continents numerous supply chains may be involved in supplying one single biorefinery.

In WP2.2 the supply chains of all biomass types relevant to the EuroBioRef project are described and data for all the involved handling elements are collected into data sheets. A model has been developed, which compute the best combination of different supply chains, based on the demands of the biorefinery. In Deliverable 2.2.4 (due M36), 2 scenarios will be described, which operate in an optional mode in terms of biomass quality, system efficiency and reduced operational costs.

5.2 Considerations regarding harvest and storage options at Madagascar

The study of the castor crop harvesting conditions in the case of Madagascar shows that the ways of managing such operations must take into account the country's cultural and logistical constraints.

Agriculture in Madagascar is made by families of 5-8 people who manage a maximum of 3-10 hectares farmland. This family unit conducts all agricultural operations from planting to harvest and storage of production. Sown surfaces are generally limited by the working capacity of this family. Productions storage is at home.
Harvesting and storage of castor plant should be similar to that of rice, because of the similarity in the conduct of their production process.

Concerning rice, family or village community harvesting is practiced; the paddy is dried and stored in their own houses and sometimes in their attics to prevent theft. The paddy is then transported by ox cart to an operator owning a rice hulling unit to separate the rice from its shell. This is usually close to the cultivation area. The rice is then stored and/or sold to collectors coming to the village.

This model can be adapted to castor seeds, as the castor production by Malagasy farmers will be primarily by families on average of 2 hectares areas. In this context, family manual harvesting is an advantage for a country like Madagascar. It will be made 2-3 times in order to maximize crop yields. In areas with limited road access, ox cart constitutes the best option to transport the capsules to a hulling unit in order to separate the seed from the capsule.
In the case of Madagascar, this model of harvest and storage management seems to be the most appropriate in our point of view to avoid the limitation imposed by road infrastructure necessary for mechanised agriculture industry.

Ideally, farmers should organise themselves into cooperative owning a unit in the center of the production area. The capsules will be transported by ox-carts to hulling units and storages, where they will undergo weighing, analysis of moisture content, additional drying if necessary and storage before hulling. Once hulled, the seeds will be transported to the pressing zone. The capsules will be compacted to limit their volume and then returned to the farmers to be used as fertilizer or coal.

An organisational model promoted by the company SOABE for the Middle West area of Madagascar has been drafted and can be seen in figure 18.

As castor capsules have low density, we will make debugging units available in the main production areas to minimise transportation by the farmer. These units will have building storage for seeds and capsules. These seeds will be progressively transported by ox-drawn cart with a carrying capacity of 1 ton to the crushing units, which also has seeds storage. The crushing unit is close to the tarred road, allowing the transportation of the produced oil containers by trucks to the port of TAMATAVE where they will be loaded to EUROPE: Marseilles, Antwerp, Le Havre

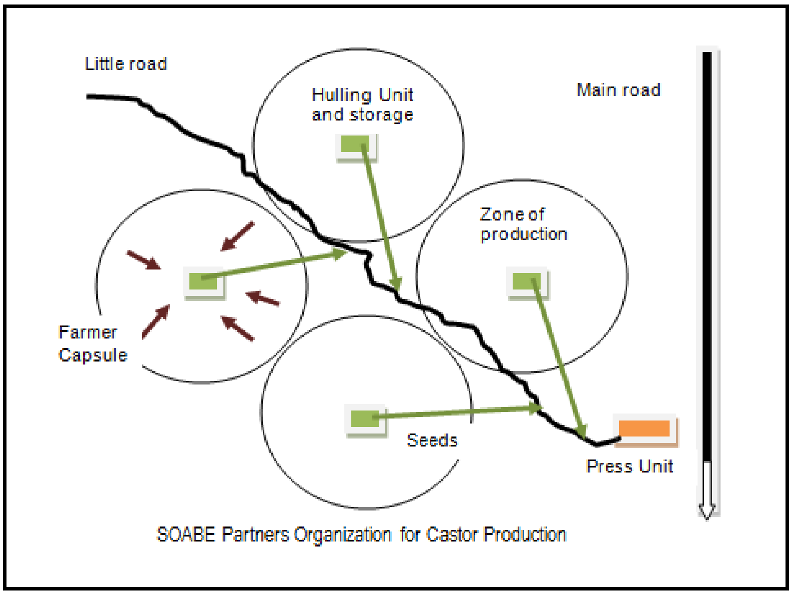

Figure 18: The organisational model for castor

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