JRC Scientific and Technical Reports

"Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

17 and 18 October 2007, Harpenden, United Kingdom

Editors J. F. Dallemand , J.E. Petersen, A. Karp

EUR 23569 EN - 2008

European Environment Agency

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Acknowledgements

This Expert Consultation on "Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives" was held in Harpenden, United Kingdom, on 17 - 18 October 2007. This meeting was jointly organised by *J. F. Dallemand* (Renewable Energies Unit, Institute for Energy, Joint Research Centre, European Commission), *J.E. Petersen* (European Environment Agency, Copenhagen, Denmark) and *A. Karp* (Rothamsted Research, Harpenden, United Kingdom).

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Short Rotation Forestry, Short Rotation Coppice and energy grasses in the European Union:

Agro-environmental aspects, present use and perspectives

Thematic introduction to SRF, SRC and energy grasses,

Rothamsted, 17 October 2007

Theo Verwijst, SLU, Uppsala

Rothamsted Research Expert Consultation

- Review of crops (SRC, SRF, perennial grasses)
- Review of current area and geographical distribution of perennial energy crops
- Context of implementation (farmer practice, economy, policy, environment); Willow example

Rothamsted Research Expert Consultation

Definitions……

- SRF, SRC
- Annual vs. perennial crops
- Rotation period (time) – harvest cycle

Rothamsted Research Expert Consultation

The plant material:

Perennial species for energy (wood crops for SRF, SRC and grasses)

SRF-species: characteristics of five genera (excluding Salix, Robinia, Eucalyptus, Castanea)

Rothamsted Research Expert Consultation

Yield:

- Potential
- Attainable
- Actual

Yield improvement???

Rothamsted Research Expert Consultation

Yield:

- SRC (yield and characteristics)
- Grasses (characteristics)

- **Yield and area:**

- All species

Rothamsted Research Expert Consultation

Other crop(ping systems)

- Energy efficiency
- Nutrient- and Water-use efficiency
- Land use efficiency
- GHG-balance of system

The willow example

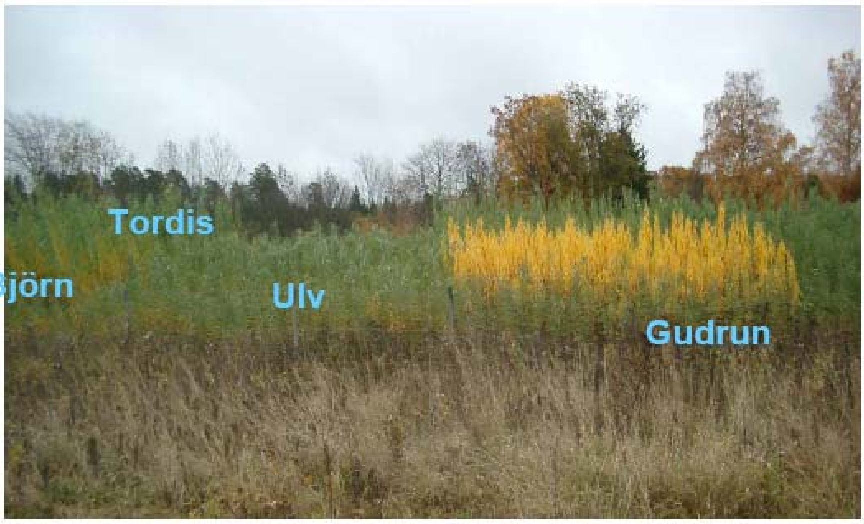
Swedish University of Agricultural Sciences
www.slu.se

Damages and pests

Swedish University of Agricultural Sciences
www.slu.se

SLU

Annual introduction of improved willow clones to the market



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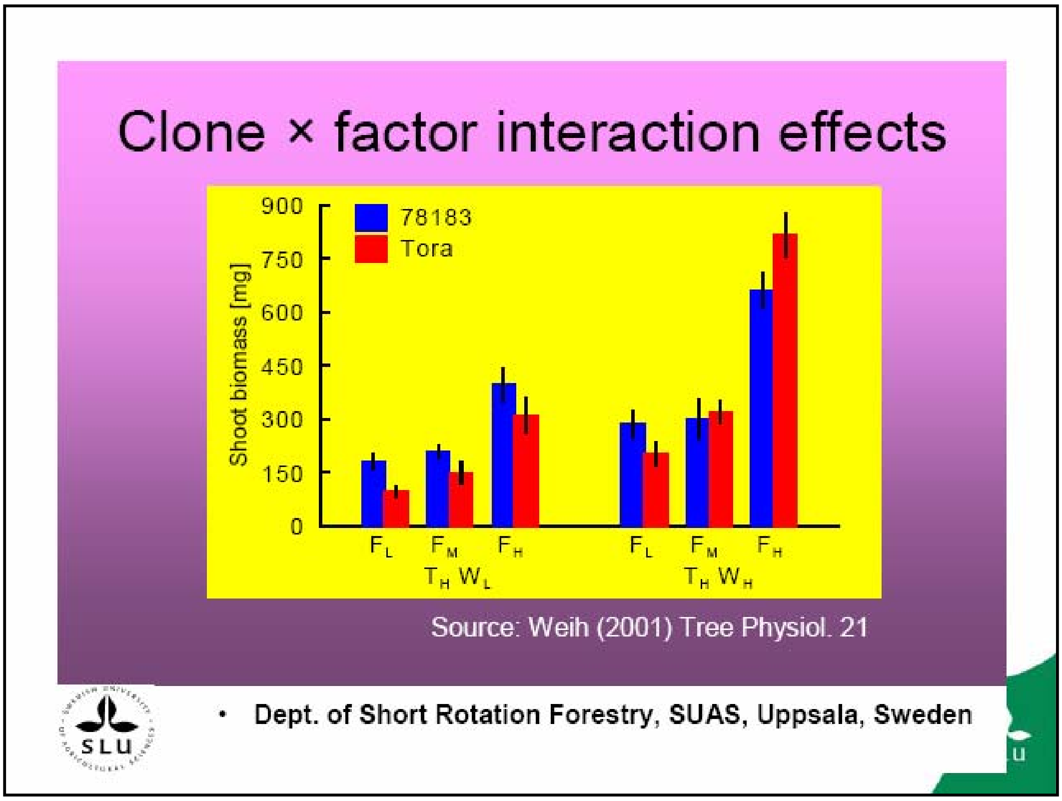
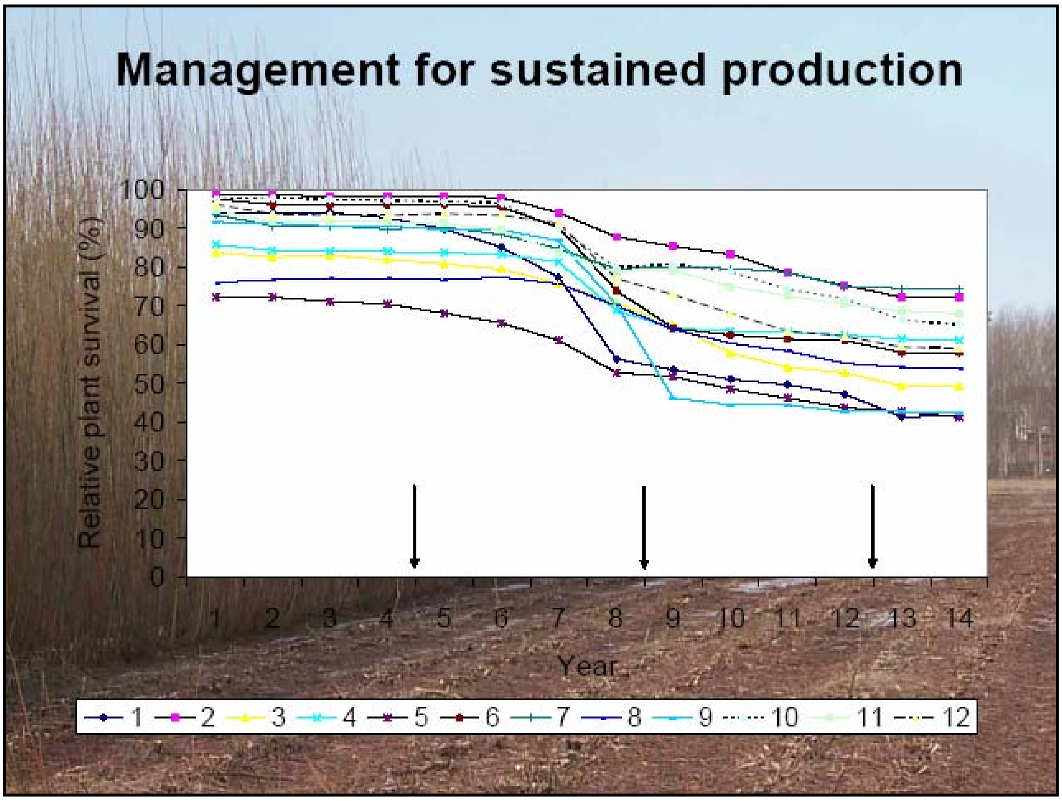

Clone × factor interaction effects
Shoot biomass [mg]
78183
Tora
900
750
600
450
300
150
0
F_L F_M F_H
T_H W_L
F_L F_M F_H
T_H W_H
Source: Weih (2001) Tree Physiol. 21
• Dept. of Short Rotation Forestry, SUAS, Uppsala, Sweden
SLU


Management for sustained production
Relative plant survival (%)
100
90
80
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14
Year
1 2 3 4 5 6 7 8 9 10 11 12

Establishment costs of willow plantations under the initial expansion period (in real terms)

Year	Index (1988=100)
1988	100
1989	69
1990	62
1991	54
1992	36
1993	31
1994	31

Källa: Rosenqvist (1997)

Large volumes are a driving force for further development. Without large-scale implementation no industrial financing for development.

Waste-water treatment in Enköping

Willow as a vegetation-filter

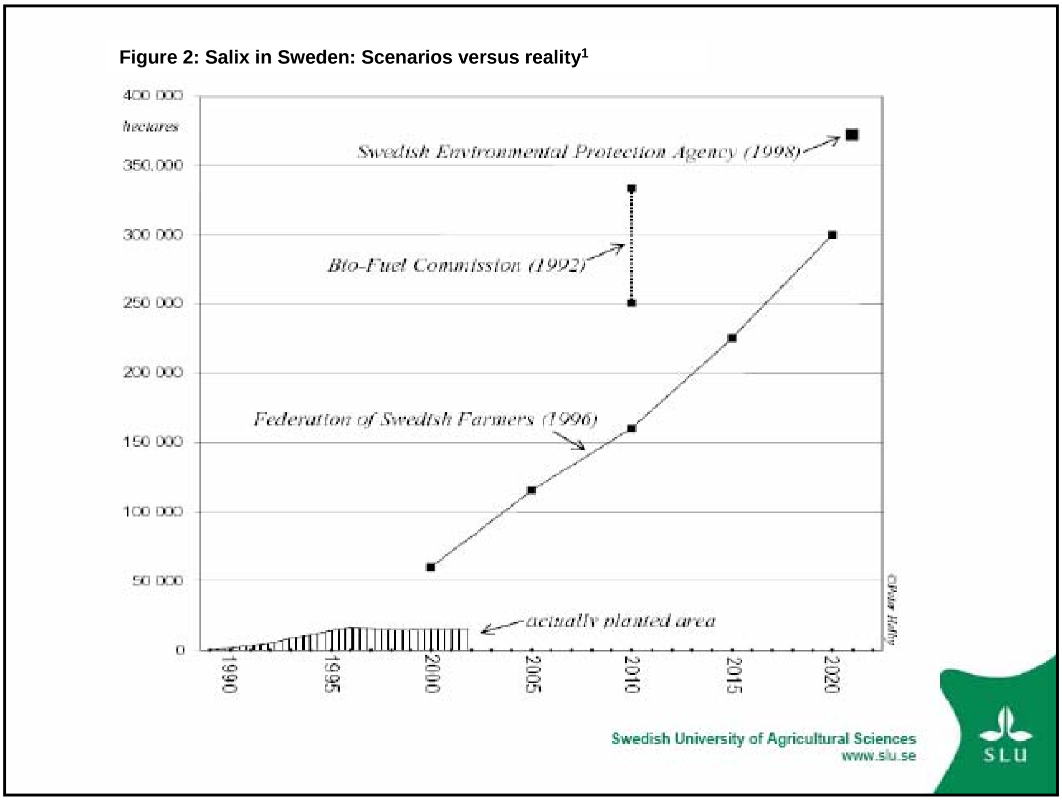


Figure 2: Salix in Sweden: Scenarios versus reality1
hectares
Swedish Environmental Protection Agency (1998)
Bio-Fuel Commission (1992)
Federation of Swedish Farmers (1996)
actually planted area
Swedish University of Agricultural Sciences
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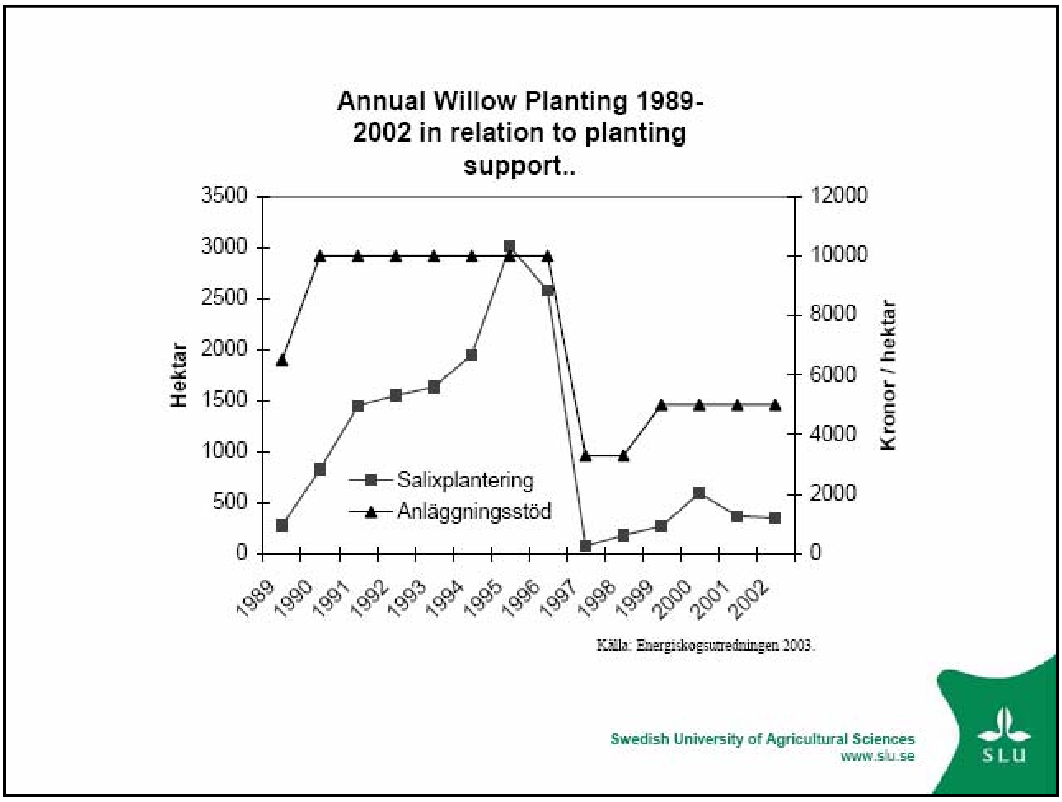
Annual Willow Planting 1989-2002 in relation to planting support..
Hektar
Kronor / hektar
Salixplantering
Anläggningsstöd
Källa: Energiskogsutredningen 2003.
Swedish University of Agricultural Sciences
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Would you make the investment… if you knew that :

- The first revenues will be obtained in five years from now.
- The prerequisites for the investment will change within five years from now. Support may increase or will disappear.
- The economy will be as good as for other crops, until the second willow harvest, which will happen in about nine years from now, therafter the willow plantation will be very profitable….if the market develops and the crop is doing well.

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ASSESSMENT OF TECHNICAL AND NON-TECHNICAL BARRIERS TO LARGE-SCALE IMPLEMENTATION (IEA)

NON-TECHNICAL BARRIERS:

- Market
- Attitudes and advisory work
- Policy
- Research and Development (Soc-Econ)
- Integration across sectors
- Public acceptance

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SRF, SRC and Energy Grasses in the European Union – Discussion Summary

Gillian Alker, Thames Valley Energy

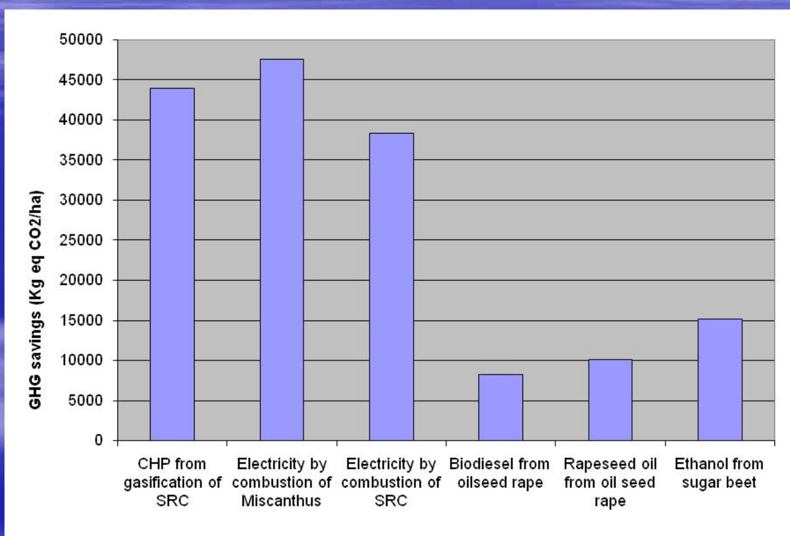
Expected v. Actual take-up

- To meet Climate Change targets, resource shift needed from annuals to perennials
- But…Large gap between expected and actual areas planted in Sweden and increasingly UK

Why is area low? – and how to resolve?

- Many knowledge gaps – further research
- Economically unsustainable – continued targeted funding
- Benefits not recognised – improved dissemination and lobbying for incentives schemes
- Lack of government leadership - Stronger policy and targets that optimise conversion chain efficiencies and environmental benefits

CO_2 savings from different bioenergy options per unit of land area



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JRC/EEA/Rothamsted Research Expert Consultation

Harpenden, 17-18 October 2007

Short rotation forestry, short rotation coppice and perennial grasses in the European Union: agro-environmental aspects, present use and perspectives

INTRODUCTION TO THE THEMATIC SESSION ON PROCESSING AND LOGISTICS

Juan E. Carrasco

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Energy crops development and efficient logistics (biomass collection and on field processing, storage and transport) are key issues to achieve the present goals with biomass in the EU.

Expected energy from biomass (Mtoe)

	EU			SPAIN		
Biomass	2003	Increment 2004-2010	Total 2010	2004	Increment 2005-2010	Total 2010
Biomass res. for heat and electricity	63,2			3,7	3,13	6,83
Energy crops for heat and electricity	0,1	62,9	130	0	1,91	1,91
Biogas	3,8			0,05	0,19	
Biofuels	3,1	15,9	19	0,23	1,97	2,2
TOTAL	70,2	78,8	149	3,98	7,20	11,18

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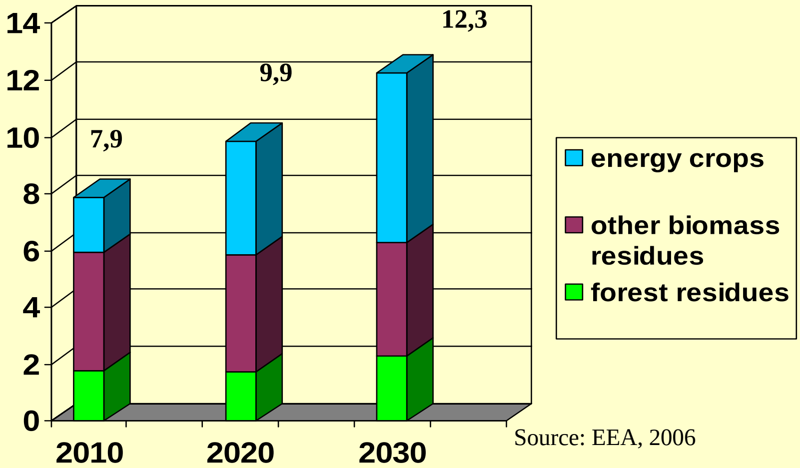
Sustainable biomass potential in EU-25 (in EJ)



Source: EEA, 2006

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Expected biomass requirements of new biomass technologies

Technology	Plant capacity	Biomass annual demand (t d.m.)
BIGCC (Biomass Integrated Gasification Combined Cycle)	100 MW	350.000- 400.000
BTL (Biomass To Liquid)	200.000 t biofuel	800.000-1.000.000
Bioethanol lignocellulose	200.000 t biofuel	800.000-1.000.000

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Minimum radius for biomass purchase.

Biomass demand t d.m./year	**Forest residues(1)**	**SR poplar (2)**
50.000	14	3,6
100.000	20	5,2
500.000	45	11
1.000.000	63	16

(1) 0,8 t d.m./ha year
(2) 12 t d.m./ha year

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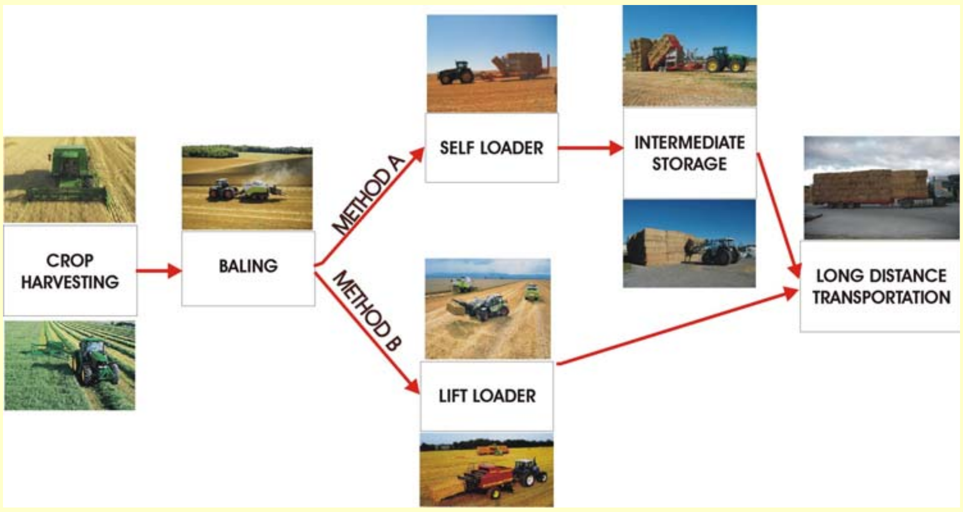

Supply chains for non woody biomasses

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Baling Miscanthus biomass

Chipping Miscanthus biomass

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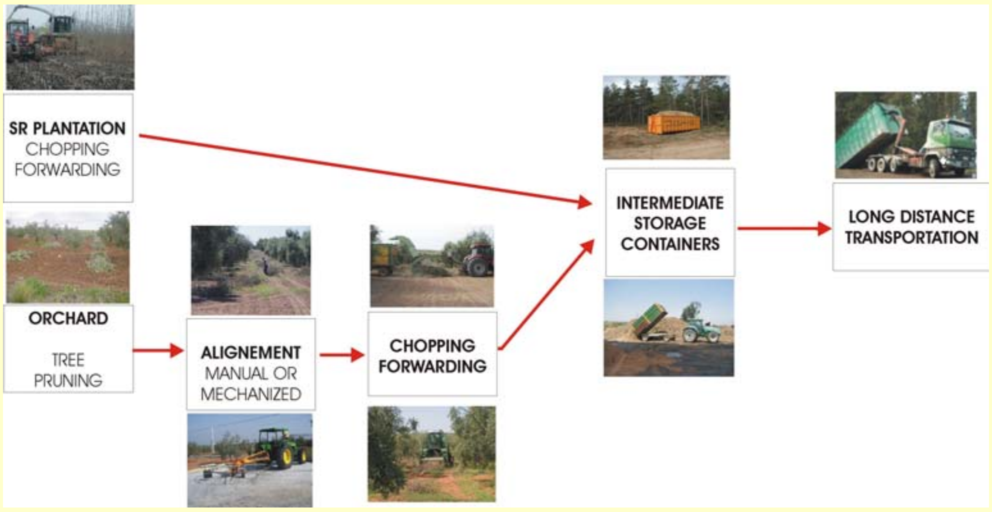

Supply chains for woody biomass

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Baling technology is not well developed for SR trees collection

Trailer truck with baled forest residues

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SR trees and perennial grasses biomass is not expected to pose particular problems for implementation as a feedstock for energy conversion technologies

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Indicative analysis of SR and perennial energy crops compared to conventional biomass

Parameter	Pine chips	Poplar	Eucaliptus	Willow	Wheat Straw	Thistle I	Thistle II
Heating Value LCV (MJ/kg) (d.m)	18	18	18	18	17	17	17
Volatiles (d.m.)	76	78	78	80	76	71	69
Ash (550ºC) (b.s.)	3,8	3,1	4,3	2,3	5,8	13,7	14,1
K	0,2	0,4	0,3	-	0,9	0,7	1,6
Ca	0,3	0,7	0,5	-	0,5	3,2	1,4
Ca/K	1,5	1,7	1,7	-	0,6	4,6	0,9
Elemental analysis (d.m.)							
C	49	50	48	49	45	43	40
H	6,0	6,5	6,4	5,9	6,2	6,2	5,4
N	0,3	1,7	0,3	1,0	0,5	0,76	1,1
S	0,05	0,04	0,06	0,13	0,08	0,29	0,15
Cl	0,08	0,1	0,16	-	1,1	0,7	2,2
TDI (ºC)	1190	>1400	1160	-	850	1250	640

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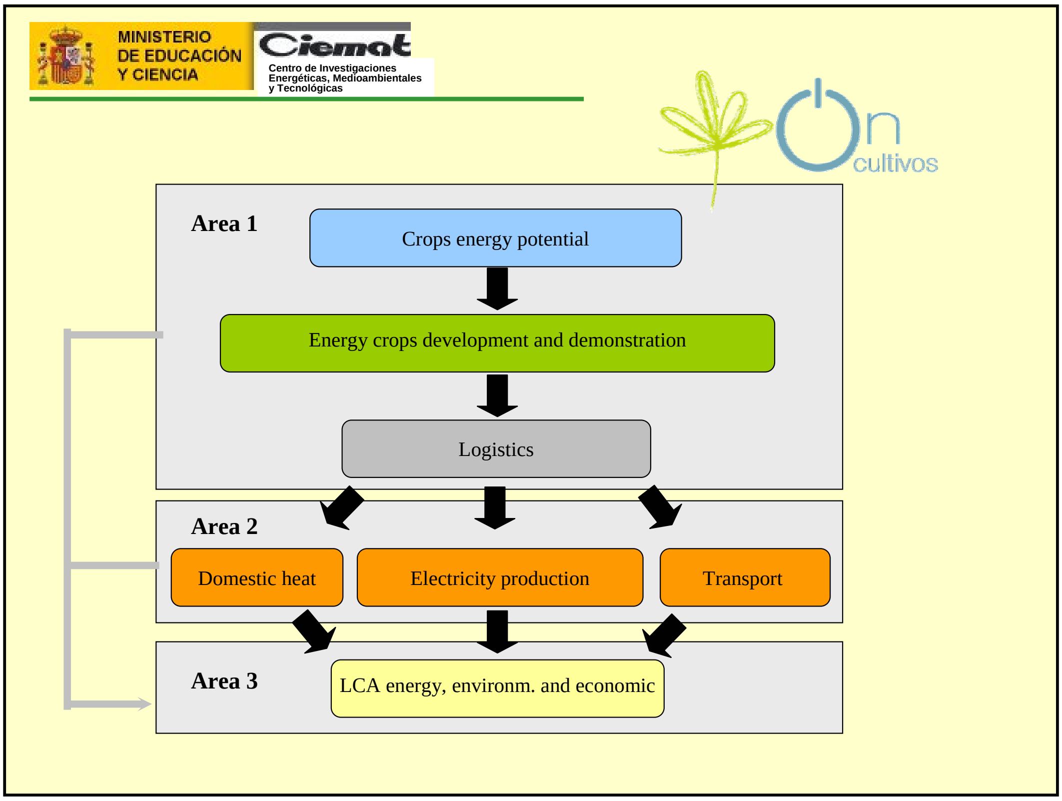
Some questions arising……

-Which are the challenges for energy crops biomass logistics?

-Which are the needs for development of sustainable energy crops biomass supply chains?

- Which are the more suitable applications for energy crops biomass and the needs for implementation?.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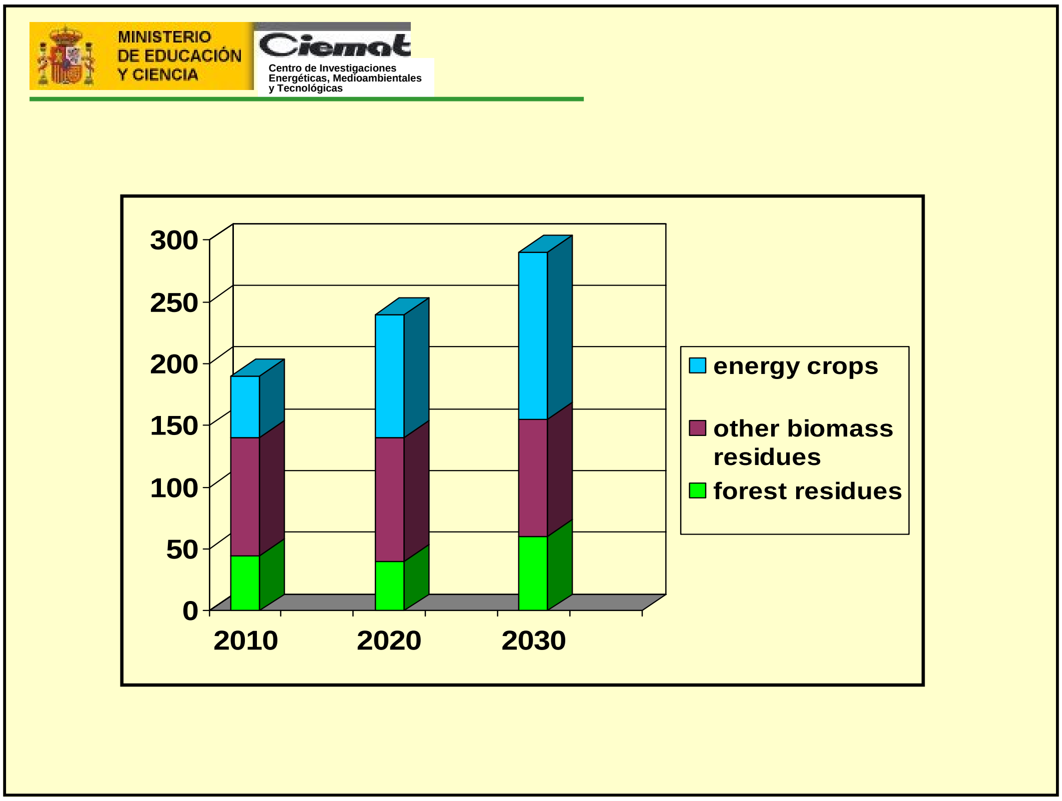
On
cultivos
Area 1
Crops energy potential
Energy crops development and demonstration
Logistics
Area 2
Domestic heat
Electricity production
Transport
Area 3
LCA energy, environm. and economic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y Tecnológicas
300
250
200
150
100
50
0
2010
2020
2030
energy crops
other biomass residues
forest residues

Processing & Logistics

Juan Carrasco & Calliope Panoutsou

Current state

- Energy crops essential to meet recent EU targets
- High- efficiency technologies require powerful 'logistics'
- Variable feedstock quality requirements arise from diverse end use options (heat & power, 2nd generation biofuels, industrial products, etc.).

Challenges

- Supply the industry with secure raw material all year round
  - Efficient land use strategies including both fertile and marginal land
  - Sustainability in biomass processing & handling
- Satisfy both large & small scale applications
- Integrate energy crops within the current crop patterns as complementary activities
- Ensure harvest window with crop selection
- Local biomass production & international biomass trade (international role of EU in supply and demand)

Harvesting & Collection

Effectiveness & Speed

- Use existing machinery
- Develop and test new machines and components
- Low contamination harvesting methods
- Harvesting and collection must be effective and high speed, deliver feedstock in optimal state, and minimize site impacts

Processing

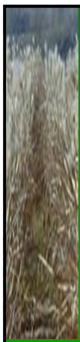
Increase the energy density

- Highly dependant on end use
- Develop physical engineering properties of biomass and their application to cleaning, densifying, and managing moisture
- Develop preprocessing technologies and equipment to clean and sort wet and dry biomass and to reduce particle size that increases density and produces a clean flowable bulk material

Storage & Transport

Reliability & Quality

- Bulky feedstocks- variable forms & physical properties
- Minimization of risks: fire, health.
- Ensure quality: feedstock physical specifications
- Optimise technology for chips / bales / pellets
- Assess different logistic structures, such as centralized fuel depots.



System integration

- System sustainability – energy and emissions balance over life cycle of chain
- System costs – bearing in mind residual feedstocks and value of process co-products.
- Stakeholders consultation – agro-industry, hauliers, energy industry, local communities.
- Demonstration of a portfolio of systems based on Best Practice (subject to regional ecology & climate)

Short Rotation Forestry, Short Rotation Coppice and energy grasses in the European Union:

Agro-environmental aspects, present use and perspectives

Introduction to background paper

Rothamsted, 17 October 2007

Jan-Erik Petersen, EEA

European Environment Agency

Objectives for background paper

- To provide a common basis for discussion
- To give a structured overview of key issues related to the production and environmental effects of permanent energy crops
- To review current data and information on:
  - Crop choice and production parameters
  - Current extent of plantations + critical factors for expanding the production of permanent energy crops
  - Agro-environmental aspects + research

➢ How can the paper be improved? What are the next steps to take for further analysis at European level?

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Section 2.1 + 2.2: Review of crop species, potential yields and area

- This section reviews standard information and relies mainly on review articles in literature; comments are requested on:

- ➢ Are the most important crop species covered?
- ➢ Tables 1 + 2 complete and correct?
- ➢ Yield and area data in table 3 complete and correct?

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Sections 2.3 + 2.4: Economic aspects and main barriers to implementation

- It was difficult to find up-to-date + comparable data on production costs and income.
- The section on barriers to implementation is taken from the IEA report on this issue.
- Comments are invited on:
  - ➢ Are tables 5 + 6 complete and correct?
  - ➢ Should section 2.3.1 be completed?
  - ➢ Is it worth or necessary to try updating the IEA work on technical and non-technical barriers?

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Chapter 3: agro-environmental aspects I

- The link between bio-energy cropping and environmental aspects is complex (multitude of factors; direct and indirect effects)
- We aimed to follow a structured approach:
  - Distinction of land use change + farm management practices
  - Review of potential impacts covers different environmental themes: soil and water resources, biodiversity and landscapes
  - Presentation of potential synergies

➢ Does this structure work?

➢ Should the emphasis be different?

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Chapter 3: agro-environmental aspects II

Potential impacts related to land use change:

- Depend very much on crop replaced
- Effects on soil and water are generally positive, but water consumption by crops emerges as an important issue
- Biodiversity and landscape effects can be very big and also negative; are scale-dependent

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Chapter 3: agro-environmental aspects III

Effects of different management practices:

- Look at different crop phases: establishment, growth, harvesting, clearance
- Risks to soil and water resources lower than with annual crops (***also in clearance phase?)***
- Consider water demand as important issue
- Landscape and biodiversity depend on spacing and scale of plantation

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Chapter 3: agro-environmental aspects IV

Examples of potential synergies:

- Create flood retention zones by using permanent energy crops
- Establish riparian buffer strips
- Combine waste water treatment and biomass production

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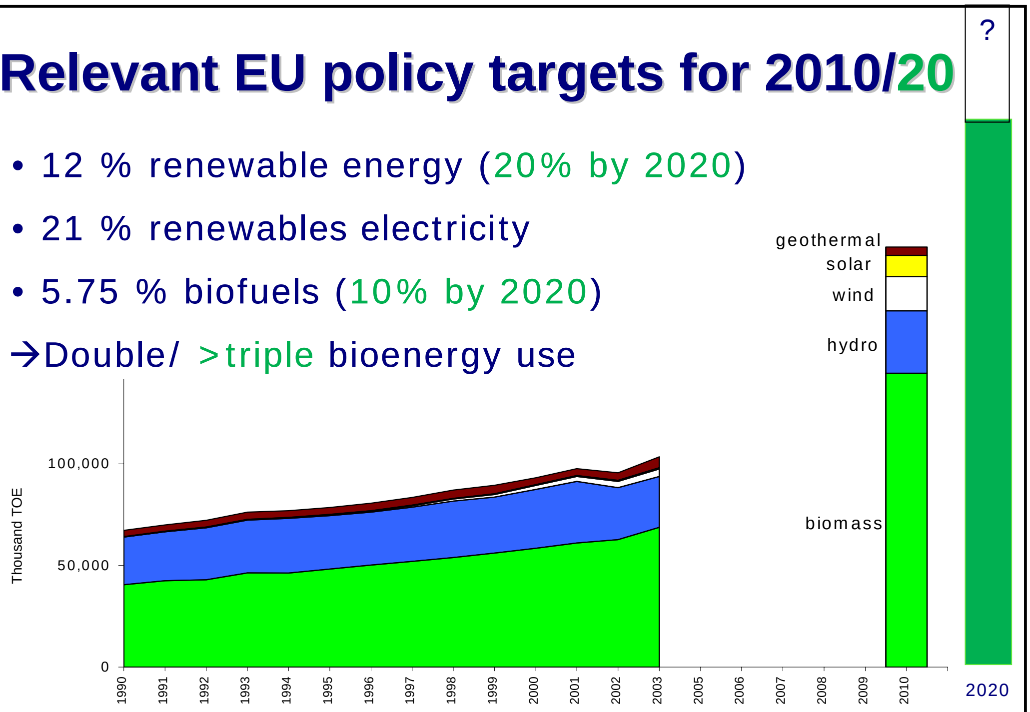
Relevant EU policy targets for 2010/20

- 12 % renewable energy (20% by 2020)
- 21 % renewables electricity
- 5.75 % biofuels (10% by 2020)

→Double/ >triple bioenergy use



Source: Eurostat for past data: EEA for projections
Please note: 2010 are modelled data, not policy targets!

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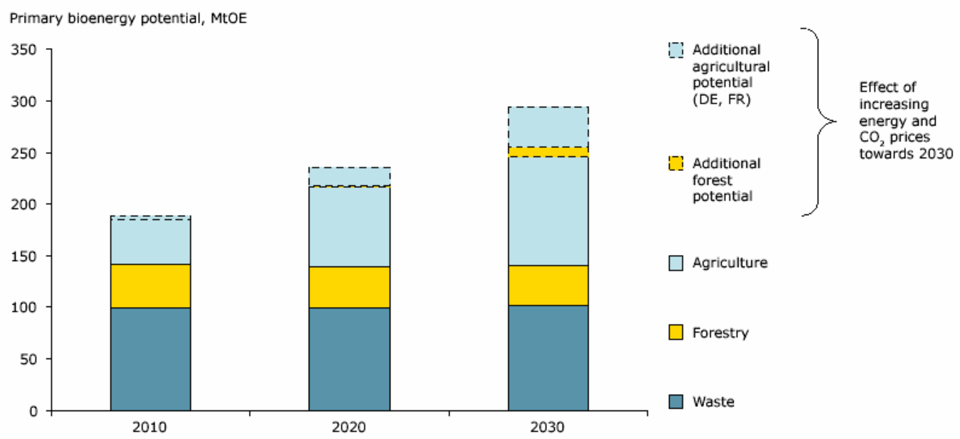
The environmentally compatible bioenergy potential, EU-25



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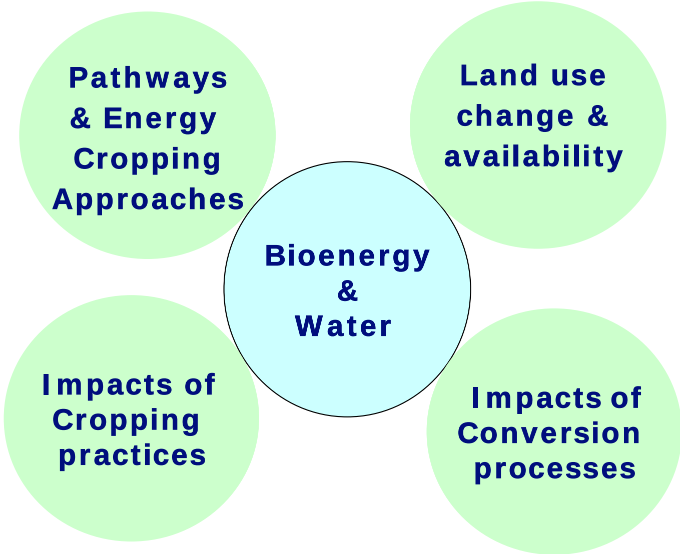
Environmental issues of energy cropping



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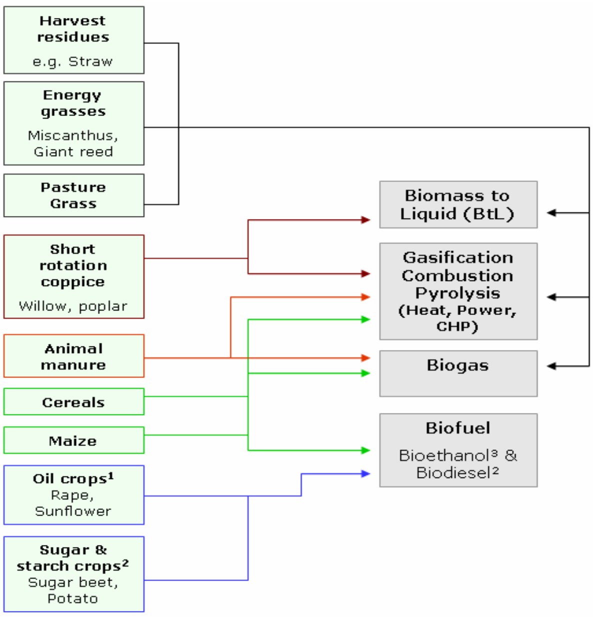
Bioenergy sources and pathways



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JRC, EEA
Expert Consultation Oct 17-18

Environmental impacts of energy crop production

Angela Karp, Chair

ROTHAMSTED RESEARCH

Bioenergy crops: impacts differ

Oil seed rape → oils → biodiesel

Wheat
Sugar beet
Sugar cane
→ starches
sugars
→ bioethanol

First generation biofuels

Second generation biofuels

Biomass crops
Miscanthus
Switchgrass
Willow
Poplar
→ lignocellulose → liquid fuels

→ biomass → heat
electricity

Heat and power

How perennial biomass crops differ

Biomass crops are:

- Perennial (in the ground for 7-25 yrs)
- Long harvesting cycles (willow)
- Winter/spring harvest
- Dense plantings of very tall crops
- Deep rooting

- Biomass crops are managed differently:
  - Minimal or no nitrate fertilisers
  - Herbicides to keep weeds down during establishment and after cut-back.
  - Typically no insecticides or fungicides

What are the potential impacts?

Physical
- Landscape
  - Character
  - Views
- Water:
  - Availability
  - Quality
  - Flood plains
- Soil:
  - Compaction
  - Drains
  - Nitrous oxide
  - Archaeology
  - Long term

Physical
- Air Quality/volatiles

Biotic
- Biodiversity
- Pests
- Diseases

Social & Economic
- Tourism
- Farming infrastructure
- Rural employment
- Family farm futures
- Vehicle movement
- Farm Viability

Rural Economy and Land Use Programme

RELU-Biomass

Social, economic and environmental implications of increasing rural land use under energy crops

http://www.relu-biomass.org.uk/

How RELU-Biomass is approaching it:

Assessing impacts of increasing land use under willow and miscanthus cf. arable crops/grassland by comparing:

- rural economics
- social acceptability
- landscape
- water use
- biodiversity

Additional Funds :

- Water quality (EA)
- Impacts on soils (EH)
- Scale (Defra)

Using 2 regions as study areas – South West and East Midlands

Conduct sustainability appraisal

Provide scientific framework for optimal location

Inform policy decisions and provide tools e.g. for

- Environmental Impact Assessments
- Strategic Environmental Assessments

Hydrology

We are measuring:

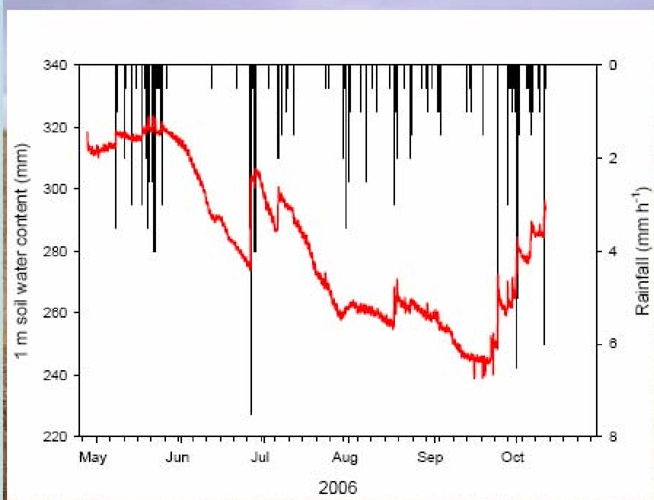
- Evaporation
- Carbon dioxide emissions
- Weather, i.e. rainfall, wind speed, solar radiation, air temperature and humidity
- Soil water contents and potentials

Hydrology

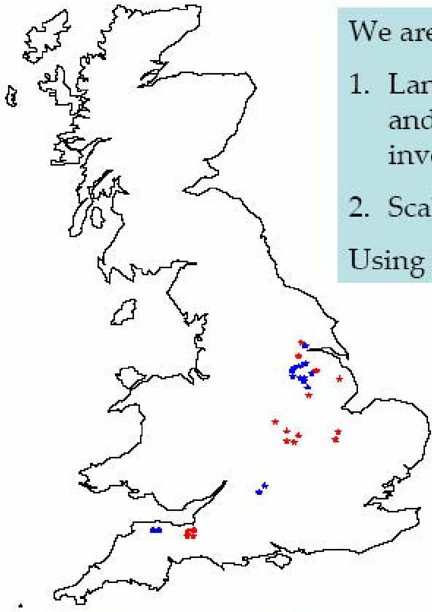
Example of results

Soil water content, from the surface down to a depth of 1 m is determined by the input of rainfall vs losses due to evaporation transpiration, runoff and soil drainage.

During June the rainfall was minimal. so soil water content decreased rapidly due to high transpiration rates.



Biodiversity



We are assessing impacts of:

1. Land-use change to willows and miscanthus on plants, invertebrates, birds
2. Scale of planting (Defra)

Using FSE-based protocols

★ Miscanthus (16 fields)
★ SRC (16 fields)

With Defra extension: total 24 fields each crop

Biodiversity sampling

- Weed species
- Weed biomass
- Weed seed return
- Seed bank

- Ground and plant active inverts
- Aerial/canopy inverts*
- Bees and butterflies
- Moths*
- Birds

* Not included in the FSEs

And: Field management: current and historical

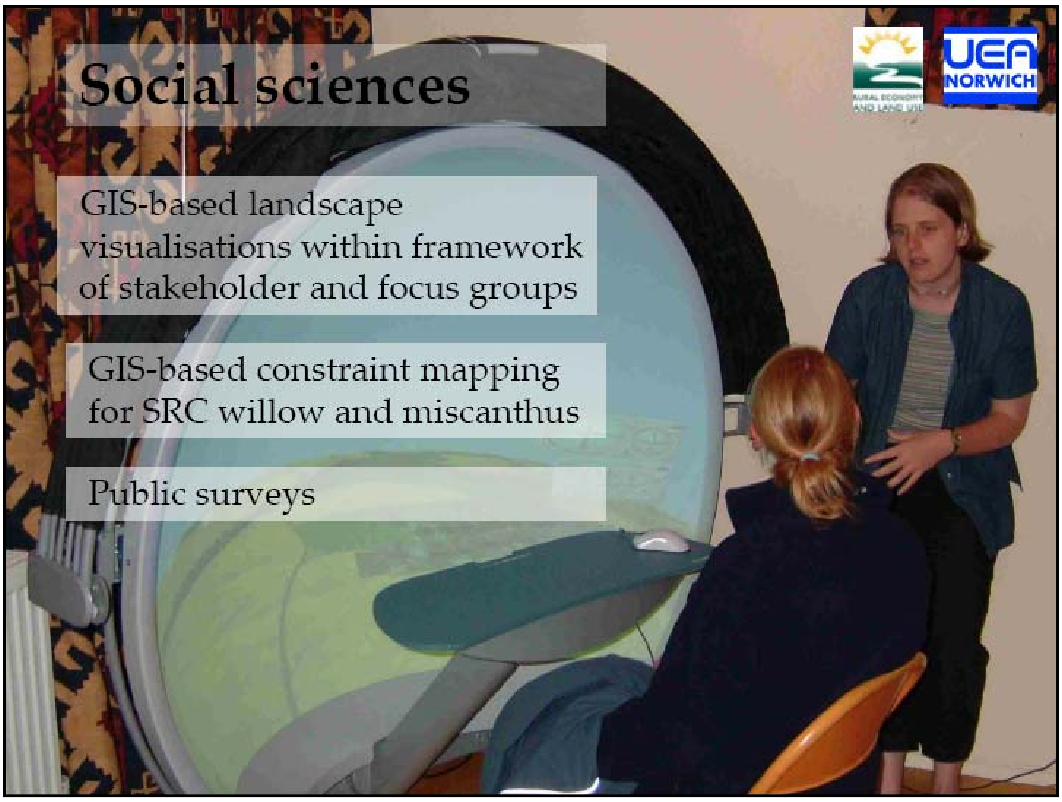
Rural economics

1. Farm system adjustment strategies, policy development and previous research
2. Farm economic survey:

   Duration 18 months

   Target size 60 farms, minimum 25 for each crop

   - Farmer characteristics
   - Farm system impacts
   - Farm-level economics
   - Rural economy implications



Issues to think about

Finding out what is known already:

1. Grey literature
2. Stakeholder involvement
   - Vital to engage early
   - Very positive experience
3. Farmers participation
4. Finding out information from industry

Scientific challenges:

1. Finding field sites that meet specification
2. Scale and integration of data at different scales
3. Translating results into sustainability appraisal
4. Lack of general awareness in public for surveys
5. Weighting the impacts

Questions posed at JRC-EEA Expert consultation

Production:

1. Estimation of yield potential
2. Scale of mapping
3. Barriers
4. Trading structures
5. Future yields

Environmental

1. Most important issues
2. Management vs crops
3. Key rules

Research gaps

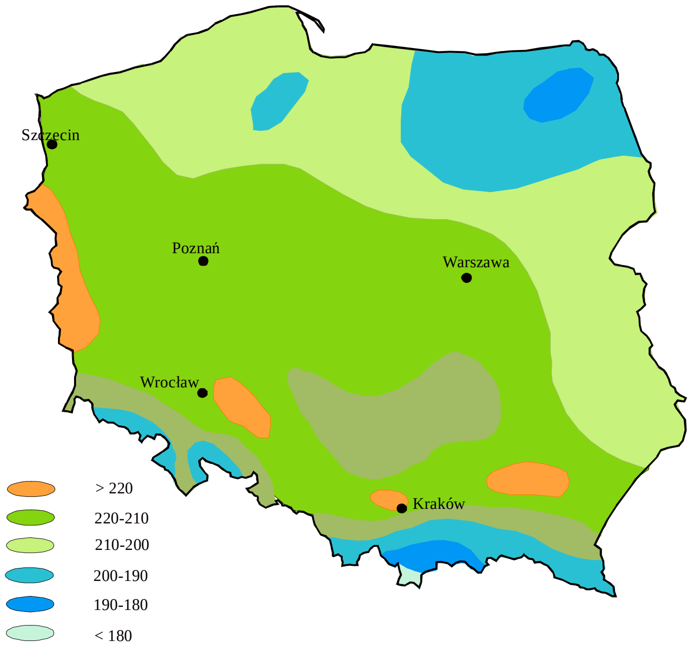

Management vs crop
ROTHAMSTED RESEARCH
THE GAME CONSERVANCY TRUST


Headland Management
THE GAME CONSERVANCY TRUST
ROTHAMSTED RESEARCH
There are crop differences
However, management (within crop and surrounds) is also very important

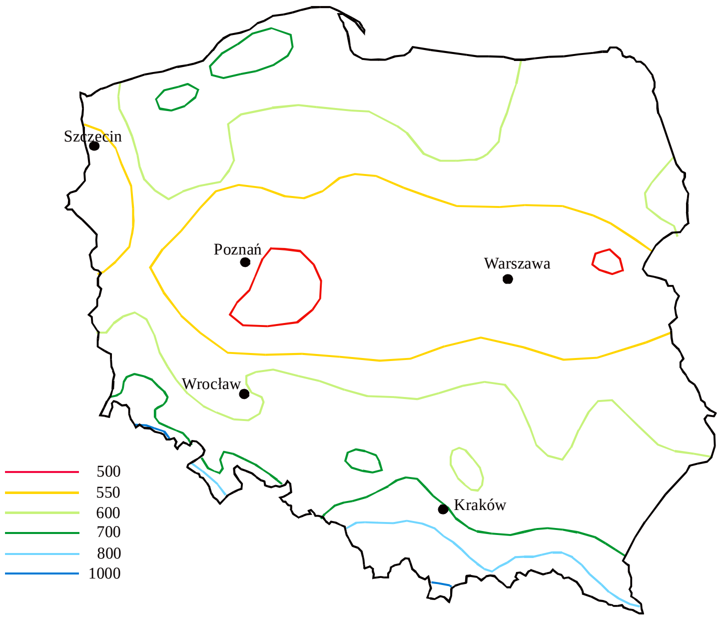
Some issues regarding Short Rotation Coppice cultivation in Poland

Paweł Rutkowski
Agricultural University of Poznań
redebede@au.poznan.pl

Average length of growing season [in days] in Poland

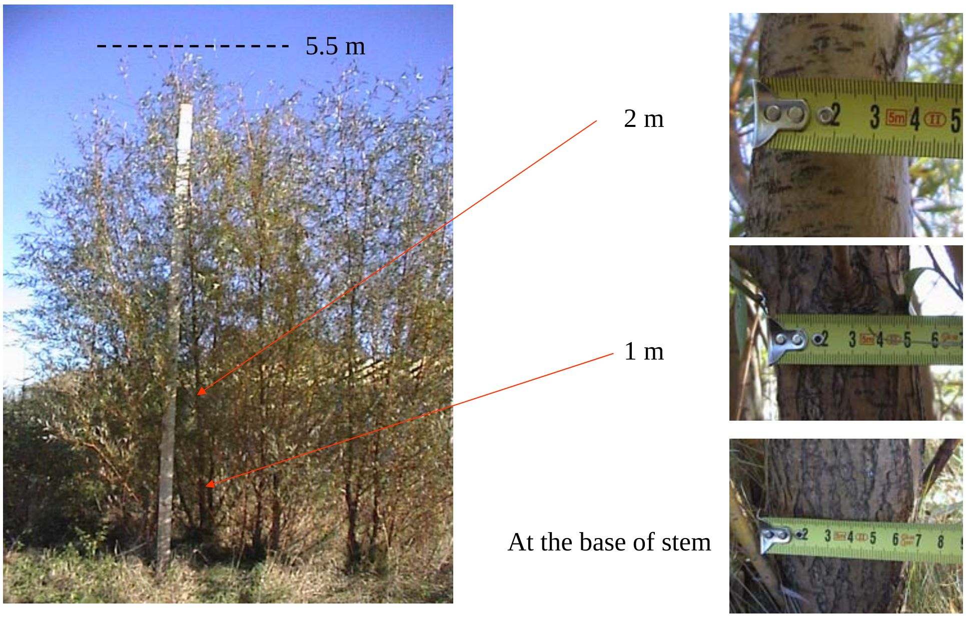


The average annual rainfall [in mm] in Poland



Salix alba

(4 years old, brown soil, experimental plot, 40 km west of Poznań)

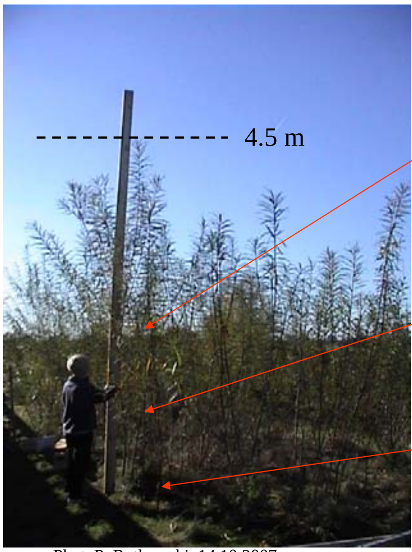


Phot. P. Rutkowski, 14.10.2007

Phot. P. Rutkowski, 14.10.2007

Salix viminalis

(2 years old, brown soil, experimental plot, 40 km west of Poznań)



Phot. P. Rutkowski, 14.10.2007

2 m

1 m

At the base of stem

Phot. P. Rutkowski, 14.10.2007

Salix viminalis needs 1kg of water for producing 6.3g of dry mass

↓

1 111 111, 11 kg of water per 7000000g (7 tons of d.m.)

↓

Precipitation – 600 mm
Evaporation – 500 mm

↓

Precipitation – Evaporation = 100 mm = 100 l/1m2 = 100kg/1m2 =

↓

1 000 000 kg of water /1 ha

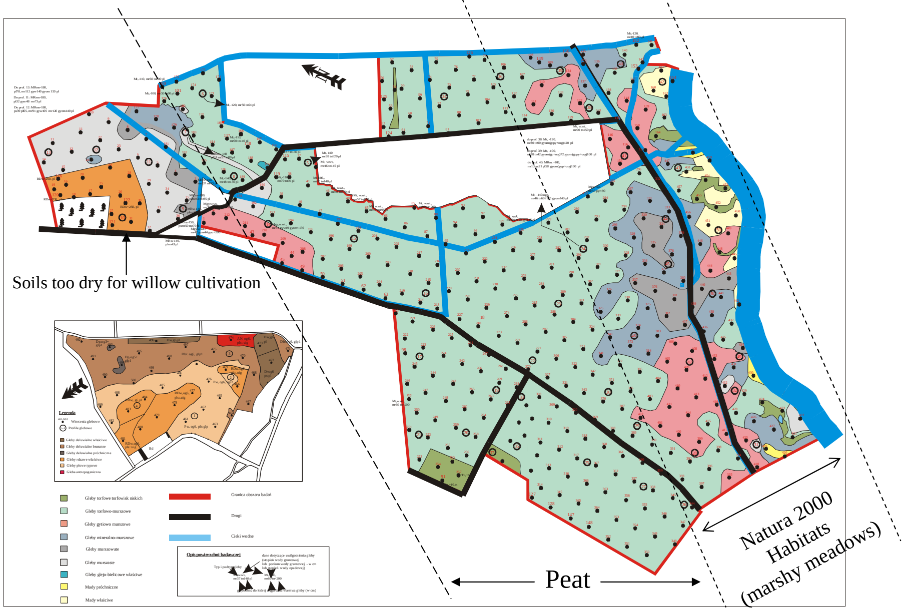
↓

Maximum crop – av. about 7t of dry mass/ha/year

Willows commercial plantation - map of soils

Area- about 400 ha

Year- 2003



The plantation after first year of cultivation.

Peat completely dried and destroyed by deep plowing

Biodiversity reduced to a few species

Oak of 40m of height

Volume of all tree = 17,59m3

100 trees/1 ha = 1759m3 at the age of 120 years

14,66 m3/1ha/1year

+/- 10 tons of wood/1ha/1year

+ biomass of other species
+ Natura 2000 habitat (9170)
+ biodiversity
+other ecological functions

100 cm in diameter

Environmental impacts of Short Rotation Coppice and Short Rotation Forestry systems

A summary of discussions at the JRC/EEA Expert Consultation, Rothamsted Research, 17-18 October 2007.

Tubby I.
Forestry Commission, Forest Research
Alice Holt Lodge, Farnham
Surrey GU10 4LH, United Kingdom

Introduction (1)

Conference agreed that the current report is a sound starting point highlighting many of the environmental issues associated with SRC and SRF biomass production systems. Group discussion identified several issues not included in the current draft in sufficient detail. These issues can be grouped under the following headings:

- ***Green House Gas emissions - carbon and energy balances of SRC and SRF systems***
- ***Impacts of SRC and SRF on biodiversity***
- ***Land use – food v fuel***
- ***Soil and water sustainability***

Introduction (2)

The extent to which these issues are likely to influence national and regional decision making process and policy is dependent on the following variables:

- ***Scale* –** is interest at the field, farm, region or country level?
- ***Crop husbandry and management*** – the availability and implementation of best practice guidance
- Availability and implementation of ***planning systems and guidance***

The relative priority of these issues is dependent on:

- The country or ***region in question*** (i.e. sustainable use of water is likley to be a high priority issue in southern regions but low priority elsewhere)
- The extent of future ***climate change and species distribution*** (crop species, pests and pathogens and wild species)

Carbon and energy balances

The reduction of greenhouse gas emissions via the displacement of fossil fuels by ‘carbon lean’ alternatives is one of the biggest drivers behind the establishment of energy crops in the EU.

The current report makes little reference to the potential carbon savings offered by biomass systems. The complex issue of soil carbon emissions and dynamics is omitted completely.

The following can reduce the potential for biomass systems to reduce carbon emissions from a ‘whole life cycle’ perspective:

- Cultivating *soils with a high carbon content* for the production of energy crops
- Using *intensive crop management regimes including inorganic fertilisers, irrigation and pesticides*
- Inefficient fuel processing and fuel transport logistics
- *Sub optimum conversion technologies*

Carbon and energy balances

Suggested sources of information and references:

- IEA Bioenergy Task 38 'The role of soil carbon in the GHG balance of bioenergy systems'

www.ieabioenergy-task38.org/publications/T38_Soil_Carbon.pdf

- IEA Bioenergy Task 38 'Answers to ten frequently asked questions about bioenergy, carbon sinks and their role in global climate change' www.ieabioenergy-task38.org/publications/faq/

- JRC 'Well to Wheels' reports, http://ies.jrc.ec.europa.eu/wtw.html

- DTI report – 'Carbon and energy balances for a range of biofuels options', www.berr.gov.uk/files/file14925.pdf

Impacts on biodiversity (1)

- It was felt that context was very important when discussing biodiversity. It is not always possible to assign individual crop species as having positive or negative impacts on biodiversity without having a better understanding of current land use and proposed energy crop management systems. SRC and SRF established on intensively farmed agricultural land is likely to have a negligible or positive effect on biodiveristy at the local scale. The same crops planted on peat heathland, moorland or wetland may have negative effects on local biodiversity. At the landscape scale SRC or SRF systems introduce additional habitat and niches into the environment. During discussion specific examples of exotic species damaging local 'high value' habitat were given. It was felt that these examples were in fact down to poor planning controls and guidance rather than the species used *per se*.
- However, it was noted that compared with other perennial energy crops, willow SRC has a relatively high potential for enhancing biodiversity in the agricultural environment (at least in northern Europe) as it can support a large number of invertebrate species. Willow SRC can support some species used by governments as 'living standards indicators'. This potential can be capitalised on if a sympathetic management regime of headlands surrounding the crop and rides and corridors within the crop is planned for at the establishment stage. Suitable planning and management could include establishing plant and shrub species native to the area along rides and mowing headlands outside bird nesting times.

Impacts on biodiversity (2)

- Harvesting SRC during the summer months (to avoid using machines on waterlogged soils) could have a detrimental affect on biodiversity.
- As there is no need for annual cultivation in SRC and SRF systems the biodiversity value of soils under these crops may be higher than for soils under conventional agricultural crops. Fungicide, herbicide and insecticide applications are likely to be absent or less frequent in SRC and SRF systems compared with conventional agricultural crops.
- Other tree and shrub species (i.e. *Castanea* spp., *Fraxinus* spp., *Betula* spp.) native or naturalised in EU countries could provide similar benefits if managed as coppice or forestry for energy production. Exotic tree species can be used successfully in SRC or SRF systems but careful consideration of local biodiversity issues and current land use is required prior to planting.

Suggested sources of information and references:

- DTI report – ARBRE monitoring, Ecology of Short Rotation Coppice www.berr.gov.uk/files/file14870.pdf
- RELU Biomass – biodiveristy studies http://www.relu-biomass.org.uk/Research.php
- LTS report – 'A review of the potential impacts of short rotation forestry' www.forestry.gov.uk/pdf/SRFFinalreport27Feb.pdf/$FILE/SRFFinalreport27Feb.pdf
- Forestry Commission Practice Note Establishment and Management of Broadleaved Coppice Plantations for Energy

www.biomassenergycentre.org.uk/portal/page?_pageid=75,15184&_dad=portal&_schema=PORTAL

Land use, food v fuel

- This issue is becoming a well established argument in the popular media as well as in scientific literature. High prices for crops such as wheat and barley make it difficult to present convincing economic arguments for the establishment of SRC and SRF on productive agricultural land. There is also growing demand for liquid biofuels produced using grain and oilseed crops. This may result in SRC and SRF being established on less productive land currently under permanent pasture or managed as heathland, moorland or wetlands.
- Cultivating this type of site could lead to the oxidisation of large quantities of soil carbon and could have negative impacts for species associated with these habitat types.
- Climate change and the exhaustion of unsustainable sources of irrigation may alter the range and area of sites currently suitable for food production. This could exacerbate competition between crops destined for use in the food and energy markets.
- These points highlight the need to use all energy crops in conjunction with the most efficient conversion technologies available in order to optimise the use of productive agricultural land. Biomass from other sources such as forestry and woodland management and from the waste stream must be exploited at the same time or prior to the establishment of perennial energy crops on agricultural land.

Suggested sources of information and references:

UN report 'Sustainable Bioenergy: A Framework for Decision Makers'

http://esa.un.org/un-energy/pdf/susdev.Biofuels.FAO.pdf

Soil and water sustainability (1)

The group cited several examples of SRC or SRF systems had or could impact the sustainable use of soil and water. Both positive and negative impacts were identified.

Potential positive impacts:

- SRC and SRF could be used to manage *flood risk*
- The production of food crops reliant on *unsustainable irrigation in southern Europe* could be replaced by growing less demanding SRC or SRF species
- The reduced cultivation of soil associated with a change of land management from annual crops to SRC or SRF could *reduce erosion and increase the organic matter content of soil*
- Large areas of land equipped with irrigation infrastructure have been abandoned in Southern Europe. SRC or SRF could be grown on this land using *modest amounts of irrigation (compared to fruit and vegetable crops)*
- Depending on management regimes, SRC and SRF have the potential to *reduce fertiliser input* on agricultural land compared to conventional crops.

Soil and water sustainability (2)

Potential negative impacts

- SRC and SRF systems may have a *higher rate of water consumption compared with conventional crops*. This may reduce aquifer recharge and river flow rates.
- The production of SRC or SRF on some soil types could lead to a *reduction in soil fertility*
- Large areas of bare soil associated with the establishment phase of SRC could lead to *soil erosion, especially on sloping sites*
- Planting SRC or SRF on flood plains could lead to *water backing up and flooding land further upstream*
- Harvesting on waterlogged soils may lead to compaction and erosion.
- Summer harvesting to avoid waterlogged soils may lead to *reduced nutrient recycling.*

Suggested sources of information and references:

- DTI report – Short Rotation Coppice for energy production hydrological guidelines

www.berr.gov.uk/files/file14960.pdf

- Centre for Ecology and Hydrology

http://www.ceh.ac.uk/sections/ph/JonFinch.html

Thematic session on current research gaps in Short Rotation Crops

What do we know for sure?
What do we know more or less?
What don't we know?

Wolter Elbersen

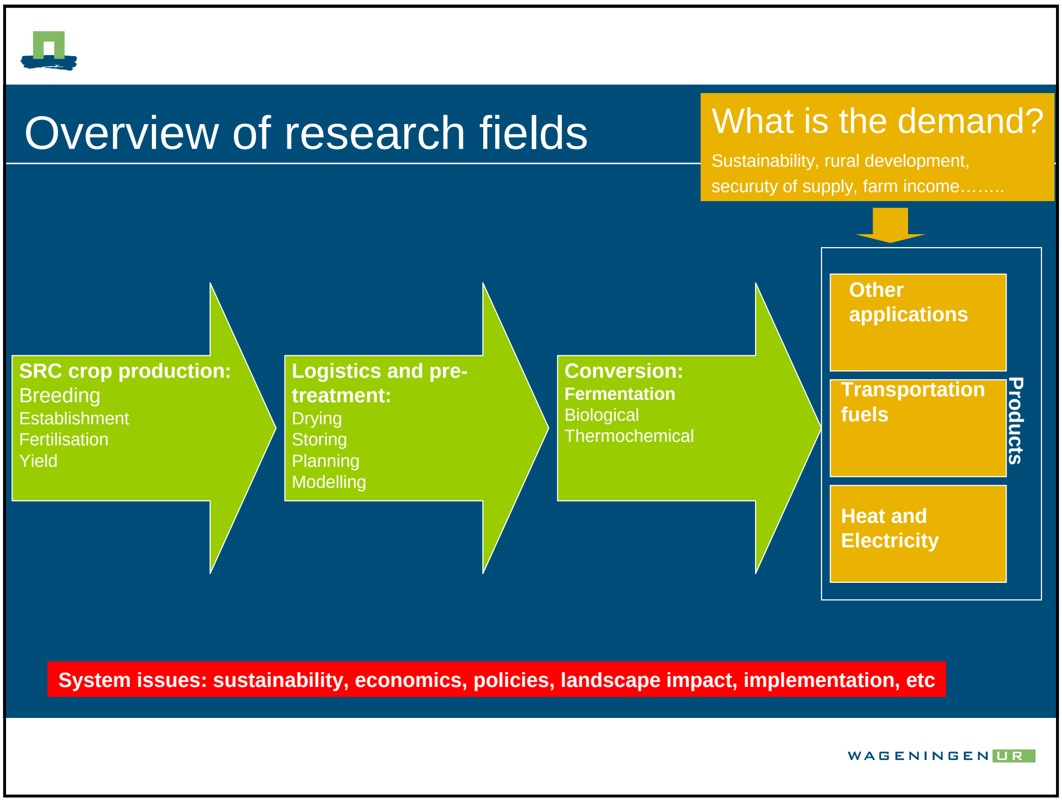
Bioenergy at WAGENINGEN UR

WAGENINGEN UR

What are the main issues in SRF Research and R&D?

- Which critical knowledge gaps have emerged from the perspective of Implementation and Agri-environmental perspective?
- In an environmental perspective should we focus on land use change, landscape effects, impacts of different cultivation practices, on direct or indirect effects?
- How do SRF, SRC or perennial grasses perform for phyto-remediation of soils, recycling of wastewater and sludge, carbon sequestration …?
- Is there ongoing research or field experimentation performed outside of the European Union that is relevant for the European situation?

WAGENINGEN UR



SRC crop production (1):

- Establishment (seed, rhizome, risk,)
- Pest control (Breeding / management)
- Fertilisation:
  - Nutrient demand (how much N/P is needed N response)
  - Do we understand the mechanisms?
  - We need to understand lack of N response in Miscanthus and switchgrass!
- Yield (potential vs practical)?
  - Database on SRC crop experiments and practical yields
  - Long term data needed
  - What do we know about stand maintenance?

WAGENINGEN UR

SRC crop production (2):

- Water
  - low water demand, erosion control
- Breeding demands……
  - How to get high yield under unfavorable conditions (low nutrients, low soil quality)
  - Biomass quality
  - Water use

WAGENINGEN UR

Logistics and pre-treatment:

- Harvest
  - Do we have the right machinery? (will business take care of this?)
  - Harvest losses?
- Handling
- Drying
- Storage (moisture, losses) - old data available
- One step vs. 2 step system (what is best?)
- Pre-treatment (pyrolysis, pellets, torrefaction, etc) research needs?

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Conversion:

- What quality is needed?
- Ash?
- Ash quality?

- Demand for Lignocellulosic ethanol (low lignin?)
- Demand for biorefinery systems?

- SRC for biogas?
  - What is the value of dry material
  - Can you harvest during season?

WAGENINGEN UR

System issues:

- Sustainability
  - SRC environmental value? (biodiversity?)

  - Is it nature with production component? Is it agriculture with a large natural value?

  - GHG balance?

WAGENINGEN UR

Sustainability criteria under development (NL)

Principle:

- *The **green house gas of the production chain** and application of the biomass must be positive*
- *Biomass production must not be at the expense of **important carbon sinks** in the vegetation and in the soil*
- The production of biomass for energy must **not endanger the food supply and** local biomass applications (energy supply, medicines, building materials).
- Biomass production must not **affect protected or vulnerable biodiversity** and will, where possible, have to strengthen biodiversity.
- In the production and processing of biomass the **soil and soil quality** are retained or improved.
- In the production and processing of biomass **ground and surface water** must not be depleted and the water quality must be maintained or improved.
- In the production and processing of biomass the **air quality** must be maintained or improved.
- The production of biomass must contribute towards **local prosperity.**
- The production of biomass must contribute to the social **well being** of the employees and the local population.

(Cramer report, 2006)

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Implementation of sustainability criteria is still unclear:

- Distributors will have to **report** on production chain GHG efficiency – CO2 calculators developed now
- **Minimal GHG efficiency** will be required: **30% for transport fuel 70% for heat and electricity** OR reward for higher efficiency
- Discussion of inclusion of **GHG effects caused by land use change**: How to include?
- "**GHG losses** due to land use change must be **recovered in 10 years**"? (direct or indirect also?)

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Perspective of

- It appears that GHG balance minimal demands are in tune with WTO and EU regulations…….
  - Will low input / high output character of SRC finally pay off?
  - We need data to make GHG balance calculations!!
  - GHG effects of land conversion related to SRC
  - N2O emissions
- Will sustainability demands change economic perspectives of SRC?

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System issues:

- Economics
  - How to deal with need for longtime commitment and short term economic outlook?
  - What is role of SRC in biomass feedstock mix? (by-products vs SRC)
  - Scale issues: small scale, low logistic cost, low conversion efficiency vs large scale
  - Comparative data between countries and projects

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System issues:

- Policies and implementation
  - Stop/start effects of policies.
  - How to get the message over to farmers?
  - How to get the message to policy makers?
  - How to model policy effects?

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System issues:

- Landscape impacts:
  - Visual aspects
  - Landscape character
    - Openness
    - diversity
  - Landscape values
    - Traditional values
    - Historic values

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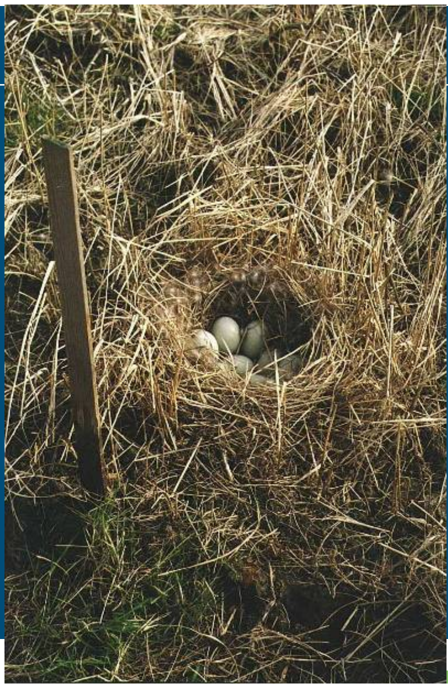
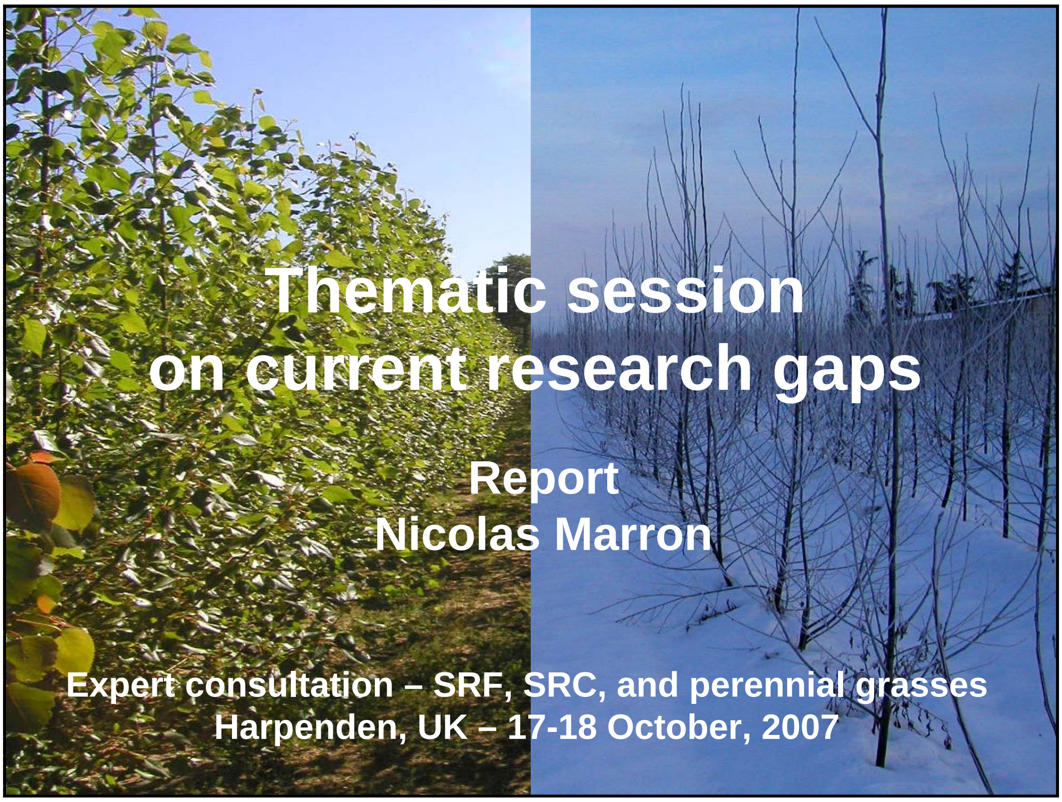
- Biodiversity:
  - What are go and no-go areas for bioenergy production?
  - What bioenergy systems fit best in the go areas?
    - Crop mix
    - Farming practice
    - Biomass chain





In general…

<u>Lack of knowledge concerning integration</u>:

1- Space / geographical integration

- ➔ European heterogeneity
- ➔ Differences linked to space scale of interest

2- Time integration

- ➔ Only few studies dealing with long term experiments

3- Process chain integration

- ➔ Large variability on the field can lead to narrow variability concerning the end-product(s)

4- Discipline integration

- ➔ Need of inter-domain studies
- ➔ Need of a better dialogue with farmers and policy makers

In more details…

Questions along the process chain:

4. System

1. Crop production

2. Logistics

3. Conversion

In more details…

Questions along the process chain:

1. Crop production

- How to maximize the production? How to make it as profitable as possible?
  - ➔ In terms of water, fertilization, used species, plantation management…
- How to maintain productivity in the long term?
  - ➔ What is the life-span of a plantation?

In more details…

Questions along the process chain:

2. Logistics

- Harvest, storage, drying, treatments…
  How to adapt / optimize them as a function of the used species and needs?

In more details…

Questions along the process chain:

3. Conversion

- What means "quality" of biomass?
  ➔ Lignin, ash contents…?

- How to evaluate biomass quality?

In more details…

Questions along the process chain:

4. System
Environmental considerations

- Biodiversity
  ➔ Very different situations in Europe (North vs. South?)
  ➔ What is acceptable? Maintenance or new species? What are the thresholds to be used?

- Go vs. no go areas
  ➔ What to plant and where?
  ➔ No general rules – Only specific cases

In more details…

Questions along the process chain:

4. System
Environmental considerations

- Greenhouse gases, oxide nitrous emissions, carbon sequestration…
  ➔ Need of a better knowledge / understanding

➔ In relation with the current climate changes

Summary

Expert Consultation

“Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

The objective of this document is to provide a Summary of the discussions held during the JRC/EEA/Rothamsted Expert Consultation on "Short Rotation Forestry, Short Rotation Coppice and energy grasses in the European Union: Agro-environmental aspects, present use and perspectives". This meeting was held at Rothamsted in Harpenden (United Kingdom) on 17- 18 October 2007 and was attended by 25 experts from 13 countries.

This document aims to provide a summary of the topics discussed and not the detailed information about the Meeting that can be found in other parts of this publication, for example: meeting objective description, agenda, meeting background document, technical session introductions, technical session reports, list of suggested references, technical Annex (Spain), list of participants. In particular it is suggested to consult the Chair Persons introductions to access quantitative data related to some aspects of Short Rotation Crops either in the European Union or in selected Member States. This document thus concentrates on conclusions and recommendations.

The Meeting was chaired by A.Karp (Rothamsted), J.F.Dallemand (European Commission Joint Research Centre), J.-E.Petersen (European Environment Agency) as co-organisers. Each Technical Session benefited from the work of a chair person providing a 20 minutes introduction and of a rapporteur providing a 5 minutes summary at the end of the meeting. Special thanks are due to them, this document being mostly based on their contribution and the input provided by the experts.

The Technical Sessions were organised as follows:
- Introduction to Short Rotation Forestry, Short Rotation Coppice and energy grasses
Chair: T.Verwijst, Swedish University of Agricultural Sciences
Rapporteur: G.Alker, Thames Valley Energy)
- Thematic session on processing and logistics
Chair: J.Carrasco, CIEMAT, Spain
Rapporteur: C.Panoutsou, Imperial College, London
- Thematic session on environmental impacts
Chair: A.Karp, Rothamsted
Rapporteur: I.Tubby, Forestry Commission, United Kingdom
- Thematic session on current research gaps
Chair: W.Elbersen, Wageningen University, Netherlands
Rapporteur: N.Marron, INRA, France.

The Expert consultation documentation can be found on JRC Biofuels Action web site http://re.jrc.ec.europa.eu/biof/

In the first **Session of Thematic Introduction to Short Rotation Forestry, Short Rotation Coppice and energy grasses,** it appeared that there are real problems of terminology, and that this complicated not only the technical exchange but also the understanding of the Background Document information. For this reason, it was decided to follow as much as possible in the future the terminology of the International Energy Agency Bioenergy Task No 30 (Short Rotation Crops for Bioenergy Systems, see www.shortrotationcrops.org).
For IEA Task 30, Short Rotation Crops means woody crops such as willows, poplars, Robinia and Eucalyptus with coppicing abilities, as well as lignocellulosic crops such as reed canary grass and Miscanthus.

Another point stressed was related to the extreme care to take with yield data circulating due to factors such as differences between experimental yield, actual yield, potential yield etc.
For Short Rotation Crops, it appeared that in Sweden but also in United Kingdom and other EU Member states, there is a significant difference between the expected and actual take-up of Short Rotation Crops. A large gap is observed between expected and actual areas. The reason explaining why the area is low and how to resolve this problem was partly discussed. One of the reasons mentioned is the weakness of specialised extension services. On this topic, it is suggested to consult the Annex to the meeting Background Paper (from IEA Bioenergy Task 30) on Technical and Non-Technical barriers to the development of Short Rotation Crops.
In order to meet Climate Change targets, a resource shift is needed from annuals to perennials. It was also stressed that there are still many knowledge gaps and that further research is necessary, for example on regionally adapted clones.
Short Rotation Crops currently also face difficulties of economic sustainability unless there is a continued targeted funding and the identification of long-term public support mechanisms.
Thus there is need to better explain to the entire society the benefits of Short Rotation Crops that are not always recognised, and to improve dissemination and lobbying for incentives schemes at various levels. The lack of government leadership was also mentioned with a plea for stronger policy and targets that optimise conversion chain efficiencies and environmental benefits.
It was stressed that in the European conditions the GHG savings per unit of land area from different bioenergy options for example in the case of electricity by combustion of miscanthus or other Short Rotation Crops are higher compared to those from first generation biofuels for transport.

The **Second session dealt with Short Rotation Crops Processing & Logistics**. Regarding the current status, energy crops are essential to meet recent EU targets. High-efficiency technologies require powerful ‘logistics’. Variable feedstock quality requirements arise from diverse end use options (heat & power, 2nd generation biofuels, industrial products…).
The challenges to be met were identified as:
- Supply the industry with secure raw material all year round (based on efficient land use strategies including both fertile and marginal land and sustainability in biomass processing & handling),
- Satisfy both large & small scale applications,
- Integrate energy crops within the current crop patterns as complementary activities,
- Ensure harvest window with crop selection,
- Ensure local biomass production while at the same time developing international biomass trade (international role of EU in supply and demand).

Regarding harvesting & collection, key factors are effectiveness and speed based on:
- Use of existing machinery,
- Development and test of new machines and components,
- Use of low contamination harvesting methods,
- Efficient harvesting and collection, at high speed, with delivery of feedstock in optimal state and the minimisation of site impacts.

For Short Rotation Crops processing, there is a need to increase the energy density, which is highly dependant on end use. This goes through:
- Development of physical engineering properties of biomass and their application to cleaning, densifying, and managing moisture,

- Development of pre-processing technologies and equipment to clean and sort wet and dry biomass and to reduce particle size that increases density and produces a clean flowable bulk material.

Regarding storage and transport of Short Rotation Crops, the importance of reliability and quality was stressed, taking into account:
- Bulky feedstocks of variable forms and physical properties,
- Minimization of risks (fire, health…),
- Quality targets based on feedstock physical specifications,
- Optimisation of the technology for chips/bales/pellets,
- Assessment of different logistic structures, such as centralized fuel depots.

The importance of system integration was also stressed considering:
- System sustainability based on the analysis of energy and emissions balance over the entire life cycle of the chain,
- System costs, bearing in mind the residual feedstocks and the value of the process co-products,
- Stakeholder consultation (agro-industry, hauliers, energy industry, local communities…),
- Demonstration of a portfolio of systems based on Best Practices (subject to regional ecology and climate).

The Expert Consultation **Third Session** dealt **with environmental impacts of Short Rotation Crops.** The meeting participants agreed that the draft Background Document was a sound starting point highlighting many of the environmental issues associated with Short Rotation Crops biomass production systems. Group discussion identified several issues that were not sufficiently discussed or included in the current draft due to resource limitations and the wish to keep the document succinct. These issues can be grouped under the following headings:
- GHG emissions - carbon and energy balances of Short Rotation Coppice and Short Rotation Forestry systems,
- Impacts of Short Rotation Coppice and Short Rotation Forestry on biodiversity,
- Land use (food vs. fuel),
- Soil and water sustainability.

The extent to which these issues are likely to influence national and regional decision making process and policy is dependent on the following variables:
- Scale – lies the interest at the field, farm, region or country level?
- Crop husbandry and management, related to the availability and implementation of best practice guidance,
- Availability and implementation of planning systems and guidance.

The relative priority of these issues is dependent on:
- The country or region in question (i.e. sustainable use of water is likely to be a high priority issue in southern regions but low priority elsewhere),
- The extent of future climate change and species distribution (crop species, pests and pathogens and wild species).

In relation to carbon and energy balances, the reduction of greenhouse gas emissions via the displacement of fossil fuels by ‘carbon clean’ alternatives is one of the biggest drivers behind the establishment of energy crops in the EU. Participants pointed out that the draft

Background Document made little reference to the potential carbon savings offered by biomass systems. The complex issue of soil carbon emissions and dynamics is omitted completely. This issue had deliberately been omitted from the draft document due to lack of resources but the EEA as sponsor of the background document agreed to review its inclusion in the post workshop revision phase for the background document.

The following can reduce the potential for biomass systems to reduce carbon emissions from a ‘whole life cycle’ perspective:
- Cultivating soils with a high carbon content for the production of energy crops,
- Using intensive crop management regimes including inorganic fertilisers, irrigation and pesticides,
- Inefficient fuel processing and fuel transport logistics,
- Sub optimum conversion technologies.

In relation to impacts on biodiversity, it was felt that context was very important when discussing biodiversity. It is not always possible to assign individual crop species as having positive or negative impacts on biodiversity without having a better understanding of current land use and proposed energy crop management systems. Short Rotation Crops established on intensively farmed agricultural land are likely to have a negligible or positive effect on biodiversity at the local scale. The same crops planted on peat heathland, moorland or wetland may have negative effects on local biodiversity. At the landscape scale Short Rotation Crops introduce additional habitat and niches into the environment. During the discussion, specific examples of exotic species damaging local ‘high value’ habitat were given. It was felt that these examples were in fact down to poor planning controls and guidance rather than the species used per se.
However, it was noted that compared with other perennial energy crops, willow in Short Rotation Coppice has a relatively high potential for enhancing biodiversity in the agricultural environment (at least in northern Europe) as it can support a large number of invertebrate species. Willow Short Rotation Coppice can support some species used by governments as ‘living standards indicators’. This potential can be capitalised on if a sympathetic management regime of headlands surrounding the crop and rides and corridors within the crop is planned for at the establishment stage. Suitable planning and management could include establishing plant and shrub species native to the area along rides and mowing headlands outside bird nesting times. On the other hand, harvesting Short Rotation Coppice during the summer months (to avoid using machines on waterlogged soils) could have a detrimental affect on biodiversity.
As there is no need for annual cultivation in Short Rotation Coppice and Short Rotation Forestry systems, the biodiversity value of soils under these crops may be higher than for soils under conventional agricultural crops. Fungicide, herbicide and insecticide applications are likely to be absent or less frequent in Short Rotation Crops systems compared with conventional agricultural crops.
Other tree and shrub species (i.e. *Castanea spp., Fraxinus spp., Betula spp.*) native or naturalised in EU countries could provide similar benefits if managed as coppice or forestry for energy production. Exotic tree species can be used successfully in Short Rotation Coppice and Short Rotation Forestry systems but careful consideration of local biodiversity issues and current land use is required prior to planting.

The issue of land use, food vs fuel was also debated. This issue is becoming a well established argument in the popular media as well as in scientific literature. High prices for crops such as wheat and barley make it currently difficult to present convincing economic arguments for the

establishment of Short Rotation Crops on productive agricultural land. There is also growing demand for liquid biofuels produced using grain and oilseed crops. This may result in Short Rotation Crops being established on less productive land currently under permanent pasture or managed as heathland, moorland or wetlands. Cultivating this type of site could lead to the oxidisation of large quantities of soil carbon and could have negative impacts for species associated with these habitat types.
Climate change and the exhaustion of unsustainable sources of irrigation may also alter the range and area of sites currently suitable for food production. This could exacerbate competition between crops destined for use in the food and energy markets.
These points highlight the need to use all energy crops in conjunction with the most efficient conversion technologies available in order to optimise the use of productive agricultural land. Biomass from other sources such as forestry and woodland management and from the waste stream must be exploited at the same time or prior to the establishment of perennial energy crops on agricultural land.

In relation to soil and water sustainability, the group cited several examples of Short Rotation Crops systems which had or could impact the sustainable use of soil and water. Both positive and negative impacts were identified. Among the potential positive impacts:
- Short Rotation Crops could be used to manage flood risk,
- The production of food crops reliant on unsustainable irrigation in southern Europe could be replaced by growing less demanding Short Rotation Crops species,
- The reduced cultivation of soil associated with a change of land management from annual crops to Short Rotation Crops could reduce erosion and increase the organic matter content of soil,
- Large areas of land equipped with irrigation infrastructure have been abandoned in Southern Europe. Short Rotation Crops could be grown on this land using modest amounts of irrigation (compared to fruit and vegetable crops),
- Depending on management regimes, Short Rotation Crops have the potential to reduce fertiliser input on agricultural land compared to conventional crops.

The potential negative impacts to be considered are:
- Short Rotation Crops systems may have a higher rate of water consumption compared with conventional crops. This may reduce aquifer recharge and river flow rates.
- The production of Short Rotation Crops on some soil types could lead to a reduction in soil fertility.
- Large areas of bare soil associated with the establishment phase of Short Rotation Crops could lead to soil erosion, especially on sloping sites.
- Planting Short Rotation Crops on flood plains could lead to water backing up and flooding land further upstream.
- Harvesting on waterlogged soils may lead to compaction and erosion.
- Summer harvesting to avoid waterlogged soils may lead to reduced nutrient recycling.

The experts also discussed very briefly the use of eucalyptus in the South of Italy. The discussion started from an example of bad practice and it was not possible to cover in this meeting the issue of the various uses of eucalyptus, the respective advantages/disadvantages of eucalyptus cultivation in Mediterranean ecosystems and its present or potential contribution to bioenergy. While various arguments were put forward that advocated caution against a wide-scale use of eucalyptus a more detailed analysis should take place in a forum explicitly devoted to Mediterranean ecosystems.

The Fourth **Thematic Session of the Expert Consultation** dealt with **current research gaps**. It was retained that there is a lack of knowledge concerning integration on topics such as:
- Space/geographical integration (due to European heterogeneity and differences linked to the scale of interest).
- Time integration, with only few studies dealing with long term experiments.
- Process chain integration, where a large variability on the field can lead to narrow variability concerning the end-product(s).
- Discipline integration, with a need of inter-domain studies and a better dialogue with farmers and policy makers.

The main questions identified along the process chain were:
- Crop production
    - Maximisation of production and profit margins
    - (In terms of water, fertilization, used species, plantation management…)
    - Productivity in the long term (life-span of a plantation)
- Logistics
    - Harvest, storage, drying, treatments…
    - (Adaptation/optimization as a function of species and needs)
- Conversion and biomass quality definition/evaluation (Lignin, ash contents…)
- Environmental considerations
    - Biodiversity
    - European variability (North vs. South?)
    - What is acceptable? Maintenance or new species?
    - Thresholds to be used
- Go vs. no go areas (Detailed crop/land suitability)
- Greenhouse gases, nitrous oxide emissions, carbon sequestration…
    - (Large uncertainties on present studies and need of a better knowledge/understanding, in relation with climate change work).

A strong point that emerged was the need to build an integrated database on all European experiments/studies and the importance to support existing experiments in order to improve the availability of long-term data. Despite uncertainties, the need of whole chain assessments, for example using Life Cycle Analysis techniques was stressed. Another point made was the need to strengthen links between the research community and farmer communities, possibly through specialized extension services.

At the end of the meeting, DG JRC expressed interest in developing further cooperation related to the scientific/technical assessment of Short Rotation Crops with the experts and institutions represented, hopefully under future calls for proposal under the Seventh Framework Programme of Research. In addition to the IEA Bioenergy Task on Short Rotation Crops which groups EU Member States and some non-EU countries, the usefulness of a European network on Short Rotation Crops in order to better assess EU 2010 and 2020 Renewable Energies targets was stressed.

Motivation

Expert Consultation

“Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

Background

This Expert Consultation is organised by the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC) of the European Commission (www.jrc.cec.eu.int) and the European Environment Agency (www.eea.europa.eu) in cooperation with Rothamsted Research (www.rothamsted.bbsrc.ac.uk). It follows a previous JRC/EEA/CENER Joint Seminar on Sustainable bioenergy cropping systems for the Mediterranean (http://streference.jrc.cec.eu.int/) and a JRC/CENER Expert Consultation (http://streference.jrc.cec.eu.int/) on the energy potential from cereals straw in the EU-25. This concept is now applied to exploring the potential and environmental aspects of growing short rotation crops for energy, which include perennial grasses, short rotation forestry and short rotation coppice.

Motivation

The European Union has set a target of 12% of total energy consumption to be produced from renewable energies. In addition, in 2010 renewables should contribute 21% of gross inland electricity consumption and 5.75 % of all transport fuels will have to be biofuels. Recently, the Commission proposed a comprehensive Energy Package on 10 January 2007 and the Council endorsed a target of 20% share of renewable energies in overall EU energy consumption and a 10% binding minimum target by all Member States for the share of biofuels in overall EU transport by 2020. Consequently, the use of biomass in transport fuel, heat and electricity production will have to increase substantially to meet these targets and biomass imports are considered or taking place. In order to reach the previously mentioned targets, at the end of 2005, the European Commission has issued a Communication on a Biomass Action Plan and its corresponding Impact Assessment. These documents can be found on:

http://ec.europa.eu/energy/energy_policy/index_en.htm

http://europa.eu.int/comm/energy/res/biomass_action_plan/green_electricity_en.htm..

National Biomass Action Plans are now in preparation, for example in United Kingdom, Netherlands and Germany. Environmental or sustainability biomass certification schemes are in preparation, at national or international levels. Policy discussions for European renewable energy targets beyond 2010 are taking place. In addition to the existing European legislation on electricity from renewables and use of biofuels, a Directive on heating and cooling from renewables is in preparation.

The cultivation of Short Rotation Coppice (SRC), Short Rotation Forestry (SRF such as poplar, eucalyptus or willow…) and perennial grasses (such as miscanthus…) for heat and power generation is often considered to be an opportunity for agricultural diversification, while at the same time contributing to environmental protection and a greater independency from imports for energy. This Expert Consultation is organised within the framework of the joint activities on renewable energy between the Renewable Energies Unit of the Institute for Environment and Sustainability (Joint Research Centre, European Commission) and the European Environment Agency. It will build on previous work by the International Energy Agency (IEA) Task No 30 (Short Rotation Crops for Bioenergy Systems) (www.ieabioenergy.com) and the European Biofuels Technology Platform.

IEA Task 30 has produced significant information on Short Rotation Crops in the world and this meeting will attempt to review and discuss the state of the art in the specific conditions of

the European Union. Even if the SRC/SRF and perennial grasses are often considered as a very promising option for the future, the actual implementation in Europe at the end of 2006 is still very limited. This meeting aims specifically at a technical discussion regarding the present situation as well as the energy and environmental perspectives of SRC/SRF and perennial grasses in the European Union. It will bring together a small group of researchers and professionals in the agronomy/forestry/environment/energy field in order to develop expertise, exchange information and improve data collection mainly on:
1) the stage of implementation of SRF/SRC and perennial grasses in the European Union,
2) the agro-environmental aspects of SRF/SRC and perennial grasses in the European Union,
3) the status of research on SRF/SRC and perennial grasses and perspectives, in the European Union and outside the European Union.

Expected outcome

Prior to the Meeting, a Background Technical Document and Agenda will be sent for information by the Meeting organisers to the Expert Consultation participants. This Expert-Consultation will be organised in such a way that instead of a sequence of presentations, a large space will be given to interactive technical discussions.

The Expert Consultation aims at collecting the state of knowledge in three main areas: the implementation stage, agro-environmental aspects, status of research and perspectives. For each of these areas we list a range of questions below. These show the diversity of aspects to be discussed but obviously cannot all be tackled in detail during the foreseen workshop.

1. SRC/SRF and perennial grasses in the EU: the implementation stage
What are the growth and yield performances of SRC/SRF and perennial grasses?
What is the cost breakdown related to the cultivation of SRC/SRF and perennial grasses?

What are present costs and prices for wood chips from SRC/SRF, perennial grasses and the evolution foreseen?

What are the main technical and non-technical barriers to the development of SRC/SRF and perennial grasses?

What are the causes and the magnitudes related to the difference between experimental and practical yields?

Are the energy yields of short rotation crops similar to those from annual crops on the same soils and climatic conditions?

2. SRC/SRF in the European Union: agro-environmental aspects

Which crops/species are adapted to European conditions?

Which environmental and agronomic constraints have to be taken into account in the case of SRC/SRF and perennial grasses?

Which are the critical land use changes linked to SRC and perennial grass production from an environmental perspective?

What are the effects of SRC/SRF, perennial cultivation for example on soil carbon content (grown on agricultural soils, grassland, forest soils….) and nutrient availability or on soil erosion risk? What are the possible needs in terms of fertilisers or chemicals, which quantities and at which stage?

What are the critical aspects on biodiversity and landscapes?

Can some rules be derived from soil/land characteristics and subsequently GIS mapped at local, regional, national or European levels?

What scale is possible and necessary for the mapping of SRC/SRF resource potential in the European Union?

What are the main farming practices related to SRC/SRF and perennial grasses?

What impacts could different cultivation techniques have on nutrient leaching?

What improvements in practical yields can be expected in the future? What are the advantages/disadvantages of various mechanised harvesting methods?

3. SRF/SRC: Status of research and perspectives
What are the main issues in the field of SRF Research and R&D?
Which critical knowledge gaps have emerged from discussions in the other two areas?
In an environmental perspective should we focus on land use change, landscape effects, impacts of different cultivation practices, on direct or indirect effects?
How do SRF, SRC or perennial grasses perform for phyto-remediation of soils, recycling of wastewater and sludge, carbon sequestration …?
Is there ongoing research or field experimentation performed outside of European Union that is relevant for the European situation?

The outcome of the Expert Consultation will be summarized in proceedings prepared by the Meeting organisers, focussing on the three areas above and based on the input provided by the Meeting participants.

Experts

This Workshop is intended to include 20 participants maximum in order to allow discussions. Experts will be invited from European Union Member States or regions active in the cultivation of SRF and SRC for bioenergy, for example from Sweden, United Kingdom, Italy…. Experts will originate mainly from agricultural and environmental institutes, renewable energy institutes, research centres and energy companies.

Of special interest for this meeting is expertise related to:

- Agronomic and forestry knowledge on SRF and SRC,
- Farming practices, mechanised harvesting methods,
- environmental impacts of SRC and SRF,
- Public support mechanisms and market organisation for bioenergy chains including SRF and SRC.
- Research and R&D on SRF cultivation and use.

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Agenda

Expert Consultation

“Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

17 October 2007

14.00 – 14.30 **Welcome, introduction and rationale**
Chair: A.Karp Rothamsted, J.F.Dallemand EC Joint Research Centre, J.E.Petersen, European Environment Agency

14.30 – 15.30 **Session of Thematic Introduction to SRF, SRC and energy grasses**
Chair: Verwijst T., Swedish University of Agricultural Sciences
Rapporteur: G.Alker, Thames Valley Energy
a) Review of different short rotation crops (SRC, SRF, perennial grasses)
b) Review of current area and geographic distribution of short rotation crop plantations

15.30 – 16.00 Coffee break

16.00 - 17.00 **Thematic session on processing and logistics**
Chair: J.Carrasco, CIEMAT, Spain
Rapporteur: C.Panoutsou, Imperial College, London
Main energy pathways for short rotation biomass; current processing capacity and logistical issues

17.00 – 18.00 **Discussion of the background paper**
Chair: J.E.Petersen European Environment Agency

18 October 2007

9.00 – 11.00 **Thematic session on environmental impacts**
Chair: A.Karp, Rothamsted, UK
Rapporteur: I.Tubby, Forestry Commission, United Kingdom
a) Short rotation trees and bushes
b) Perennial grasses

11.00 – 11.20 Coffee break

11.20 – 12.20 **Thematic session on current research gaps**
Chair: W.Elbersen, Wageningen University, Netherlands
Rapporteur: N.Marron, INRA, France

12.20-12.30 Break

12.30 – 13.00 **Final Session**
Chair: J.F.Dallemand Joint Resarch Centre, A.Karp, Rothamsted, J.E.Petersen European Environment Agency
Reporting back and conclusions

13.00 -14.00 Lunch

14.00 – 18.00 **Bioenergy excursion**

List of Participants

Expert Consultation

“Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

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Background Paper

“Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives"

Ulrike Eppler, University of Eberswalde

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Christian Couturier, Solagro

1. Introduction and outline

1.1 Policy background

Energy production from biomass currently has a high political priority, as for example shown by the European Union target of a 20% share of renewable energy by 2020 (Council of the European Union, 8/9 March 2007, note 7224/1/07). The cultivation of Short Rotation Coppice (SRC) and Perennial Energy Grasses (PEG) for heat and power generation can make a substantial contribution to meeting this target. At the same time, it is considered an opportunity for agricultural diversification, while supporting environmental goals and a greater independency from energy imports.

Today, most agricultural bioenergy production is linked to oil crops which are converted into biofuels. However, other energy pathways related to heat and electricity are gaining importance. In addition it is expected that there will be a shift from first-generation biofuels (plant oil, FAME= biodiesel and ethanol from cereals, sugar beet or potatoes) into second-generation biofuel production by synthetic biofuels (BtL), and ethanol from ligno-cellulosic material. The second-generation biofuels can use various feedstocks, including agriculture and forestry waste as well as dedicated energy crops. Perennial energy grasses (PEG) and short rotation coppice (SRC) are key examples for such crops and usually characterised by high yields per hectare as well as mostly low environmental pressures.

It can be expected that PEG and SRC become more important in the crop mixes after 2010 when new technologies enter the market and bio-heat options are further developed. Nevertheless, even if the cultivation of PEG and SRC are often considered as a very promising renewable energy option for the future, their actual implementation in Europe at the end of 2006 was still very limited. Current plantations (whether PEG or SRC) are mostly grown on an experimental basis, with the exceptions of the UK, Sweden, Finland and to some extent Italy (Barto, 2006).

1.2 Outline of paper

This background paper aims to review available information on cultivation patterns of PEG and SRC in the European Union, discuss associated agro-environmental aspects and provides information on research issues relating to PEG and SRC. This review aims to support the development of SRC and PEG based-energy pathways in Europe while taking account of environmental limitations. The paper served as background to discussions at a joint JRC/EEA/Rothamsted Institute expert consultation organized at Harpenden (UK) in October 2007 and has subsequently been improved on the basis of feedback received from workshop participants.

Chapter 2 gives an insight into definitions and the most common species used for PEG and SRC in Europe. It reviews crop characteristics and yields, provides available data on production costs and summarises work of IEA (International Energy Agency) Task 30: "Short

Rotation Crops for bioenergy systems” on barriers to the further development of permanent energy crops (Alker, *et al*., 2005).

Chapter 3 discusses the potential agri-environmental impacts of growing short rotation coppice and energy grasses, with special attention on impacts related to land use changes and environmental effects of cultivation practices.

Finally, chapter 4 briefly reviews current research efforts and the issues that were discussed at the workshop. It also provides a discussion of key issues that appear particularly relevant for future research on the cultivation and energetic use of SRC and PEG. Details relevant to chapters 2 -3 are made available in annexes.

It is obvious that this background paper is only a starting point for future work. There are still considerable information gaps in terms of data on cultivation patterns, environmental and agronomic limitations as well as the role of SRC and PEG in renewable energy systems. We hope that the paper contributes to stimulating further research in this important area.

2. SRC and PEG in the EU: the implementation stage

2.1 Suitable species for European conditions

A large number of annual and perennial crops have been investigated for their potential use as energy crops in Europe. However, it is mainly annual crops that have reached beyond the level of R&D and have become commercialised and grown on larger areas. These examples mostly exist due to the political and financial support given, and they have provided valuable information on possibilities for the implementation of energy crops in European agriculture. The main examples for large-scale commercial energy crop production are oil seed crops for bio-diesel or cereals for bio-ethanol in e.g. France, Germany, Austria and Italy. However, the production of SRC willow for heat and power in the UK, Sweden and Finland has also made considerable progress. While annual crops such as rape, sunflower and wheat are well known crops in agriculture due to their use for food and feed purposes, the production of SRC and perennial grasses as agricultural crops has to be developed in all aspects from breeding to harvesting methods.

Short rotation coppice and perennial energy grasses can be grown to gain cellulosic material for heat and power generation or for conversion to liquid fuels via so-called 2nd generation processes. They are usually harvested when their dry matter content is highest, i.e. in autumn or winter, and are self-regenerating after harvest. PEG are harvested annually whereas SRC plantations require short rotation cycles of generally between 2 and 6 years before harvesting.

As their name suggests perennial energy grasses consist principally of grass species that have a multi-annual lifecycle that can extend to several decades. Certain non-graminean species have similar growth and cultivation characteristics, e.g. the thistle species *Cynara carduncului* or the dock *Rumex uteusa*.

Short rotation coppice is formed by woody species that re-sprout when cut down at the stem base. Coppicing is a very old cultivation technique for woody plants that was used to obtain specific types of plant material, i.e. thin flexible branches from hazel or willow for baskets and fences or bark from young oak trees for leather treatment processes. Both bushes and trees can be coppiced but only some tree species re-sprout well. Short rotation coppice can be considered to be a sub-type of short rotation forestry. The term short rotation coppice is generally applied to plantations where the stands are harvested several times in a short-term rotation before the plantation is renewed. Short rotation forestry applies to tree species that are fast-growing and can be harvested after 20-30 years; however, the trees/plantation needs to be replanted before another harvest is possible.

The perennial grasses and woody species investigated are suited to different climatic conditions throughout Europe. Certain crops, such as Giant Reed, grow best in the southern parts of Europe. On the other hand, Reed Canary Grass, which is native in Sweden and other Nordic countries, is well adapted to the cold climate of Scandinavia, while willow or poplar can be grown in most countries of northern Europe. Miscanthus is grown throughout the more central parts of Europe, as far apart as Denmark and Sicily[1].

2.1.1 Short rotation coppice (SRC)

Short Rotation Coppice (SRC) plantations consist, of densely planted, high-yielding varieties with very short rotations of between 2 and 6 years. When harvested, the crop is usually converted into wood chips which can be used for energy production. Species that are currently being employed in SRC plantations for energy purposes are mainly Willow and Poplar, but Black locust (Robinia) and Eucalyptus are also used.

Willow is grown mainly in the northern parts of the European Union. Sweden, UK, Finland, Denmark, Ireland and the Netherlands produce willow for energy purposes. Romania also holds substantial willow plantations, planted for wood production and environmental purposes.

Poplar can be grown in warmer climates than willow (Italy, Spain). In many countries, e.g. the UK, Ireland, Belgium, The Netherlands, Austria, France and Germany both species are grown.

The largest area of Black locust is found in Hungary, but Italy (Spinelli, 2007) and Poland (Rutkowski, 2007) also have substantial plantations. Black locust grows fast in youth, sprouts well both from root and trunk, has got large volume density and low moisture content, but burns well even when it is wet. A ten year old locust plantation contains as much dry material as a twenty year old traditional forest.

Eucalyptus is an exotic species in Europe and is the main raw material for the pulp industries of Portugal and Spain. During the last decade several studies concerning the possibilities of managing eucalyptus as a coppice crop have been conducted. The results show high growth rates and high calorimetric energy yields. However, Eucalyptus is a problematic – and controversial - genus from an environmental point of view; serious concerns exist on its impact on a series of aspects, such as soil quality, groundwater tables, biodiversity, forest fires.

Many other woody species can and have traditionally been coppiced, e.g. Ash, Hazel or Sweet Chestnut, but most of the traditional coppice species do not appear to be under trial for energy production. In Spain, trees such as Elm (*Ulmus pumila*) and *Pawlonia* sp. are being evaluated.

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[1] A list of common and Latin names of the species mentioned is provided in Annex II.

The following table details some characteristics of SRC. These data are only indicative. They vary considerably according to soil and climatic conditions as well as cultivation practices (fertilization, irrigation).

Table 1: Overview of the main characteristics of Short Rotation Coppice (SRC)

Species	Willow	Poplar	Black locust (Robinia)
Part of Europe	Northern, central and western Europe	Central and Southern Europe	Mediterranean Europe, Hungary, Poland
Crop density stools/ha	12,500-15.000	8-12,000	8-12,000
Harvesting cycle (years)	1-4	1-6	2-4
Av. butt diameter at harvest (mm)	15-40	20-80	20-40
Av height at harvest (m)	3.5-5.0	2.5-7.5	2.0-5.0
Growing stock at harvest (fresh tons/ha)	30-60	20-45	15-40
Moisture content (% weight)	45-62	50-55	40-45

Source: EUBIA, 2007b ; EEA/JRC/Rothamsted Institute expert consultation workshop, 2007

2.1.2 Perennial energy grasses (PEG) and similar crops

The adoption of perennial energy grasses, such as Miscanthus, Giant reed, Switchgrass, Reed Canary Grass, has and is being investigated in several studies all over Europe. Perennial energy grasses are normally harvested once a year, with a delayed harvesting approach (i.e. harvest during autumn or winter).

Miscanthus was introduced to Europe as an ornamental plant some 50 years ago. It is a C4 perennial grass, and therefore adapted to warmer climates. Many countries have established test plots, e.g. Denmark, Germany, France, Austria, Belgium, Greece, Ireland, UK, Italy, Portugal and Spain.

Reed Canary Grass (RCG) is native in northern Europe. Several thousand hectares of RCG have been established in Sweden due to earlier grants for converting arable land into non-food crops. The main production area is Finland: 17,000 hectares of RCG were cultivated, in 2006 (+65% from 2005[2]). The crop is chopped and mixed with peat before being burned for commercial use in a heat-power plant. The spring harvest in 2007 corresponded to 130 GWh, compared to 50 GWh in 2006, and the target is 500 GWh in 2010[3]. Cultivation has also started in Sweden and Estonia. Furthermore small research plots have been established in the UK, Ireland, Germany and Denmark through an EU-project on RCG (Luger, no year).

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[2] Source : TIKE, Maa-Ja Metsätalousministeriön Tiertopalvelkeskus,14/12/ 2006: farm register, utilized agricultural area in 2006, www.mmmtike.fi
[3] http://www.vapoviesti.fi/

Switchgrass is a perennial C4 grass native to North America. It is a prairie grass growing well on marginal lands and is used in the US for erosion prevention purposes. Since 1998 switchgrass is being investigated in the EU as a novel lignocellulosic C4 biomass crop for adaptation to European conditions (test plots are in the Netherlands, UK, Germany, Italy and Greece – collaborating in the EU switchgrass project[4]). It is propagated by seed, which contributes to low cultivation costs (in contrast to Miscanthus where split rhizomes have to be used).

Giant reed is thought to have originated from Asia but is also considered a native species in the countries surrounding the Mediterranean sea. Giant reed is a very tall growing C3 grass. It tolerates a wide range of ecological conditions and is adapted to both warm temperate and subtropical regions.

Cynara cardunculus is not a grass but belongs to the thistle family. It is currently being tested as energy crop in Spain and the wider Mediterranean area. The average yield ranges from 12 to 18 t biomass dry weight /year without irrigation and rainfall of ca 450 mm/y. Cynara sprouts in autumn, passes the winter as a rosette, a floral scape is developed in spring and the dried scape is harvested in late summer.

Rumex was originally bred in Ukraine as a forage crop. The species Rumex OK-2, or Sorrel-Dock hybrid 'Uteusa', was grown on approximately 1000-1200 hectares in the year 2004 in the Czech Republic. Is it seen as a promising non-woody energy crop and can be seeded in early spring by conventional machinery. Primary leaves appear in April-May and they can be used as quality forage. From the second year after planting plants produce 2-3 meter tall stems which should be harvested in late June to early July to prevent loss of seeds. Bales of straw were experimentally burned in commercially operating boilers. Most types of soils are suitable except those with high level of underground water. Straw yields around 5-12 oven dry ton (odt)/ha/year can be expected. It requires energy inputs such as fertilizing, herbicides and insecticides. It is expected to grow between 7-12 years on one site.

Table 2 provides an overview of the main characteristics, cultivation requirements and agri-environmental effects of the four perennial grasses based on a literature survey (EEA, 2007).

[4] The EU switchgrass project (FAIR 5-CT97-3701): "Switchgrass (*Panicum virgatum* L.) as an alternative energy crop in Europe" - Initiation of a productivity network. More information under: www.switchgrass.nl

Table 2: Overview of main characteristics, cultivation requirements and agri-environmental effects of four perennial biomass grasses

Attribute	Miscanthus	Switchgrass	Reed canary grass (RCG)	Giant reed
Photosynthesis system	C4	C4	C3	C3
Height	Up to 4 m	Up to 2.5 m	Up to 2 m	Up to 5 m
Rotation time	15 years	15 years	10/15 years	15 years
Adaptation	Moderate winters, sufficient/low moisture	Moderate winters, sufficient/low moisture	Colder regions, moist conditions	Warm regions, moist conditions
Adaptation range in Europe	All Europe	All Europe	Cold and wet regions of north-western Europe (Finland, Sweden, UK, Netherland, Eastern Europe)	Southern Europe, Southern France, Italy, Greece, Spain
Fertiliser input per ha	In northern EU up to 50 kg N. In the south 50 to 100 kg N	In northern EU up to 50 kg N. In the south 50 to 100 kg N	Higher than for C4 grasses	Higher than for C4 grasses
Pesticide input	Low, possibly in first year	Low, possibly in first year	Low, possibly in first year	Low, possibly in first year
Runoff potential	Low	Low	Low	Low
Water use	High	Low	High	High
Field pass frequency	Once per year after establishment	Once per year at harvest	Once per year at harvest	Once per year at harvest
Erosion control	Good/ very good	Very good	Very good	Good/very good
% slope of terrain	Only machinery limitations need to be taken into account	Only machinery limitations need to be taken into account	Only machinery limitations need to be taken into account	Only machinery limitations need to be taken into account
Risk of fires	High	High	High	High

(Source: EEA, 2007)

2.2 Yields and area under SRC and perennial grasses in Europe

Yield information is always difficult to interpret since a distinction should be made between:

a) Potential yield, which refers to what is possible under the most optimal soil-weather circumstances.

b) Attainable yield, which is possible applying all types of optimal cultivation practices such as agro-chemical inputs and irrigation.

c) Actual yield, which refers to a yield that is reached in a normal farming system.

In research, yield improvements are always very feasible, but to raise actual yields is more complicated and has always gone more slowly. This is because farmers' practices cannot be changed that quickly and these determine what is really feasible.

In general, neither SRC nor perennial grasses have been trialled long enough or on a sufficiently extensive scale to provide reliable information of yield potentials under commercial conditions. Table 3 presents a fairly extensive overview of yields reached, mostly in research plots. These data refer more to potential and attainable yields than to actual yields. We have not found much yield information relating to commercial sites.

Future possible yield increases for both SRC and the perennial grasses can be expected to be higher than for traditional agricultural crops, in particular since the breeding potential of the crops for non-food purposes has only recently begun to be exploited.

Tables 3a and 3b summarise the available data on yields and the cultivation area of SRC and perennial grasses derived from literature research and conference presentations.

Yields are given in odt (= "oven dry ton"), that is the biomass dried at a temperature of 105^{o}C.

Table 3a: Overview on yields and area of SRC in Europe

	Yield		Area		Source
Species	t ha^{-1} a^{-1}	odt ha^{-1} a^{-1}	Country	Ha	
Willow			RO	2,400	Ball *et al.*, 2005
	10 – 12 [1]	20-25 [2]	SE	15,000	Weih, 2007
		8-20 [2]	UK	2.500	Riche, 2007, Luger, n.y.
		7-8	DK		Luger, n.y.
		5	IE		Luger, n.y.
	9		PL	1,000-2,000	
	5 – 11		EE		Heinsoo *et al.* 2002
		15-20 [2]	IT		Luger, n.y.
Poplar			EU	370,000	Ball *et al.*, 2005
		16-20 (irrigated)	IT	4,500	Spinelli, 2007, Luger, n.y.
		5-7 [2]			Riche, 2007
		10 (3 rotations of 3 years each)	BE	ca 25 ha	Laureysens *et al.* 2005a Al Afas *et al.* 2008
			UK	5	Luger n.y.
		6-12 [1]	NL [3]	32,000	Luger n.y.
			FR [3]	350	Luger, n.y.
		12-35	ES	16 ha (‚On Cultivos' project)	Carrasco & Sixto, 2007
			AT, DE	test plots	Luger n.y.
Black Locust (*Robinia*)			HU	n.d.	
			IT	500	Spinelli, 2007

[1] In commercial plantations.

[2] On experimental fields.

[3] Plantations established but not for energy purposes. The same in France where plantations are used for pulp production.

Table 3b: Overview on yields and area of PEG in Europe

	Yield		Area		Source
Species	t ha^{-1} a^{-1}	odt ha^{-1} a$^{-1 (*)}$	Country	Ha	
Miscanthus		7-9 [2]; 7-14 [1]	DK	30	Luger, n.y.
		6-7	DE	100	Luger, n.y.
	12-16 [3]		UK	6-8,000	Riche, 2007
			UK	14,671 [4]	Defra, 2006
			FR, AT, BE, IT, IE, PT, ES & GR	Test plots	Luger, n.y.
		20-25 [1] (irrigated)	IT		Luger, n.y.
		18-29 [2] (irrigated)	GR		Luger, n.y.
Switchgrass		17.54 (7th yr), mean of 14.40 (yr 5 to 9)	UK	test plots	Riche, 2007
	5-22		IT		EUBIA, 2007a
	15-24		GR		EUBIA, 2007a
		10-19 (3rd yr)	NL	test plots	EU switchgrass project
Reed canary grass			SE	several 1000	Luger, n.y.
		4 – 10 [5]		15,000 ha	Pahkala, 2007
		8-14	FI	50	Luger, n.y.
Giant reed	7-31		GR (south)		EUBIA, 2007a
	5-17		GR (north)		EUBIA, 2007a
	8-37		ES		EUBIA, 2007a
	15-34		IT (south)		EUBIA, 2007a
	3-32		IT (north)		EUBIA, 2007a
	15-20		D		EUBIA, 2007a
		6.38 (3rd yr)	UK	70	Riche, 2007
Dock x Sorrel hybrid (Rumex pati-entina x R. thaishanicus)		5–6 [6] 7–9 [7]	CZ	1,200	Weger, 2007

[1] In commercial plantations.

[2] On experimental fields.

[3] DEFRA 2007b. Planting and growing Miscanthus

[4] Planted in the UK up to the end of 2006 (The Non-Food Crops Centre, 2006; DEFRA, 2006).

[5] Yield for early spring harvest and highly dependent on harvesting techniques. Pahkkala 2007 available at :

http://www.bioenergybaltic.ee/bw_client_files//public/img/File/Field_energy_crops.pdf

[6] Average sites

[7] Optimal sites

2.3 Economic aspects of SRC and PEG cultivation

Current studies show that most energy crops and trees can be cultivated across different regions of Europe. In each region or country the yield and input parameters are different and therefore the price of resulting biomass will differ. It is currently not possible to give an overview or general guidance, as reliable data are available only in some EU countries.

In most countries commercial markets for biomass from energy crops have not yet developed. In the UK, studies for the government (Defra, 2003) concluded that without financial support short-rotation coppice willow and Miscanthus are not economically viable at current biomass yields and production costs.

In some countries economic incentives for energy crops have been created via energy subsidies. In Spain, with a feed-in tariff of 156 €/MWh electricty produced with energy crop biomass, we estimate that the bioelectricity plants could pay about 60-70 €/t dry chips on plant site (40-55 €/t on field site).

For some countries, where SRC or PEG have been cultivated for some years, production costs are available, but there are differences in the way different countries have calculated their costs. The chip production costs from SRC or PEG range from 20 to 60 €/t in most cases. The total costs can be separated into direct costs (consumable goods) and labour / machine costs, both specified in euros per hectare (€/ha).

Direct costs are costs for consumable goods, such as seeds, pesticides and fertilisers.

Labour and machine costs do not have the same meaning in the different countries. Sometimes labour costs are explicitly mentioned (in Germany for example), or the labour costs are integrated in the costs for different activities. Examples of labour and machine costs are costs for ploughing, using the power harrow, rotary cultivating, drilling, rolling, spraying, fertilising, irrigating, mowing, baling and transporting.

Little can be said about current trading structures, since in most countries there seems to be no market for biomass from SRC or PEG until now (Barto, 2006), with the possible exceptions of the Netherlands and Finland.

2.3.1 Short rotation coppice (SRC)

For the establishment of energy short rotation coppice in agricultural systems, mechanisation of the whole process is fundamental. Just the planting and harvesting of the trees can account for 20 to 60 percent of the total costs, depending on the method. Harvesting costs dominate, since crops are harvested up to 15 times in some cases (Scholz, 2007). In general, harvesting and the transport must not exceed the cost limit of 20-25 €/green ton, beyond which SRC is no longer profitable (Spinelli, 2007).

In Germany production of SRC is still in the experimental stage. The SRC sites are rather small and only very few SRC sites have been farmed for more than one rotation period. Hence, the calculation base for a sound economic analysis is not yet satisfactory. Nevertheless, a first assessment of the basic economic data for SRC production is provided by Schweinle (2007). Fixed costs for administration, buildings and insurance as well as EU public support are not considered in the calculation. Table 4 presents a literature review of costs, collected from different sources.

Table 4: Literature review on SRC production costs under German conditions

	Source				
Management	Low costs	High costs	unit	Low costs	High costs
Ploughing and harrowing (one time)	Vetter* (2005)	Hofmann* (1998)	€/ha	47	125
Herbicide treatment (one time)	Vetter* (2005)	KTBL* (2006)	€/ha	41	80
Planting (no replanting) 14,000p	Ohrner* (2005)	Vetter* (2005)	€/ha	200	562
Total labour costs for operation 1-3		Vetter* (2005)	€/ha	n.a.	44
Cuttings (material costs) 14,000 p. A 0.08 or 0.22 €	Hofmann* (1998)	Wilwerding, Rösch* (1999)	€/ha	1,120	3,078
Harvesting plus hoeing (after each rotation)	Vetter* (2005)	Schneider* (2002)	€/ha harvest	112	517
Mulching (after each rotation)	Vetter* (2005)	Vetter* (2005)	€/ha harvest	18	18
Transport (after each rotation	Vetter* (2005)	Hofmann* (1998)	€/ha harvest	69	240
Total labour costs for operation 5-7	Vetter* (2005)		€/ha harvest	124	n.a.
Clearing (one time, labour costs included)	Schneider* (2002)	KTBL* (2006)	€/ha	200	1,400

Source: Schweinle, 2007; details of references marked with * are provided in this source.

A different example from Poland compares the annual cost distribution of willow SRC against wheat and barley, as common annual crops. The cost of producing willow wood chips, including transport to the heating plant, amounts to about 235 €/ha under Polish conditions, excluding land rental costs and overheads (Table 5). This cost is based on a yield of 9 tonne/ha/yr and corresponds to 7 €/MWh. Costs related to harvesting, such as harvest, field and road transport and brokerage, account for about half of the total cost. Costs related to the establishment of a willow plantation account for 27% of the total. Despite their modest share of the total cost, the establishment costs have a significant effect on the farmer's liquidity, since they are incurred during the first and second years of the lifespan of the plantation. The first income, subsidies excluded, is not obtained until the fourth year. The cost of fertilizers and weed control is low for willow compared with those for wheat and barley (Table 5). The costs for wheat are €442 and for barley €320, excluding land rental costs and common business overheads. On the other hand, the road transportation cost is relatively high for willow.

However, given the assumptions of the main calculation, willow was in 2004/2005 a competitive choice of crop in relation to wheat and barley from a Polish farmer's perspective. In fact, during the period before the strong recent rise of global grain prices, growing willow provided the farmer with an annual gross margin that was larger than those of both wheat and barley, assuming the higher wood chip price (11 €/MW h) given by Ericsson *et al*. (2006).

Table 5a: Annual cost distribution (EUR/ha) of growing willow at farm level, excluding land rental costs and common business overheads. Labour costs are included in all items.

Management practice		Year of operation	Average cost/year (€/ha)
Establishment			64.09
	Cuttings+transport	1	48.64
	Pruning	1	0.91
	Glyphosate and wetting agent	0	1.59
	Transplanter	1	6.36
	Mechanical weed control	1, 2	4.55
	Harrowing	1	1.59
	Rolling	1	0.45
Fertilization			38.64
	Nitrogen	2, 3, 5, 6, 8, 9, 11, 12, 14, 15, 17, 18, 20, 21	26.82
	Phosphor	5, 8, 11, 14, 17, 20, 23	3.41
	Potassium	5, 8, 11, 14, 17, 20, 23	5.68
	Spreading	3, 6, 9, 12, 15, 18, 21	2.73
Harvest		4, 7, 10, 13, 16, 19, 22	61.59
Field transport		4, 7,10, 13, 16, 19, 22	12.50
Transport to thermal plant		4, 7,10, 13, 16, 19, 22	28.18
Brokerage		4, 7,10, 13, 16, 19, 22	22.50
Supervision, administration		1, 2, …., 22	2.95
Wind up		22	2.05
Weed control after harvest			2.95
	Glyphosate and wetting agent	5, 11, 17	1.59
	Spraying	5, 11, 17	1.36
Total			235.45

Table 5b: Annual cost distribution (€/ha) for cultivation of winter wheat and spring barley, excluding land rental costs and common business overheads. Labour costs are included in all items. The item *labour* refers to work done by the farmer himself and not by a contractor.

Management practice	Management practice	Wheat (€/ha)	Barley (€/ha)
Seed		57.95	30.91
Fertilization (P, K, N)		107.50	78.18
Ca, Mg (every fourth year)		15.45	15.45
Weed, fungus and pest control		42.73	13.18
Drying		12.05	8.41
Machines		192.27	175.45
	Stubble harrowing	10.45	10.45
	Ploughing	39.09	39.09
	Harrowing, ploughing, sowing	33.41	33.41
	Fertilizer and Ca and Mg spreading	12.95	7.27
	Spraying	20.45	13.64
	Threshing	61.36	61.36
	Transport	14.55	10.23
	Topping weeds		
Interest		8.64	2.73
Labour		5.91	5.91
Total	Total	442.50	330.23

Source: Ericsson *et al*., 2006

Note: These calculations probably do not take into account the costs of clearing of willow plantation at the end of the SRC lifetime (removal of the roots).

In Spain, the cost for poplar SRC ranges from 190 €/ha/year (harvest by baling) to 210€/ha/year (harvest by chipping) with rotation every three years (1+15 years, five rotation cycles), excluding irrigation costs. The irrigation costs are very variable depending on the water cost and requirements and the type of irrigation. Thus it is only suitable for very high production areas (about 30-35t/ha dry biomass). Accordingly the poplar biomass production costs in Spain can be estimated at 20-40 €/t dry biomass (Carrasco & Sixto, 2007).

In the following table the cost distribution of willow growing in Sweden, Northern Ireland and Denmark is illustrated[5].

[5] The economics of growing willow, wheat and barley were analysed at farm level using a model presented by Rosenqvist (1997). This model was developed for analysis of the annual economics of growing willow, thus making the economics of

Table 6: Annual cost distribution for willow cultivation in Poland, Sweden, Northern Ireland and Denmark.[6]

		Annual cost distribution (€/ha)			
		Poland	Sweden [1]	N. Ireland [2]	Denmark [3]
Establishment		64	86	159	86
Fertilization		39	93	83	88
Harvest		62	106	140	84
Field transport		12	33	51	51
Transport to thermal plant		28	116	106	97
Brokerage		23	39		
Supervision, administration		3	17	11	15
Wind up		2	5	8	14
Weed control after harvest		3	4		1
Total	(€/ha)	236	499	558	436
Total	(€/MWh)	7	15	12	15

Source: Ericsson *et al*. (2006).

[1] The annual willow yield is 5.25 t/ha until year 4 and 9 t/ha after that.

[2] The annual willow yield is 12 t/ha from year 5 and onwards. Farm labour cost is 4.5 £/h. Road transport distance is 20 km.

[3] The economics refer to clay soils. The annual willow yield is 6.25 tonne/ha until year 4 and then 9 tonne/ha after that. Costs refer to 1997/98 price levels.

Generally, it is difficult to compare results from different studies. However, the economic calculations in these four studies are based on the same model and major assumptions, which enables a valid comparison of costs. It should be noted though, that the cost estimates refer to different years. A comparison of costs shows that the total cost of growing willow is similar in Sweden, Denmark and Northern Ireland[6], whereas it is only half as much in Poland. This disparity is mainly the result of the substantially lower costs for labour, diesel and fertilizers in Poland, a disparity that is likely to diminish over time due to the general harmonization of prices in the EU. The price of grain (which has recently increased strongly), on the other hand, is more or less the same within the EU. Only minor price differences exist due to transportation costs (Ericsson *et al*., 2006).

An additional recent, but spatially limited overview on current prices and trends can be

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willow, a perennial crop, comparable to that of wheat and barley, which are annual crops. The model employs a total-step calculation method, in which all disbursements and revenues over the estimated lifespan of the plantation are discounted.

[6] The costs refer to a situation where an area of at least 10,000 ha is covered by willow plantations in each country. Land rental costs and common business overheads are excluded. The discount rate is 6%. The lifespan of the willow plantation is 22 years. First harvest is after 4 years and then every third year. Planting density is 12,240 cuttings per ha. Energy content of the willow crop is 4.5 MWh/tonne. Average exchange rates from 2003 are used: 1 € = 9.1 SEK, 1 € = £ 0.63, 1€ = 7.4 DKK.

reported, summarising the results of workshops held in Germany in June and July 2007 (ATB, 2007; BMBF, 2007). The current market price for harvested SRC wood chips in Germany is 60 €/$t_{oven\ dry}$. That is a profit of 7.00 €/$t_{oven\ dry}$, so 35 €/ha in a year. Since wood prices are expected to increase in the near future, a market price for example of 80 €/$t_{oven\ dry}$ would have a net contribution to farm income of 103.50 €/ha*a (Landgraf *et al*, 2007).

In Italy 40-50 €/t for green chips are reported in 2007 (Spinelli, 2007).

In Denmark the economic aspects of energy willow have been thoroughly documented, and the contribution margin is now at a level which made the crop very attractive in comparison with traditional crops (at 2006 cereal prices). The price per GJ is 4.30 EUR, the energy per ton of dry substance is 18.4 GJ – every third year 36 tons of dry substance are harvested (12 tons per year). The income per year is 864 € per ha minus the production costs of 561.50 € per ha, which makes a net profit excluding grants of 302.50 €/ha (Bach, 2007).

In the UK, the production cost (per ton) over a 20 year plantation lifetime for SRC willow, including all variable costs and cost of machinery operations, amounts to 36.46 €/t (based on a 3 year cutting cycle with harvests in years 4, 7, 10, 13, 16, and 19; year 20 is used to destroy and remove the crop (Riche, 2007)).

In summary, it can be said that with low investment costs, good yields, and relatively high income per ha, SRC can deliver satisfactory profit margins after few rotation periods. To amortise the high investment costs, high yields and high profits over a long life time of a SRC plantation are necessary. In addition, the recent rise in world cereal prices is likely to have altered the balance in the direction of annual food crops.

2.3.2 Perennial energy grasses (PEG)

Far fewer production cost data are available for perennial energy grasses than for SRC/SRF plantations. This is linked to the fact that energy production chains based on energy grasses are still in the experimental phase. Hence only some examples can be provided in this brief section.

In the UK the production costs (per ton) over a 20year plantation lifetime for Miscanthus, including all variable costs and cost of machinery operations, amounts to 42.50 EUR/t, for Switchgrass to 40.20 EUR/t, and for Reed canary grass to 53,25 EUR/t (Riche, 2007).

In Spain, Cynara cardunculus production costs in dry conditions are estimated at 300-350 €/ha, with yields ranging from 12 to 18 t/ha. Thus the biomass production costs (including packing) can be estimated at 25-30 €/t dry biomass (Carrasco & Sixto, 2007).

2.4 Main technical and non-technical barriers to the development of SRC & PEG

Until recently, the development of short rotation crops for energy generation in the majority of EU and IEA (International Energy Agency) member countries has been slow. Alternative uses for SRC, such as phyto-remediation, bio-remediation and waste water treatment have dominated the development of these crops, whereas energy production has in many cases, not been a top priority.

An IEA report investigated the technical and non-technical barriers to a full-scale implementation of short rotation systems. As it is the current state-of-the-art, a summary of the findings of this report is provided below (Alker *et al*., 2005).

‘Most of the technical barriers could broadly be grouped into three overarching technically-based categories; unfamiliar fuel barriers, unfamiliar crop barriers and underdeveloped technologies. The first of these categories, included barriers related to the different fuel characteristics of SRC compared to coal and the effects these differences had on transportation impacts and costs, fuel handling and the performance of the conversion technologies. The second category included barriers which related to uncertainty over the crops nutritional and water requirements, effects on biodiversity, optimum conditions for maximising yields and the strong need for dedicated crop breeding initiatives.

Unlike the technical barriers, non-technical barriers could not be easily categorised and tended to be much more complex. For example, the issue of competition was raised in relation to many aspects. Competition with non-renewable technologies not only in its utilisation for energy production, but also for funding, research and development efforts was highlighted. Competition of SRC with other biomass fuels for bioenergy production and competition for land between SRC and other crops, particularly food crops, were concerns. Many of the non-technical barriers can simply be explained by the youth of the industry and the novelty of the approach to farming the crop and generating biomass power. All the technical and non-technical barriers are summarised in Annex I.

In the majority of cases the technical barriers related to supply chain and conversion technologies are on the verge of resolution, although work is still needed in many member countries on the development of conversion, planting and harvesting technologies. Conversion technologies are becoming more advanced and development in the engineering field is on-going with many commercial power generation plants in existence.

However, it is the non-technical barriers that appear to be the more obstructive and if anything more pervasive. Issues of disjointed legislation and guidelines from government, public misconceptions and fear of an uncertain future will be the toughest obstacles requiring much effort in lobbying and education’ (Alker *et al*., 2005)

3. SRC and PEG in the EU: agro-environmental aspects

3.1 Introduction: reviewing potential environmental impacts

The production of both SRC and perennial biomass grasses is fundamentally different from arable crops. They can be regarded as permanent crops with a plantation life time of at least 15 – 25 years and harvest of the biomass will only start after two to five years. Input use and management of the crop are much more limited than with arable crops (EEA 2007).

Overall, much less information is available on the environmental performance of these perennials compared to annual crops, especially in the long term. However, the general cultivation requirements and the studies performed until now suggest that SRC/PEG generally exert lower environmental pressures than most annual crops.

The longer growing season, year-round soil cover (after the establishment phase) and extensive rooting systems of perennial energy crops all help to reduce nitrate leaching and soil erosion in comparison to annual row crops.

Nevertheless, there are also potential negative environmental aspects associated with these energy cropping systems, in particular with regard to landscape and biological diversity. Since limited research has been carried out on perennial biomass crops and their environmental performance the long term effects are unknown. There is lack of knowledge on the effects of the scale of plantations and even more unknown is the variation in effects of different hybrids in relation to environmental aspects, such as nitrate leaching, water use efficiency and consumption, pest resistance, crop structure, etc. Due to lack of information and limited resources available for writing this paper, the potential effects of varieties of the same crop are not discussed. However, we emphasize the importance of this aspect, and recommend further research in this area.

The following sections provide a brief review of the main environmental effects of SRC and PEG plantations associated with land use change and likely crop management practices. A further detailed review of the environmental, particularly biodiversity, impacts of SRC and short rotation forestry can be found in Hardcastle *et al*., (2006).

Attention is also paid to the GHG emissions of the cropping phase of the perennials, as mitigating climate change is one of the main reasons why biomass crops should be grown for energy purposes.

In reality all these factors interact in a complex way, but the review below hopefully provides a reasonable introduction to the potential environmental effects of perennial energy crops.

3.1.1 Relative effect compared to previous land use

The actual positive or negative effects of any energy crop ultimately depend on which current land use (in terms of type and intensity) it is replacing. The following discussion distinguishes in most cases intensive arable crops from permanent crops and/or grassland.

3.1.2 Spatial and temporal scale

Spatial and temporal scale are important factors for the environmental impact of perennial energy crops, as their effect can vary significantly at different growing stages and with different scales of the plantation.

For example, perennial energy crops improve biodiversity when implemented at small scale in intensive agricultural areas, but may threaten bird species adapted to open landscapes if these plantations become predominant (Sage *et al*., 2006).

Large scale plantations alter the landscape in a significant way, not only because of the height of the SRC or PEG compared to grasslands or annual crops, but also of the change of the growing cycle from annual to multi-annual crops.

3.1.3 Choice of species and clones

Large difference may occur in environmental performance between different species of SRC and PEG and also between hybrids of the same crop.

For example, aluminium exportation from Poplar soil remediation experiments ranges from 1.5 g/ha for ‘Gaver’ clone, to 13.9 g/ha with the ‘Fritzi Pauley’ clone (Laureysens *et al*. 2005b)..

In the Scarlino experiments (see section 3.3.5), 26 clones were used (from eucalyptus, poplar and willow). Arsenic accumulation in leafs of the eucalyptus clones (2.691 mg/Kg) is on average higher than that of poplar (2.176 mg/Kg) and willow clones (1.781 mg). The high variability of the accumulation aptitude in the eucalyptus clones suggests the possibility of selection of the most favourable ones (Mughini *et al*. 2007).

Other important differences could link to water demand, fertilisation requirements or suppression of weeds.

3.1.4 Management practices

The management regime applied to permanent energy crops plays an important role in determining the overall environmental impacts of these crops on the ground. While the inherent characteristics of SRC and PEG cannot be changed, cultivation practices can reinforce positive environmental impacts and reduce negative ones.

3.2 Potential impacts associated with land use change

Land use change can be positive or negative for the environment, depending on the type of original land use and the land use to be established. On productive cropland the establishment of SRC or PEG plantations will in most instances lead to a positive environmental balance, but there can also be no-go areas for energy crop plantations, e.g. semi-natural grasslands or wetlands. The environmental implications of the most common type of potential conversions are briefly discussed in the bullet points below.

The highest yields for SRC and PEG plantations can be obtained on productive croplands. However, such plantations compete with food markets and also with liquid biofuels produced from grain and oilseed crops. High prices for crops such as wheat and barley make it difficult to present convincing economic arguments for the establishment of SRC and PEG on productive agricultural land. Due to this competition for productive area, SRC/PEG plantations might be established on less productive area or re-allocated agricultural land, if relative economic returns are in favour of perennial plantations. Cultivation types in this category include grassland, long-term set-aside, fallow land, olive grove, vineyards etc. In this case, the negative environmental implications can be considerable, as discussed below.

SRC/PEG plantations may also be established to treat wastewater, create flood retention areas and riparian buffer zones, or for phyto-remediation purposes. Examples of potential environmental opportunities linked to the cultivation of permanent energy crops are discussed in section 3.3.

- **Conversion of productive cropland**

The conversion of current arable land to SRC or PEG plantations should in most instances bring positive benefits for soil resources and water quality. Due to the high water requirements of many perennial energy crops there could be, however, negative consequences for groundwater re-charge or water cycles (Dworak *et al*., 2007).

Where permanent energy crops improve the range and spatial distribution of different habitats in intensive agricultural landscapes their impact on biodiversity is likely to be positive (mostly for already common species); where they have the opposite effect or become dominant they are likely to decrease biodiversity in mixed agricultural landscapes (see also section 3.5.2).

- **Conversion of grasslands, permanent pasture, moorlands, wetlands**

Work by the Joint Research Centre (JRC) and others shows that cultivating this type of site would lead to the loss of significant amounts of soil carbon, up to a point where the greenhouse gas benefits of SRC or PEG energy pathways would be negated for more than one decade (JEC, 2007). Soil erosion risks, effects on water pollution and impacts on water cycles would all increase compared to the previous land use, in some cases to a very strong degree. Biodiversity and landscape values would in most cases also be negatively affected.

- **Conversion of fallow land or (long-term) set-aside**

Land that is currently lying fallow can still be found in the new Member States (much of it was previously under grass and all would now have had a grass cover for several years). On the Iberian Peninsula one can also still find fallow land as part of traditional arable crop rotations. Lastly, there is long-term set-aside in the EU, mostly linked to agri-environment schemes. The environmental impact of establishing SRC/PEG plantations on such land vary, but would mostly be negative.

The case of traditional arable fallow in Iberia is most clear cut: if rainfall and soil conditions would allow the establishment of perennial energy crops the soil carbon effects would be positive, water pollution would probably be reduced, water cycles/groundwater re-charge would most likely be strongly affected, and characteristic biodiversity and landscape values would suffer serious negative consequences. However, this type is mostly a case of rotational fallow; hence the crop rotation may actually not be affected as such, just the total area of arable cropland would be reduced (with the same environmental effects).

The establishment of SRC or energy grass plantations could be an option for the use of land that currently lies fallow, whether as long-term set-aside or economic fallow in the new Member States (see DG Agriculture, 2002). In the Czech Republic, for example, there are 0.5 million ha of fallow land at the moment (Barto, 2006). The total extent of this land is difficult to estimate; but it seems to cover a significant area in the EU-27. Most of the land affected is below average productivity, often it is the wetter fields and steeper slopes as well as poorer soils that are abandoned first. Higher crop prices and strong biomass demand are likely to make the cultivation of at least a part of this land reserve attractive to farmers.

However, given the land use history and current vegetation cover of this land many of the environmental concerns expressed for grasslands, permanent pastures and wetlands apply. Consequently, considerable attention must be paid to issues of carbon release, impacts on soil and water resources as well as consequences for biodiversity and landscape values.

- **Conversion of permanent crops**

Another potential land reserve is the area of permanent crops that becomes surplus to future food demand. The 2006 EEA study on the EU bioenergy potential estimated that up to 5 million ha of ‘grassland and olive groves’ in the EU-25 would become surplus to food requirements by 2030 (a lot of this would fall in the dehesa/montado land use category).

Under several environmental aspects (water and soil conservation, biodiversity and landscapes) the future use of part of the permanent crop area is very sensitive.

Dehesas/montados, extensive olive groves etc should only be used in a way for energetic purposes that maintains their current land cover (EEA, 2006), i.e. they should not be cleared and converted to SRC or PEG plantations. Extensive vineyards, on the other hand, play a positive environmental role (where they still exist) but the environmental balance of converting intensive current vineyards to SCR or PEG (where agronomically possible) is most likely to be positive. Certainly in comparison with a follow-up arable land use SRC or PEG seem to be advantageous although water cycle issues need to be considered. The same judgement probably applies to intensive fruit tree or olive tree plantations but further research is required on this issue.

3.3 Soil and water effects

SRC or PEG plantations have potential impacts on soil and water resources that can be both positive and negative. The direction or scale of many of these impacts depend on the land use change associated with the establishment of SRC/PEG plantations, and have been discussed in the previous section. Others depend on the physiology and agronomic characteristics of perennial energy crops and the specific farm management applied. The discussion in this section focuses on such issues. In addition, options for improving soil and water management via SRC/PEG are briefly presented.

3.3.1 Soil erosion

Given the crop characteristics of most SRC and energy grasses (permanent soil cover, low input use, little use of machinery outside planting and harvesting) the establishment of such permanent energy crops is likely to bring benefits for soil erosion, compared to annual agricultural crops. This applies in a more limited way also to the conversion from permanent agricultural crops, in particular intensive vineyards (see also section 3.2).

Due to their near-permanent soil cover SRC and energy grass plantations lead to a reduction in soil erosion risks compared with most agricultural crops, in particular arable crops. However, certain authors consider that the decrease in erosion due to planting SRC will be greater if a cover crop is used to stabilise soils during the first two growing seasons (Ranney and Mann, 1994). Furthermore, it has been pointed out that the harvesting of Miscanthus during the winter period on wet, non-frozen ground can lead to soil compaction and risk of erosion if inappropriate machinery operations are used.

3.3.2 Diffuse water pollution

When compared with the conversion of grassland to arable crops or a continuation of current cultivation, SRC plantations and perennial energy grasses offer a significant reduction of water pollution risks (Christian and Riche, 1998). Research carried out by the Danish Institute of Agricultural Sciences (Jørgensen, 2005) on perennial crops showed very low levels of nitrate leaching over a seven-year period. This was also the case in optimally fertilised crops for willow and Miscanthus. The results indicate that a shift from conventional agricultural crops to perennial energy crops can potentially reduce nitrate leaching by 70%. The extended growing season of perennial crops means that they are particularly effective at minimising nitrate leaching from animal manure.

However nitrate leaching has to be considered in the first year of planting, when ground cover is poor and nitrate from former plantings might be washed out (Christian and Richie, 1998). In addition, there is a significant potential for a sudden release of nitrogen from the mineralisation of organic matter (a so-called nitrate flush) to occur when SRC plantations are renewed at the end of their lifetime. It seems that not much work has been done on this issue (most SRC plantations are only at the beginning of their life cycle), but this question certainly seems worth further investigation.

On the other hand, riparian buffer strips with permanent vegetation, such as perennial grasses and short rotation woody crops (SRC) located within and between agricultural fields and the water courses to which they drain could help to reduce nutrient inputs to water bodies (Shepard and Tolbert, 1996). So using buffer strips for bioenergy production could allow farmers to reduce diffuse pollution loads while obtaining an income from buffer strips due to the production of biomass for energy.

However the application of such buffer strips has to be done with care. Broad strips of energy crops grown in riparian zones could use up to twice as much water as the same crop grown in the same spatial arrangement on an upland site without access to ground water (Stephens *et al.*, 2001, see also section 3.3.3 below).

3.3.3 Water requirements

Depending on crop type (especially for Miscanthus and switchgrass), perennial crops can reduce water abstraction needs substantially compared to irrigated annual food crops (EEA, 2006, and Kleinschmit, 2007).

However, some short rotation crops and energy grasses can have high water requirements which could alter hydrological regimes or exacerbate water shortages compared to non-irrigated arable crops. Comparing the water use of winter wheat, permanent grass, Miscanthus and willow SRC with no restrictions to growth at three sites in different agro-climatic zones in England suggests that both energy crops consistently used more water than the crops they might replace (Stephens, *et al*., 2001).

Evidence from a number of studies suggests that Miscanthus and SRC are able to extract water from as deep as 2 and 3 m respectively and trees are able to supply much of their water requirement from ground water when it is within the root zone. Deep rooted energy crops grown on soils with large available water content will cause substantial reductions in the amount of water percolating below the root zone. Soil water deficits of up to 250 mm may develop over the growing season and in drier areas there may be insufficient rainfall during the winter months to re-wet the soil to field capacity (Stephens *et al*., 2001).

The implication of the relatively high water requirements of permanent energy crops is that care needs to be taken in decisions on the placement and also the type of such crops at landscape and farm level. The need to maintain the hydrological regimes of wetland areas and groundwater re-charge capacity is likely to impose certain limitations on the spatial placing and density of permanent energy crop plantations in regions where water is not abundant. In times of increasing water scarcity it does not seem appropriate to use water resources for the irrigation of energy crops. In such situations it would seem preferable to develop novel permanent energy crops (e.g. cynara or jatropha) that can cope with conditions of summer drought. Sustainable Bioenergy Cropping Systems for the Mediterranean were discussed at a joint JRC/EEA/CENER/CIEMAT workshop (see JRC/EEA, 2006).

Particular care must be taken in wetland areas (Land use Consultants, 2007), where hydrological regimes may be altered, with negative impacts on habitats and downstream water dynamics.

3.3.4 Waste water reuse and treatment in SRC or PEG

The practice of applying wastewater/sludge on SRC/PEG is a quite new approach in Europe and therefore not many research projects specially focused on such practices have been completed. However, due to the increasing interest in such systems for treating and reusing waste residues and simultaneously producing biomass for energy, such research projects have been increasingly initiated in recent years.

In most cases, research projects have been initiated in countries where the establishment of SRC/PEG always had a strong tradition (e.g. Sweden, Denmark, UK etc), and in countries where the scarcity of water resources has lately led to alternative uses of wastewater, namely its reuse in SRC (Spain, Italy, Portugal, Cyprus, Greece etc). In other parts of the world besides Europe, irrigation of SRC with wastewater or the application of sludge is not a common practice (Aronsson *et al*., 2006).

Nevertheless if located, designed and managed wisely, energy crop plantations can, besides producing renewable energy, also generate local environmental benefits. Such benefits could arise from the nutrient content in wastewater. Theoretically, the nutrients in domestic wastewater and organic waste are almost sufficient to fertilise crops. As much as 80-90% of the major plant nutrients (nitrogen, phosphorus and potassium) in wastewater are present in the toilet waste. This could reduce the need for additional fertiliser and increase profit margins due to lower input costs.

Another opportunity is to use willow plantations as vegetation filters for the treatment of nutrient-rich, polluted water, such as municipal wastewater and drainage water. The purification efficiency of willow vegetation filters has been demonstrated in several countries, e.g. Sweden, Poland, Denmark and Estonia, since the beginning of the 1990s (see Box 1). Other projects have shown that willow plantations can lead to soil carbon accumulation, increased soil fertility, reduced nutrient leaching and erosion, removal of cadmium from the soil, etc.

Box 1: Willow plantations for waste water treatment

The average nutrient content in municipal waste water normally corresponds fairly well to the nutrient requirements in willow cultivation.

An annual municipal wastewater load of 600 mm, containing about 100 kg N, 20 kg P, and 65 kg K, will supply not only the required water, but also the requirements of N and other macro-nutrients. The wastewater is pumped to the willow vegetation filter or to the storage ponds in the winter, so that the nutrient is re-circulated to the willow plantation. The root systems will then take up 75-95% of the nitrogen (N) and phosphorus (P) in the wastewater. The generation of sewage sludge will also be significantly reduced when willow vegetation filters are used, by up to 80%.

Water deficiency is often a growth-limiting factor in willow cultivation, even in countries with significant precipitation throughout the year. The regional variation in biomass yields can be significant due to differences in water availability during the vegetation period. Thus, the biomass yield response to wastewater irrigation will be more significant in regions with relatively low precipitation during the vegetation period. In Sweden, for example, the biomass yield can increase by 4 to 8 tonnes dry matter per hectare per year, or 30 to 100 percent compared to average yields for well managed, rain-fed willow plantations on good soils.

Willow vegetation filters are attractive from an economic point of view. This is due to reduced willow cultivation costs and also to the fact that willow vegetation filters provide a treatment option that is lower in cost than conventional treatment at sewage plants. The nitrogen treatment cost could be 3-6 € lower per kg N in vegetation filters, compared with in conventional sewage plants, where the nitrogen treatment cost normally amount to approximately 10 € per kg N. The cultivation cost could be reduced by 1.2 to 1.8 € per GJ biomass, due to reduced costs of fertilisation and increased biomass yields. This reduction is equivalent to 30-50% of the cultivation cost in conventional plantations.

Despite the various benefits of willow vegetation filters, several potential barriers exist against their large-scale implementation. Some of these are due to lack of knowledge, such as regarding the risk of the spread of pathogens. Others concern the allocation of benefits and risks among the actors involved. Such a defective allocation could be overcome by developing mutual agreements between the sewage plant operator, the energy plant operator and the willow producer (farmer), which has been successfully achieved in some cases in Sweden.

Wetland treatment systems currently use aquatic plants such as reeds. The difficulties with this system is usually that urban wastewater treatment works with effluent flows high enough to justify the establishment of a commercially sized SRC plantation are situated within or close to urban areas, i.e. with no or insufficient suitable land area close by. Where land may be available, i.e. in rural areas, the wastewater treatment works do not have high enough flows due to low populations.

3.3.5 Phytoremediation

Fast growing trees planted on soils contaminated by heavy metals allow simultaneous biomass production for energy and a reduction of contaminants in the soil through phytoextraction. Various experiments on phytoextractive ability have been carried out across Europe, using poplar, willow and eucalypt clones.

The extractive capability of different species and clones were confirmed by experiments lead for example in the alluvial area of Scarlino (IT) where high As Arsenic concentrations were found in the soil, due to geological and/or anthropical causes (mining and industry).

The phytoremediation potential of a poplar or willow plantation depends on both the biomass productivity rate and the concentration of the element (heavy metal) in the biomass. For each metal, the extractive capability varies according to the species and to the clones, over a wide range (Laureysens *et al*. 2004 ; Laureysens *et al*., 2005b.).

3.3.6 Creation of flood retention areas

The modification of water courses, the construction of barrage weirs and a lack of water retention due to the expansion of settlement areas and intensive farming as well as other factors have led to diminishing flood plains and an acceleration of flood waves and thus to an increased number of flood events. In order to address these problems new flood protection policies aim to give rivers more space by using agricultural land as flood retention zones.

Cropping perennial crops for bioenergy purposes in such cases could create win-win solutions for farmers and flood protection (Dworak *et al*., 2007). Studies in the US have considered the planting of bioenergy crops in flood-prone areas because as perennial crops they do not have to be re-established annually and can withstand periods of flooding. Harvesting of these crops on wet areas would have to be timed carefully to occur during dry periods to minimize rutting and compaction of the soil (U.S. Congress, Office of Technology Assessment, 1993)

Furthermore, agro-forestry systems could also be used in flood-prone areas. Hershey and Wallace (1993) found that water breaks of trees planted perpendicular to the flow of high energy flood waters were economic based solely on the reduction of damages to crops, assuming floods of 10 year frequency.

3.3.7 Establishment of riparian buffer strips

Riparian buffer strips with permanent vegetation, such as perennial grasses and short rotation coppice located within and between agricultural fields and the water courses to which they drain could create win-win situations. Research has shown buffers to be most effective in trapping particulate pollutants but they also are beneficial in reducing the export of soluble pollutants. So, buffers are expected to reduce concentrations of nitrogen, phosphorus, and sediment in surface water runoff. Riparian buffer strips thus improve water quality (Shepard and Tolbert 1996); and crops grown can be used for energy production. However, where ground water recharge is limited due to low precipitation in the summer it has to be considered that the application of such buffer strips could use up to twice as much water as the same crop grown in the same spatial arrangement on an upland site without access to ground water (Stephens *et al*., 2001).

3.4 Fertilisation and pest control

3.4.1 Fertilisation

All SRC and PEG require less fertiliser input than arable crops. Nevertheless, mineral fertilisers are often used to stimulate the growth of perennial energy crops. The environmental impact of these practices will be determined by the quantities applied, the timing of application and the ability of the perennial crops fertilized to make use of the fertilizers applied.

Jørgensen (2005) showed very low levels of nitrate leaching over a seven-year period on perennial crops, and reductions in nitrate leaching of up to 70% compared to conventional annual crops (see section 3.3.2).

In Spain, 450 kg/ha, N:P:K (8:15:15) are applied when establishing Poplar SRC plantations. A second fertilizer application during the first vegetative period was shown to improve production only if soils have low fertility. For *Cynara cardunculus*, the fertilisation depends on soil composition. A normal fertilization dose is 75 kg/ha of nitrogen utilizing N:P:K (15-15-15) prior to sowing in the autumn; and a similar dose in spring each year (also including the first year for poor soils) (Carrasco & Sixto, 2007). In this experiment, results with organic fertilizer (pig manure and sewage sludge) have been similar to those obtained with mineral fertilizers.

Overall, it can be assumed that the environmental risks related to the application of fertiliser and pesticide inputs are small, in particular when compared to annual crops. However, the type of substances used as well as the timing and type of applications will still have a significant impact on relative environmental risks. Further work in this area seems necessary, in particular on the question of using organic manure.

3.4.2 Pest control

Fungicide, herbicide and insecticide applications are likely to be absent or less frequent in SRC and PEG systems compared with conventional agricultural crops. Hence risks to the environment from input use, in particular on water quality, will decrease significantly. Nevertheless, weed control is regarded as necessary for short rotation coppice before cultivation, shortly after planting and following harvest (Tubby and Armstrong, 2002).

In the case of energy grasses (e.g. Miscanthus) herbicide applications may only be required during the early establishment phase to keep out competitors. These recommendations represent a significant reduction of water pollution risks. However, together with the effective shading-out effect of dense, tall permanent energy crops, they provide similar or even more effective suppression of associated weed flora than in intensive cereal cropping systems, for example. For perennial biomass grasses Carey (2005, unpublished) found that the best practice guidelines produced by DEFRA stated for growing *Miscanthus* that weeds are effectively suppressed after the second year of growth because of the dense litter layer.

Recent experience is available from experiments in Spain. Weed control prior to planting and just before planting is considered essential for the adequate establishment of plantations and for the success of any new rotation cycle. Researchers are also checking the use of a second application in terms of increase in yield and costs. In some situations it could be necessary and profitable. In order to minimize the use of chemicals for pest control and to increase the diversity of the material, genetically tolerant varieties are used.

A concrete example is available for poplar SRC in Spain where Oxifluorfen at 4 l/ha is being used. Herbicides are also applied on Cynara plantations for weed control, normally in spring the first and eventually the second year after sowing (after that the crop covers the land surface, thus suppressing most weed growth) (Carrasco & Sixto, 2007).

3.5 Biodiversity

The effects of SRC and PEG plantations on biodiversity will depend on a range of factors. These include the land use to be replaced, choice and management of the perennial energy crop, as well as questions of scale and location. Much more research has been carried out on effects of SRC on biodiversity than on the effects of energy grasses. Most of the following information applies to SRC but not PEG, and should not be extrapolated to the latter. The following sections briefly review the issues listed above.

3.5.1 Issues associated with land use change and landscape character

It is generally not possible to assign positive or negative impacts on biodiversity to individual crop species without having a better understanding of current land use and the proposed energy crop choice and management system. SRC established on intensively farmed agricultural land is likely to have a negligible or positive effect on biodiversity at the local scale. However, the same crops planted on heathland, moorland or wetland would have negative effects on local biodiversity.

In general, SRC systems can introduce additional habitat and niches into the environment at the landscape scale. So, where permanent energy crops improve the range and spatial distribution of different habitats in intensive agricultural landscapes their impact on biodiversity is likely to be positive (mostly for already common species); where they have the opposite effect or become dominant they are likely to decrease biodiversity in mixed agricultural landscapes.

Agroecological knowledge on the species diversity associated with low-intensity arable land use or permanent crops as well as the habitat requirements of threatened meadow birds, for example, also points out substantial biodiversity risks associated with the establishment of SRC/PEG. These relate above all to the change in habitat characteristics that can be brought about by dense plantations of permanent energy crops. For example, if open wet grassland landscapes such as the Somerset levels were converted to willow SRC plantations, the specialised and threatened species communities associated with wet grasslands would disappear almost entirely.

For species that require long distance visibility (e.g. meadow birds, as protection against potential predators) even a low share of high SRC or energy grass plantations would bring strong negative impacts. This assessment is likely to apply also to extensive cereal steppes in Iberia, the UK uplands or mountain grasslands across Europe.

A lot of permanent crops may be released from agricultural production in southern Europe, in particular olive groves, dehesas and vineyards. Where they are under extensive management these make a substantial contribution to species richness, linked to their structural diversity that derives from low-density plantations and the combination of vertical structures (trees) with open arable weed or grassland vegetation layers. If permanent energy crop plantations are not able to reproduce these habitat features they are also likely to lead to substantial biodiversity losses where they replace extensive permanent crops in southern Europe.

3.5.2 Biodiversity effects by species group

- **Soil fauna, invertebrates, insects**

After establishment, there is generally little soil disturbance or use of agrochemicals in SRC/PEG plantations, which is beneficial for soil biodiversity, especially decomposers, and other flora and fauna.

Semere & Slater (2007) have compared different biomass grass plantations (*Miscanthus*, canary grass and switch grass) and have shown that in the early years after planting *Miscanthus* had higher populations of invertebrates than the other tested energy grasses. It has been shown that SRC maintains large densities of phytophagous insects (Sage & Tucker, 1998).

- **Birds**

The high densities of microfauna in SRC plantations benefit insectivorous woodland birds e.g. Turdidae (thrushes) and Paridae (tits) (Sage & Robertson 1996, Coates & Say 1999), *Phylloscopus trochilus* (willow warbler), *Silvia borin* (garden warbler) and *Phylloscopus collybita* (chiffchaff). Game birds such as *Phasianus colchicus* (pheasant) use SRC as cover (Britt, 2002).

In a predictive study Londo (2002) has listed different management practices and created a list of birds that will live in SRC. A table was produced showing which practices are likely to affect different bird species. For example, whitethroat and wren are predicted to decrease with planting density once the canopy has closed and there is no longer much ground vegetation. Conversely if there is a high edge to area ratio all ground or leaf foraging birds are predicted to increase as are woodland birds that use mixed habitats.

Sage *et al*., (2006) have carried out a comparative study of short rotation willow coppice with arable crops in central England. Overall, more individuals and species were recorded in and around willow SRC than equivalent arable or grassland throughout the year. Even farmland specialists such as skylark used willow SRC fields, at least in the vegetation period after harvesting. The authors point out that SRC crops are often weedy and insect rich and have potential, therefore, as foraging habitats in summer and winter. However, the success of breeding in SRC plantations could not be investigated, hence further work on population effects is still required.

- **Mammals**

Carey (2004) did not find any studies on mammals inhabiting SRC but observations have been made (Sage & Tucker, 1998; Coates & Say, 1999). In a survey of five SRC sites 13 mammal species were seen, four of which were common rabbit, brown hare, mole and woodmouse. How the figures compare with conventional agriculture is not given.

Small mammal populations were found to decrease in SRC established on former pasture in the first year and this was caused by destruction of the ground flora. If SRC has high levels of weed control vole populations will not be supported (Britt 2002). It is possible that SRC may provide hunting grounds for bats but this has not been demonstrated and whether they are better or worse than arable fields is also unknown (Britt, 2002).

There is only a short period between about March when the crops are harvested and July as they begin to grow again when the ground is open. Therefore, for large parts of the year the crops provide cover for birds and animals. However, the open period in spring is when many creatures would normally be raising their young and when cover would be most useful. The winter cover would be particularly useful to brown hares.

- **Bioenergy crops as invasive species?**

An underestimated problem concerns the introduction of new energy crop species. Several perennial species or hybrids with high biomass yield and high tolerance to different environmental conditions can be attractive for cultivation. However, large scale usage and distribution of these species may become out of control causing these species to invade natural habitats which would result in the loss of natural biodiversity. Furthermore, such environmental weeds will be expensive to get rid of (Heinsoo *et al.*,, 2007). In order to avoid such problems, species natural to a given region should be preferred as energy crops.

Concerns have been expressed that *Miscanthus* may escape in a similar way to Japanese knotweed i.e. by rhizome fragments, and as it is so competitive will have a detrimental effect on native biodiversity. However, no concrete evidence of such events has been provided so far.

During the SRC/PEG expert meeting in October 2007, specific examples of exotic species damaging local ‘high value’ habitat were given. It was felt, however, that these examples were in fact down to poor planning controls and guidance rather than the species used *per se*.

Willow SRC is an example of an energy crop that due to its natural characteristics can provide substantial biodiversity benefits (see above). Other native tree and shrub species (i.e. *Castanea* spp., *Fraxinus* spp., *Betula* spp., *Corylus* spp.) could provide similar benefits if managed as coppice or forestry for energy production.

3.5.3 Effects of spatial and temporal scale

The results of a Swedish study show that plantations of *Salix* and other fast-growing trees grown on agricultural land can improve biodiversity at landscape level, in particular if the plantations are established instead of cultures of cereals and spruce in a homogeneous agricultural landscape (Weih, 2006).

However, these conclusions are likely to hold only for small-scale plantations in intensively used agricultural areas where they increase habitat diversity. If a large part or all of current arable or mixed agricultural landscapes were converted to dense SRC plantations or tall energy grasses the impact on farmland bird communities and invertebrates adapted to open landscapes are likely to be negative (see section 3.5.1). In addition, the type of perennial chosen will also determine to a large extent what the net effect will be.

Many perennial energy crops provide potential benefits for biodiversity, e.g. willow SRC. This potential can be improved via sympathetic management regimes at local and landscape scale, for example by establishing headlands surrounding the crop and rides and corridors within the energy plantation. Suitable planning and management could include establishing plant and shrub species native to the area along rides and mowing headlands outside bird nesting times. Spatial variation can, however, also be achieved via temporal variation in the management of adjacent energy plots in the landscape. If the planting and harvesting cycle of energy plantations at landscape level is staggered across time then the different stages in the rotational cycle also provide spatial variation in habitat types and quality.

3.6 Landscape

The landscape effect of SRC and PEG is likely to be very strong due to the dense tall structures they are going to create. As with biodiversity, the establishment of permanent energy crop plantations at a small-scale in intensively used and open agricultural landscapes will contribute to landscape diversity. Where they become dominant, however, or destroy the characteristics of traditional open landscapes (e.g. the extensive cereal steppes in Iberia or the UK uplands) they bring about a very strong change of landscape characteristics. It is likely that this will be perceived as a negative impact by most observers and users of the European landscapes[7]. Recent work in the UK has researched the initial reactions by local populations to different types of perennial energy crop plantations (Lovett, pers. Comm., 2007).

Energy crop management aspects that are relevant from a landscape and biodiversity perspective can be dealt with together. In both instances the size and placing of energy crop plantations has an important influence on their environmental effect. Smaller plantation sizes will in most instances be better than large ones and sensitive sites should be avoided. Preserving current landscape character would be favoured by avoiding sites that have particularly important visual impacts, e.g. sites that block specific vistas or impact on traditional landscape character.

From a landscape ecology perspective, the planting of semi-natural areas with energy crops needs to be avoided. In currently intensively cropped areas, plantations should ideally be spaced in a way that they can provide shelter and migratory stepping stones. In addition, giving room to spontaneous vegetation, whether annual weeds or grass/herb strips, must be considered, as this is an important element for ensuring food supply and shelter for species adapted to agricultural landscapes. This can be achieved by leaving strips unplanted within energy crop plantations or by spacing trees and energy grasses more widely, allowing other vegetation to co-exist.

3.7 Carbon balance

A key objective behind the use of biomass for energy purposes is that it may help to reduce greenhouse gas (GHG) emissions, an obligation under the Kyoto Protocol. The GHG emissions of the cropping phase of perennial energy crops are therefore very relevant when looking at overall environmental performance. This section will briefly review the potential carbon savings offered by perennial energy systems.

There are two main aspects of energy cropping that are assumed to positively affect the GHG-

[7] The ‘quality’ of a landscape depends ultimately on subjective assessments by humans as they use and appreciate landscapes during their daily life and/or leisure time. However, it is known that diversity and openness of landscapes are considered as positive attributes by most observers.

balance: carbon sequestration in the soil and decreasing "fossil-fuel"-derived CO_2 emissions via fuel/energy source substitution. While the energy input for growing energy crops is an important factor to consider, two issues affect the GHG balance particularly in the field phase:

- soil carbon evolution
- nitrous oxide emissions

- **Carbon balance**

Soil carbon evolution depends on the ability of perennial crops to fix carbon, compared to the previous use of the land. Soil carbon is affected by the input of organic material, the conversion rate of organic material to nutrients and CO_2, and the uptake and loss of nutrients.

In a closed system, thriving plants add the organic material to the soil in the form of roots and foliage, which over time are converted to nutrients and CO_2. Environmental aspects are important factors for the potential soil carbon level. A sandy soil can hold less organic material than a clay soil. In cropping systems, the amount of organic material incorporated in the soil depends on the crop type (Zan, C.S. *et al*., 2001) and management practices, e.g. the proportion of biomass harvested (IEA, Bioenergy Task 38).

The decomposition in the soil of organic material is affected by temperature and moisture conditions (Cowie *et al*.., 2006). The conversion rate increases with warmer temperatures and requires sufficient humidity. Carbon soil pools in natural systems can be ranked in the following order: largest carbon soil pools exist in cool temperate forests and wetlands (plant growth > conversion rate in the soil), smaller carbon soil pools in the wet tropics (rapid conversion in the soil in addition to plant growth), and smallest carbon pools in dry environments (limited plant growth and conversion) (Cowie *et al*., 2006).

Cropping systems affect soil carbon via the input of organic matter, the conversion rate and extraction of nutrients for plant growth. There are general differences between perennials and annuals, which mean perennials benefit soil carbon. As opposed to annual crops, perennials provide a year-round supply of organic matter via roots and foliage. A smaller proportion of biomass is harvested per year (Deckmyn *et al*. 2004). Additionally, year-round soil cover reduces soil erosion and nutrient leaching. In terms of farming practices perennials are also likely to have a better GHG balance then annuals because once the crop is established, they require, lower mechanization and input levels.

The IEA (Bioenergy Task 38) recommends land management options to enhance the soil carbon balance of energy cropping systems. These include the following: retain slash and crop residues on site, maintain fertility (including by returning ash), apply organic matter, plant mixed species, and minimise cultivation disturbance to reduce mineralisation and erosion losses. According to the IEA, "*the most significant factor for enhancing soil carbon is strong plant growth. Therefore, management practices for a bioenergy system should be designed to address site-specific growth limitations to the crop or forest so as to ensure successful establishment and maximum growth rate*".

- **Nitrous oxide (N_2O) emissions**

Nitrous oxide emissions remain one of the major uncertainties in GHG emissions from agriculture (e.g. Crutzen *et al*., 2008). They are particularly relevant for crops that receive significant amounts of mineral fertiliser, e.g. oilseed rape (MNP, 2008). Perennial crops, however, are fertilised less than usual annual crops, and the permanent soil cover they provide reduces the leaching of nutrients. Thus nitrous oxide emissions from perennial energy crops are likely to be significantly smaller than those from annual crops. Nevertheless, this remains a factor to be watched in case standard SRC/PEG cropping practices develop in direction of higher nitrogen applications.

3.8 Climate change effects on biomass cropping systems

Most research programmes until now have focused on using bioenergy production for mitigating climate change. Few studies have been carried out for evaluating the potential effects of the climate change on perennial energy crops. Climate change has an obvious effect on growing conditions for energy crops by changing temperature and precipitation patterns. The likely growth areas for perennial crops will move northward in the future and water may become a more strongly limiting factor in many areas.

The growth conditions for, and necessary responses in, energy cropping will also affect their likely environmental impact, but we do not have sufficient knowledge on the direction of change in most instances for the time being. Consequently, there is a need for developing research approaches for a better understanding of climate change effects on biomass cropping systems, utilizing both up-scaling and downscaling procedures.

Table 7 summarises the main points of the environmental assessment provided above.

Table 7: Potential environmental effects of SRC/PEG

Environmental factor	Small-scale plantations on intensive farmland	Large-scale plantations on intensive farmland	Small-scale plantations in extensive farming systems	Large-scale plantations in extensive farming systems
Soil conservation	Positive	Positive	Positive (if it does not replace permanent grassland)	Positive (if it does not replace permanent grassland)
Water quality	Positive	Generally positive	Mostly positive (if it does not replace permanent grassland)	Mostly positive (if it does not replace permanent grassland)
Water quantity	Small risk of lowering water tables and groundwater re-charge *	Considerable risk of lowering water tables and groundwater re-charge *	Small risk of lowering water tables and groundwater re-charge	Considerable risk of lowering water tables and groundwater re-charge
Biodiversity	Mostly positive	Can be positive to negative	Neutral to negative	Most likely negative
Landscapes	Mostly positive	More negative than positive	Neutral to slightly negative	Generally negative

Note: * Should non-irrigated permanent energy crops replace irrigated agricultural crops there would be considerable benefits from a water quantity perspective.

4. Status of research and perspectives

4.1 Introduction to and overview of research topics

In the brief space and time available it was not really possible to review or summarise the large amount of research that is currently focused on different aspects of perennial energy crop production, or to discuss research approaches and the inter-linkages between different research areas in sufficient detail.

However, this section lists the main research areas and highlights key issues that are of particular environmental or practical relevance (see Figure 1). Further information on past and ongoing research projects can be found at the following web addresses:

http://ec.europa.eu/research/index.cfm?lg=en&pg=enquiries

http://ec.europa.eu/research/infocentre/theme_en.cfm?item=Energy&subitem=Renewable%20energy%20sources

4.2 Present research programmes

Research on the implementation of SRC plantations aiming at highest biomass production was initiated in the 1970s and involved mainly research on broadleaved trees with the following characteristics: fast-growing, cultivated in dense stands, harvested after short periods, and good coppicing ability. Based on these criteria, mainly willow, poplar and eucalyptus were used for establishing short rotation plantations and associated research projects.

A wide range of research questions are currently being investigated, including the suitability of tree species under different climatic conditions, crop management and choice of land, crop establishment, fertilisation, weed and pest management, harvest intensity as well as environmental and economic issues.

Not surprisingly, research on suitable varieties, cultivation practices and the energy chain associated with permanent energy crops is further advanced than the analysis of their potential environmental impacts. The following list provides an (incomplete) overview of relevant research issues (issues that would often benefit from being covered in research project or cluster):

- Crop breeding aspects: crop protection, yield potentials etc. of suitable varieties and species for EU conditions
- Cultivation aspects: management techniques, economic and environmental planting, managing and harvesting, fertilisation
- Environmental aspects: water management (water demand, effect on hydrological systems), low input-high yield, soil impacts (erosion control), biodiversity and landscapes
- Economic aspects of the production of SRC and perennial grasses
- Bioenergy crops and bio-remediation
- Bioenergy crops and carbon sequestration
- Fuel chain: logistic/storage/harvesting/pre-treatment
- Conversion processes/end use

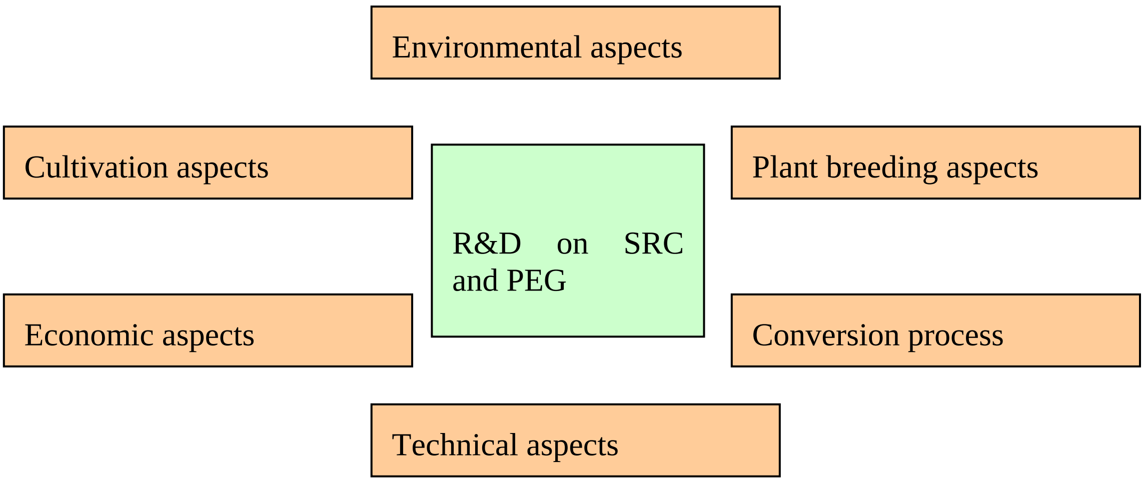
4.3 Research challenges

Research on SRC/PEG production systems is a complex and rapidly advancing field. Economic and environmental aspects need to be integrated with research on production systems and yields as well as consider growers and end users. Future research programmes should therefore build as much as possible on interdisciplinarity; construct links between field application and basic research; include dissemination activities; and tackle spatial and temporal scale effects. These issues are briefly discussed in the following sections.

- **Interdisciplinarity**

The development of SRC plantations and perennial grasses is often still in the establishment phase. Consequently, associated research involves a range of different issues from energy yields and agronomic aspects to environmental questions (see also Figure 4.1). It appears wise, therefore, to focus further research effort and investment not only on certain limited research fields and to aim for working in an inter-disciplinary fashion where possible.

Figure 1: Research issues associated with perennial energy crop production



As can be seen from Figure 1 the range of research linked to perennial energy crop production is very wide and involves a great range of disciplines. To be successful in integrating energy production, agronomic and environmental aspects a cooperation between different research fields is generally required.

- **Link between basic research and field application, and dissemination**

To advance from research to large-scale implementation, it seems very important to link up basic research with the practical cultivation of permanent energy crops by farmers (or others) in the field. Such a combination seems best suited for overcoming critical technical and non-technical barriers and to reach the level of up-scaling that is required in the perspective of renewable energy targets. The evaluation of recent research projects and practical experience can provide important starting points in this regard.

Experience in Spain shows that for poplar (results obtained within the ‘On Cultivos’ Project), differences in yield between different types of research plots ranged from 1% to 50% between experimental plots (0.25 ha) and demonstration plots (4 ha). The average lies therefore around 24%. The possible causes for these differences include different management practices between small and big plots (more accurate in small plots) and the soil heterogeneity in big parcels~~.~~

Several years of field trials (at least 5 years) are necessary before reaching a good evaluation of yields. Constraints to production need to be further investigated. In trials very high yields occur while farmers often have very low yields because they often use lower quality land (e.g. set-aside land).

Experience in Sweden shows that the farmers with the longest experience produced the highest yields. The recent evaluation of the first commercial willow plantations in Sweden has yielded the following conclusions (Luger, n.y.):

- good advice to farmers is essential;
- weed treatment techniques need further development;
- good and cheap establishment is essential for the long-term production capacity and for the necessary economic returns to the farmers;
- crop water requirement is high, and often water availability is the limiting factor for production;
- heterogeneity of fields has a strong influence on yield;
- fertilization below recommendation has decreased yield by about 20%;
- fertilizer effect is strongly dependent on successful weed treatment;
- the highest yields have been obtained on organic soils.

This highlights the large gap between what was expected and what happened in practice, especially with regard to expected yields and the transfer of management know-how to farmers in research programmes. Communication must be adapted to farmers' characteristics. Practical demonstrations can be very efficient for convincing farmers and relevant industries. Farmers generally have higher trust in information received from other farmers rather than from industry or institutions. The lack of technical knowledge amongst farmers leads to misconceptions regarding SRC or PEG management issues: for example they are considered as difficult to remove or as blocking drains.

Farmers are rarely aware of the environmental impacts – positive or negative - of SRC and PEG plantations: biodiversity, soil conditions, pesticide inputs, comparisons to conventional cropping, energy balance.

- **Long term / large scale research**

Environmental impacts must be evaluated on a large scale and over the longer term. Ideally, a research programme should last more than one – or even several - rotation cycles, i.e. one to two decades. Usually, research programmes are focused on certain phases (establishment, cropping cycle, clearing…), and only the oldest experiments can provide the benefit of long term time series.

A database on all experiments over Europe, and an inventory of past and on-going studies (including grey literature) within the EU would be very useful and could partly compensate for the lack of sufficient longitudinal studies until now. This database should also include reliable national data and the geographic distribution of different SRC and PEG crops across the EU-27. The recent increase of reed canary grass cultivation in Finland, for example, highlights the possibility for quick change at large scale.

4.4 Topics for further research

4.4.1 Research on likely environmental impacts

Available literature and expert views point to the need for a strong research effort in this field to make sure that the environmental expectations associated with permanent energy crops can be met as there are potential risks as well as benefits. In an environmental perspective research needs to review the impacts of likely land use change and the effects of different cultivation practices. The environmental issues that are of particular relevance appear to be the potential effect on water regimes and groundwater re-charge of water-demanding permanent energy crops and questions linked to potential biodiversity and landscape impacts.

The priority is to develop a framework for determining possible trade-offs in order to identify the most important and the less important issues. For example, are crop characteristics more or less important than the size and management of permanent energy crop plantations for determining final environmental impact? Key rules need to be developed for avoiding the main environmental impacts. Several issues can be raised already.

Research on plants types adapted to sub-optimal land should be conducted in order to reach relatively high yields on less productive areas. The pressure on productive cropland will increase tremendously due to the competition between food markets, bioenergy production, bioproducts and environmental constraints. The announced performance for energy crops – yields in relation to fertilizer and water use – must be realistic and not be based only on the best results obtained on productive cropland, but also on lands of poorer quality.

A suitable plant/land association is the one that maximizes yields in relation to nutrient and water availability at local scale. Research should take into account all the input/output variables of different systems; nitrogen deposition, for example, can vary enormously between locations. Pest tolerance is another important characteristic for SRC/PEG crops.

Further research into the most suitable types and hybrids of perennials in different parts of Europe is needed. Furthermore, this research should be done in close collaboration with farmers. Until now nearly all (types of) crops have been selected by researchers. However, farmers have different approaches and needs for the selection of bioenergy crops.

Systematic analysis may help to select promising combinations of plant types with land types for various contexts and regions, in order to optimize the sustainability of SRC or PEG. Such an analysis should consider potential alternative uses of the land as well as socio-economic environmental and energy concerns.

Much research is needed about biodiversity values, especially for perennial grasses (Miscanthus, Switchgrass). Particular attention should be paid to sensitive events - such as harvesting, establishment, clearing - affecting biodiversity, but also nutrient release and soil structure. Taking into account scale effects – temporal and spatial- is essential in biodiversity studies, as they influence the type of assessments that are possible and the type of aspects that can be addressed.

Specific energy cropping systems that offer potential synergies, e.g. waste water treatment, flood control and other multi-environmental benefits, are of highest interest.

4.4.2 Socio-economic problems at farm level (supply)

The further development of SRC or PEG plantations is held back by numerous non-technical barriers at farm level.

The price paid for wood chips from SRC or PEG can currently not hope to compete with cereal prices. The price of wheat has very much affected the decision to take up perennials from 2007 onwards. Farmers are even planting wheat on land coming out of long-term set-aside.

Payments for SRC or PEG are only made at 2-4 years with a large cash outlay needed by the grower in years 1 and 2. Miscanthus has a major advantage over SRC in this regard as it is harvested annually. It also has less need for specialist machinery. Farmers prefer to grow crops they know, e.g. oilseed rape, wheat, etc, for food or biofuel production as they provide annual payments and have no requirement for specialist machinery or contractors. They have a preference for flexibility as they do not know what the future brings.

Farmers are generally not used to tying up their land for 10 or more years, or to signing a long term contract, particularly with large industrial end-users, such as co-firers or power generators, who have no previous connection to the agriculture industry. The real life-span of SRC or PEG plantations is also uncertain and long term trials are needed, to see whether yields decrease or pest sensitivity increases with the age of the plantation.

This cultural change, moving from a traditional annual cycle (agriculture) to a pluri-annual cycle (closer to forestry) must not be underestimated when planning the expansion of perennial energy crop area. Research should also focus on cost reduction and supply organization, working together with end-users (long term contracting, payment facilities).

4.4.3 Energy systems / fuel chain (demand)

End-users need secure amounts of biomass, with enough biomass all year round, and so long term contracting is essential. The challenges are related to the size of the plant, but fuel supply approaches have to satisfy both large and small scale application.

New developers of biomass power plants often do not intend to develop their own dedicated contracted supply from a local group of farmers. Specialized companies may do this on their behalf, including logistics.

Logistics must be optimized at all different steps, from conditioning (baling, chipping…) to storage, drying, as necessary. Further conditioning (pyrolysis, pelleting, torrefaction) should be evaluated. The fuel chain efficiency varies according to the end-use and the energy substituted (heat, transportation fuel, electricity).

Better estimates of cultivation and yield potentials for perennial energy crops are important in the planning of downstream uses. It would thus be very useful to develop approaches for GIS mapping of biomass potential at national or European level that are built up from soil/land characteristics, precipitation patterns and other relevant factors at regional to local level. Such approaches should, however, not only describe technical potentials but aim for estimates that include economic, logistic and environmental constraints (see the JRC straw study as a relevant example:
http://re.jrc.ec.europa.eu/biof/pdf/documents/pamplona_proceedings_cereal_straw.pdf).

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ANNEX I

Assessment of the technical and non technical barriers to implement Short Rotation Crops

International Energy Agency Bioenergy Task 30: Short Rotation Crops for Bioenergy Systems.

Technical barriers	Non technical barriers
Poor understanding of soil-site-productivity interactions	Lack of innovation or communication of innovative ideas
High transport costs due to fuel characteristics	Lack and misdirection of public funding for R&D
Limited availability of planting stock	Insufficient clear and consistent government policy
Poor understanding of the optimal combination of varieties	Mismatch between the transient nature of policy and the long-term nature of the crop
Lack of national breeding programmes	Planning policy is too restrictive.
Insufficiently developed harvesting equipment	Policy does not reflect the multiple benefits of SRC
Uneconomic yields	Uncompetitive compared to fossil fuels
Mismatch in the constancy of supply and demand	Subsidies on either fossil fuels or biomass negatively effect the competitiveness of SRC
Period between investment and return is too long	Competition of SRC with waste and residues biomass
Poor understanding of material properties of SRC fuels	Low investor confidence
Energy balance is not favourable	Development of monopolies
Concern over depletion of soil nutrients	Poor communication between sectors
Concern over depletion of water resources	Concern that implementation of SRC will also threaten native forests
Concerns over biodiversity and effects on wildlife	Non-renewable solutions are not often the first choice
Concerns over invasive nature of crops	Public misconception about biomass
Increased environmental pressures due to traffic	Lack of awareness and misconceptions about the crop
Poor performance of advanced technologies	Competition with the production of other crops
Inconsistencies in fuel quality causing poor performance of conventional technologies	Concern that if SRC becomes too economically attractive, food might become scare
Concern over air emissions	Lack of support for development of production systems
	Slow or no adoption of crop production costs and risks by power producers
	Focus diverted from SRC energy objectives by other crops or other activities
	Low availability of suitable staff in the fuel production industry
	Underdeveloped supply chain
	Partnering of two industries with different experiences and drivers
	Poor public perception of SRC energy
	Competition with fossil fuels for conversion technology development
	Low availability of suitable staff in the conversion technology industry
	Under-funding of advanced technologies

ANNEX II

Latin and common English names of energy crops for short rotation systems

Latin name	Common english name
Alnus spp.	Alder
Arundo donax L.	Giant reed
Betula spp.	Birch
Corylus avellana	Hazel
Cynara cardunculus	Cardoon
Eucalyptus spp.	Eucalyptus
Fraxinus excelsior	Ash
Miscanthus spp.	Miscanthus
Panicum virgatum L.	Switchgrass
Phalaris arundinacea L.	Reed Canary grass
Populus spp.	Poplar
Robinia pseudoaccacia	Black locust
Rumex uteusa	Dock
Salix spp.	Willow

ANNEX III

Some elements regarding the status of Short Rotation Crops in Spain

J.Carrasco (CIEMAT, Madrid) and H.Sixto (INIA, Madrid)

1. Short rotation Crops in the European Union: the implementation stage

1.1. Growth and yield performances of Short Rotation Crops

- For *Poplar* in Short Rotation Coppice, yield ranging from 12 to 35 tons dry material per hectare/year, depending on the site.

A few optimistic predictions estimate the possibility to reach up to 50t/ha dry biomass in cycles of 1-2 years in the Genil River Valley Area (Granada-south of Spain) if water is available (normally there is sufficient water for irrigation in this area, but in the last two years strong restrictions have been imposed due to the lack of rainfall). The reasons for very high production are the very long vegetative period and the very favorable soil and climatic conditions for poplar growth.

In the context of demonstration activities (*On Cultivos Project*, 4 ha. parcel) and experiments (*RTA* Project. 0.25 ha per plot), a tree-growth in height from 2 m to 4 m (average of the different shoots) and growth in diameter$_{10\ cm}$ ranging from 18 to 28 mm. has been observed.

- *Poplar* in Short Rotation Forestry (now for veneer), yield ranging from 250 to 300 m^3/ha for a 15-year rotation and 277 trees/ha.

- *Miscanthus* is not considered to be of significant interest in Spain because of its high demand for water. Only some relatively small areas, e.g. in North Western Spain, could be suitable for this crop under dry conditions. Some very small-scale parcels have been established, but there is no reliable data available up to now.

- *Cynara cardunculus*. This is a largerly tested crop in Spain and in the Mediterranean area. The average yield range from 12 to 18 t biomass dry weight /year without irrigation and with 450 mm/year of rainfall. A programme for seed breeding is needed to make this crop reliable.

- *Arundo donax* and *Ulmus pumila*. Some experimentation is starting now on these crops but data are not yet available.

1.2 Cost breakdown related to the cultivation of SRC/SRF and perennial grasses

- *Poplar* in Short rotation Coppice. The costs range from 190 €/ha/year (harvest by baling) to 210€/ha/year (harvest by chipping) with rotation every three years (16 years, five rotation cycles), excluding irrigation costs.

The irrigation costs are highly variable depending on the water cost, the requirements and the type of irrigation chosen. The *poplar* biomass field production costs can be estimated to range between 300 to 1400€/ha. These last costs are only suitable for very high production areas (about 30-35t/ha dry biomass). Otherwise, the *poplar* biomass production costs in Spain can be estimated at 20-40€/t dry biomass.

- *Poplar* in Short Rotation Forestry (for veneer)

In the case of deep planting, (between 2/2,5m), the cost is around 520 €/ha/year (rotation 15 years, in this case no irrigation is needed, all cultural treatment including pruning taken into account).

- *Cynara cardunculus* production costs in dry conditions are estimated at 300-350€/ha, with yields ranging from 12-18t/ha, thus the biomass production costs (including packing) can be estimated at 25-30€/t dry biomass.

1.3 Present costs and prices for wood chips from Short Rotation Forestry

The chips production costs from *poplar* can be estimated at 20-40€/t. The market is not currently developed. Under the present bioelectricity tariffs (about 156€/MWh produced with energy crops biomass), it can be estimated that the bioelectricity plants could pay about 60-70€/t dry chips on plant site (indicatively 40-55€/t on field site).

1.4 Main technical and non-technical barriers to the development of Short Rotation Crops

By order of importance, the present technical barriers in Spain are the following:

- Plant breeding
- Need to select genotypes adapted to the Spanish conditions
- Need for adequate densities and rotation to the most suitable genotypes
- Need to optimise cultural treatment under sustainable criteria
- Need to mechanise (planting but mainly harvesting).

Non-Technical barriers in Spain are:

- Need for market development
- Need for specific aids to farmers or biomass producers.

1.5 Causes and the magnitudes related to the difference between experimental and practical yields

For *poplar* (results obtained within *On Cultivos* Project), differences ranged from 1% to 50%, between experimental plots (0,25 ha) and demonstration plots (4 ha). The average is around 24%. The causes explaining these differences could be the different management practices between small and large plots (more accurate in small plots) and the soil heterogeneity in large parcels.

1.6. Energy yields of Short Rotation Crops and those from annual crops on the same soils and climatic conditions

Not sufficiently reliable data at this moment.

2. SRC/SRF in the European Union: agro-environmental aspects

2.1. Crops/species adapted to European conditions

Under the Spanish conditions *Populus* sp, *Eucalyptys* and probably also *Cynara cardunculus* could be the most adapted because we have previous information in many Spanish areas with these plantations, although for a different productive purpose (except for thistle). *Poplar, eucalyptus and thistle* have been grown in different Spanish areas (although *poplar and eucalyptus* mostly for other applications) and it can be said they are adapted to Spanish conditions for energy use. Other species which are being evaluated in short rotation are *Paulownia* sp or their hybrids, *Ulmus pumila*, and *Arundo donax*.

2.2 Environmental and agronomic constraints to be taken into account in the case of Short Rotation Crops

In relation to environmental restrictions it is necessary to define different sustainable indicators like:

- Water availability (main environmental restriction in many areas of Spain)

- Real amount of CO^2 fixed

- Effects on the soil, for example:

  Quantification of the loss of soil fertility due to successive rotations and of the contribution of leaves to soil fertility.

  Invasive capacity (*Robinia*, for example)

  Compaction (effects of machinery…)

- New criteria in the selection of the genetic material, in relation to resources use efficiency. In this sense, the water use efficiency of different clones in the Spanish conditions is being tested.

- Diversity of species and varieties to prevent the landscape impact and also biotic stresses, like fungus.

In relation to the agronomic restrictions, it is considered that in comparison with annual energy crops, short rotation woody crops have major environmental benefits, not yet well known. In addition, they also generate minor social alarm because they have no impact on the food market. Now a major restriction in relation to annual crops is the longer period for land occupation of the permanent crops, which is often not well perceived by the farmers, although this perception could change when the bioenergy market develops further.

2.3. Critical land use changes linked to Short Rotation Crops production from an environmental perspective

Principally those derived from the implementation of the Common Agricultural Policy (around 2 million hectares will be abandoned, in majority annual crops). The environmental perspectives of using short rotation woody crops will be better in general (for example less use of agrochemicals).

2.4 Effects of Short Rotation Crops, perennial cultivation for example on soil carbon content (grown on agricultural soils, grassland, forest soils….) and nutrient availability or on soil erosion risk

No data are available at this moment on these issues (on going study in the project *On Cultivos*).

2.5. Possible needs in terms of fertilizers or chemicals

Poplar Short Rotation Coppice. Work is being performed on this topic. Based on preliminary data we consider the following:
- Herbicides: Weed control prior to plantation and just before plantation is essential for the adequate implantation and also when a new rotation begins. Oxifluorfen 4 l/ha is being used. We are also checking the use of a second application in terms of increase of the yield and cost. In some situations it could be necessary.

- Fertilization: We have applied 450 kg/ha, N/P/K (8:15:15) before plantation.

A second fertilizer application during the first vegetative period was positive in order to improve the production only if soils have shown a low fertility. Results with organic fertilizer (pig manure and sewage sludge) have been similar to those obtained with mineral fertilizers.

- Chemicals for pest control: We have to minimize their use and for this purpose we advise to use genetic tolerant material and also to increase the diversity of the material.

Cynara cardunculus

- Herbicides: A first application for weed control, normally in spring and possibly the second year after sowing (once the crop covers the land surface avoiding weed growth).

- Fertilization: depends on soil composition. A normal fertilization dose is 75 kg/ha of nitrogen utilizing N/P/K (15-15-15) prior to sowing, in autumn. Then, similar doses in spring each year (also including the first year for poor soils) .

2.6.Critical aspects on biodiversity and landscapes

- Size of the plantations with energy permanent crops and type of farming.

- Increased genetic diversity. Forestry crops exhibit increased species richness in relation to annual crops.

2.7. Possible rules to be derived from soil/land characteristics and subsequently GIS mapped at local, regional, national or European levels?

No data are available in Spain. In other projects, data on *Populus* clones and *Cynara* varieties responses (biomass composition and yield) to different soil characteristics.

2.8. Possible scale for the mapping of SRC/SRF resource potential in the European Union

To our knowledge, there is no information on this issue. For mapping the resource potential of a determinate crop it is very important that data are taken with a common methodology in all countries. In addition, the parcels from where the information is collected must be developed in areas with homogeneous and different climatic/soil conditions (in Spain this corresponds to *"comarcas agrícolas")* and in real conditions (parcel surface, management techniques, implication of farmers etc).

2.9. Main farming practices related to Short Rotation Crops

Poplar Short Rotation Coppice

- Ground preparations. Adequate ground preparation: harrowing at 60cm depth and again at 30cm depth just before plantation
- Perennial weed control
- Fertilization
- Adequate conservation of cuttings
- Cutting installations
- Pre-emergence weed control before cutting sprouting
- Irrigation (it depends on the site, but around 2000-25000 m^3/ha/vegetative by sprinkler system)
- Pest and disease control

- Harvesting
- Post-harvesting operations

Cynara cardunculus

- Ground preparation: harrowing at 30cm
- Fertilization
- Sowing
- Weed control (mechanical or with herbicides)
- Pest and diseases control
- Harvesting

2.10. Impacts of different cultivation techniques on nutrient leaching

No data are available on this subject.

2.11.Improvements in practical yields to be expected in the future

The impact of different aspects like improvement of genetic material, cultural treatment optimisation, mechanisation and logistical process can be estimated to provide biomass yield increases between 10 to 15% in the short term to 30 to 50% in the long term.

2.12. Advantages/disadvantages of various mechanised harvesting methods

No data are available. In fact this is one the most important weaknesses for the implementation of energy crops.

3. SRF/SRC: Status of research and perspectives

3.1. Main issues in the field of Short Rotation Crops Research and R&D?

- Selection and genetic improvement paying attention to some additional criteria (e.g. resources use efficiency, stress tolerance or clonal architecture)
- Genotype-environment interaction
- Densities, rotation and designing plantations according to species and clones and also the mechanisation techniques
- Normalisation of biofuels.
- Behaviour (sintering, corrosion) of the herbaceous permanent crops in combustion processes.
- Logistics of biomass supply and mechanisation development
- Evaluation of the sustainability criteria for biomass production and use.
- Development of new energy conversion technologies (electricity production, second generation biofuels).

3.2 Critical knowledge gaps having emerged

<u>Area 1:</u>

- Need to better characterise the wood quality in case of use as fuel
- Wood pre-treatment and logistics

<u>Area 2:</u>

Social impact of the crops:

- Promotion of rural development
- Positive impact of Short Rotation Crops in the food market

3.3. Proposed focus in an environmental perspective: land use change, landscape effects, impacts of different cultivation practices, direct or indirect effects…

All of them may be taken into account in a global environmental perspective, although particular attention must be paid on those related to the local conditions.

3.4. Performance of Short Rotation Crops for phyto-remediation of soils, recycling of waste water and sludge, carbon sequestration

- The effect of these plantations for phyto-remediation and waste water recycling should be considered as an additional positive effect from an environmental point of view in relation to other crops for energy. In Spain, there are convincing examples of green filters with poplar planting for veneer with good performance for water depuration (Huesca, La Rioja, Ciudad Real etc..) In the south of Spain (Granada), waste water use has been demonstrated with success for irrigation of *poplar* Short Rotation Coppice plantation.
- The role of Short Rotation Forestry plantations could also be quite significant compared to other non permanent crops in terms of CO^2 fixation and therefore an important task is to quantify the real amount of carbon fixed in the different biomass fractions (roots, leaves…).

3.5. Ongoing research or field experimentation performed outside of the European Union that is relevant for the European situation

No data available

Other data

Projects in Spain related with biomass production in Short Rotation Crops

1. *On-Cultivos* (2005-2012): Probably the most important current project at national level to promote energy crops, including perennial grasses and woody species. www.oncultivos.com
2. RTA Project (2006-2008) (Resources and Agricultural Technologies). This is a specific project about poplar in Short Rotation Coppice and is performed at national level.
3. A third project, not yet approved, has been proposed in order to develop in the Autonomous Community of Asturias (at local level) energy crops such as *Poplar, eucalyptus, Betula and Salix*, for the purpose of being used in land abandoned from mining or/and agriculture. The acronym of this project is *Ecocombos-Biocul.* (Serida, ENCE, HUNOSA and Oviedo University are participating)

Comments about the terminology for Short Rotation Crops
Short Rotation Forestry and Short Rotation Coppice are both forestry plantations, densely planted, using high-yielding species and varieties and applying rotations shorter than usual for the species.
Crop regeneration in Short Rotation Coppice is produced from shoots of stump after the cutting, while in Short Rotation Forestry a new plantation after cutting is needed.

Annex IV

Some elements regarding phytoremediation and Short Rotation Coppice

R. Ceulemans (University of Antwerpen, Belgium)

Phytoremediation - Heavy metals

The phytoremediation potential of a poplar or willow plantation depends on both the biomass productivity rate and the concentration of the element (heavy metal) in the biomass. In the study of Laureysens et al. (2004, 2005) the phytoremediation potential of 13 different poplar clones was examined, together with the analysis of canopy profiles of heavy metals as well of differences in concentrations among leaves, stems and bark. In terms of productivity, clones Wolterson (N), Fritzi Pauley (T) and Balsam Spire (TxB) showed the highest above ground woody biomass production (wood + bark), averaging 18, 15 and 14 Mg ha^{-1} respectively after two years. In combination with its relatively high Al and Zn wood concentration in wood, this clone showed potential for the phytoextraction of both metals (Al and Zn) (see Table 1). Clones Fritzi Pauley (T), Columbia River (T), Trichobel (TxT) and Balsam Spire (TxB) also had a relatively high biomass production, i.e. 15, 12, 13 and 15 Mg ha^{-1} (two-years period). In combination with a relatively high wood and bark metal concentration, Trichobel (TxT) showed potential for Al phytoextraction, while Balsam Spire (TxB) showed potential for Cd and Zn uptake (Tables 1 and 2).

Leaf, wood and bark concentrations

Variations in leaf concentrations between clones were high for all metals, ranging between 112 and 174 µg g^{-1} for Al, 3.07 and 8.26 µg g^{-1} for Cd, and 411 and 695 µg g^{-1} for Zn in mature leaves (Figure 1). Analyses showed that there was a significant clonal variation for mature and senescing leaves for Fe and Pb; for Cu, clonal variation was significant for all three leaf ages. One single clone containing the highest concentration of all metals at the same time was not found. Generally, clonal rankings in leaf concentration were significantly different among metals and among leaf ages per metal (Figure 1).

Little or no Co, Cr, Cu, Ni or Pb was accumulated in the wood, and the concentration of Cr in bark was also below the detection limit (0.1 µg l^{-1}). The metal concentrations in bark were significantly higher than the concentrations in wood (Table 1), both when samples were collected in August and in November ($P<0.001$). On average, the Al concentration in bark was ten-fold the concentration in wood; likewise, the bark concentration of Mn and Zn was six-fold the wood concentration. The bark concentration of Fe and Cd was respectively four and three times higher than the wood concentration, on average.

When sampled in November, clone Fritzi Pauley (T) showed a mean Al concentration in wood of 90 µg g^{-1}, while for clones Wolterson (N) and Balsam Spire (TxB) wood Al concentration averaged 34 and 64 µg g^{-1} respectively (Table 1). For Cd, the concentration averaged 2.2 and 3.3 µg g^{-1} in clones Wolterson (N) and Balsam Spire (TxB) respectively; for Zn, the concentration averaged 147 and 144 µg g^{-1} in clones Wolterson (N) and Balsam Spire (TxB) respectively (Table 1). Clone Fritzi Pauley (T) had a mean Cd and Zn concentration of respectively 0.7 and 92 µg g^{-1}. Furthermore, metal content per plot was significantly correlated with wood dry mass and total biomass production, but not with bark dry mass. For Cd and Zn, a significant correlation between metal content per plot and number of shoots was found, because clones Wolterson (N) and Balsam Spire (TxB) had the highest Cd and Zn concentration and accumulation (Table 2). These results suggest that selection and improvement of poplar clones for phytoextraction should focus on biomass production, stool survival and metal concentration; population dynamics should not be taken into account.

When the transfer coefficients (= plant tissue concentration/total soil concentration) were calculated, Cd, Zn and Cu showed to be most easily taken up by poplar: Cd>Zn>Cu>Mn>Co,Ni>Pb>Cr>Fe>Al. Transfer coefficients differed among leaves, wood and bark, due to the different tissue metal concentrations, but the sequence in the transfer coefficients was similar for these three organs.

Phytoextraction potential

In contrast to the metal content per plant (or stool), the metal content per plot (or per unit of ground area) represents the real phytoextraction potential (Table 2), as it includes stool mortality. Clone Fritzi Pauley (T) showed the highest Al accumulation over two years, i.e. 1.4 kg ha^{-1} (Table 2). For Al, metal content per plot was significantly correlated with woody dry mass (r=0.513) and woody biomass production (r=0.587); no significant correlation was found with bark dry mass, number of shoots or mean shoot diameter. Clones Wolterson (N) and Balsam Spire (TxB) showed the highest accumulation of Cd, i.e. 47 and 57 g ha^{-1} respectively, and of Zn, i.e. 2.4 and 2.0 kg ha^{-1} (Table 2). For Cd, metal content per plot was significantly correlated with wood dry mass (r=0.472), woody biomass production (r=0.503), and number of shoots per stool (r=0.719) and per plot (r=0.706). For Zn, metal content was significantly correlated with wood dry mass (r=0.746), woody biomass production (r=0.806), stool mortality (r=-0.543), and number of shoots per stool (r=0.492) and per plot (r=0.526).

Significant clonal variation in uptake and accumulation was observed for most metals (Tables 1 and 2) that were analysed, as also shown for willow (e.g. Rachwal et al., 1992; Watson et al., 1999; Aronsson and Perttu, 2001; Pulford et al., 2001). However, clones with the highest concentration of all metals were not found, confirming earlier observations for willow (Riddell-Black, 1994; Pulford et al., 2002).

After two years, clone Fritzi Pauley showed the highest accumulation of Al, i.e. averaging 1.4 kg ha^{-1}, while clones Wolterson and Balsam Spire showed phytoextraction potential for Cd and Zn, i.e. averaging respectively 47 and 57 kg ha^{-1} for Cd and 2.4 and 2.0 kg ha^{-1} for Zn (Table 2). Several studies have shown that clones with a high uptake of a combination of several metals have not yet been identified (Riddell-Black, 1994; Pulford et al., 2001). This is probably due to the antagonistic properties of several metals. Likewise, hyperaccumulators accumulate only one or a limited number of metals. However, the uptake by these plants is much higher in comparison with poplar or willow. Therefore, Ernst (1996) suggested using these short rotation coppice cultures on slightly contaminated soils. The trees will take up part of the heavy metals and will additionally stabilise the soil, reducing metal leaching and dust blow. The combination of wood for energy production with phytoremediation will make both economically more feasible. Metals in the biomass remain in the ashes or are filtered to avoid translocation of the heavy metal pollutants to the atmosphere (Punshon and Dickinson, 1997).

We did not study root accumulation, although many studies have shown that most metals accumulate in the roots (Kabata-Pendias and Pendias, 1984; Landberg and Greger, 1996). This would imply that for phytoremediation purposes roots need to be ploughed up after the last rotation cycle rather than be rotovated and left in the soil. Root metal concentrations and possible clonal differences could be the objects of further research. We have, however, shown that poplar SRC offer possibilities for phytoremediation of slightly contaminated soils.

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Abbreviations used: N = P. nigra; T = P. trichocarpa; B = P. balsamifera; D = P. deltoides;

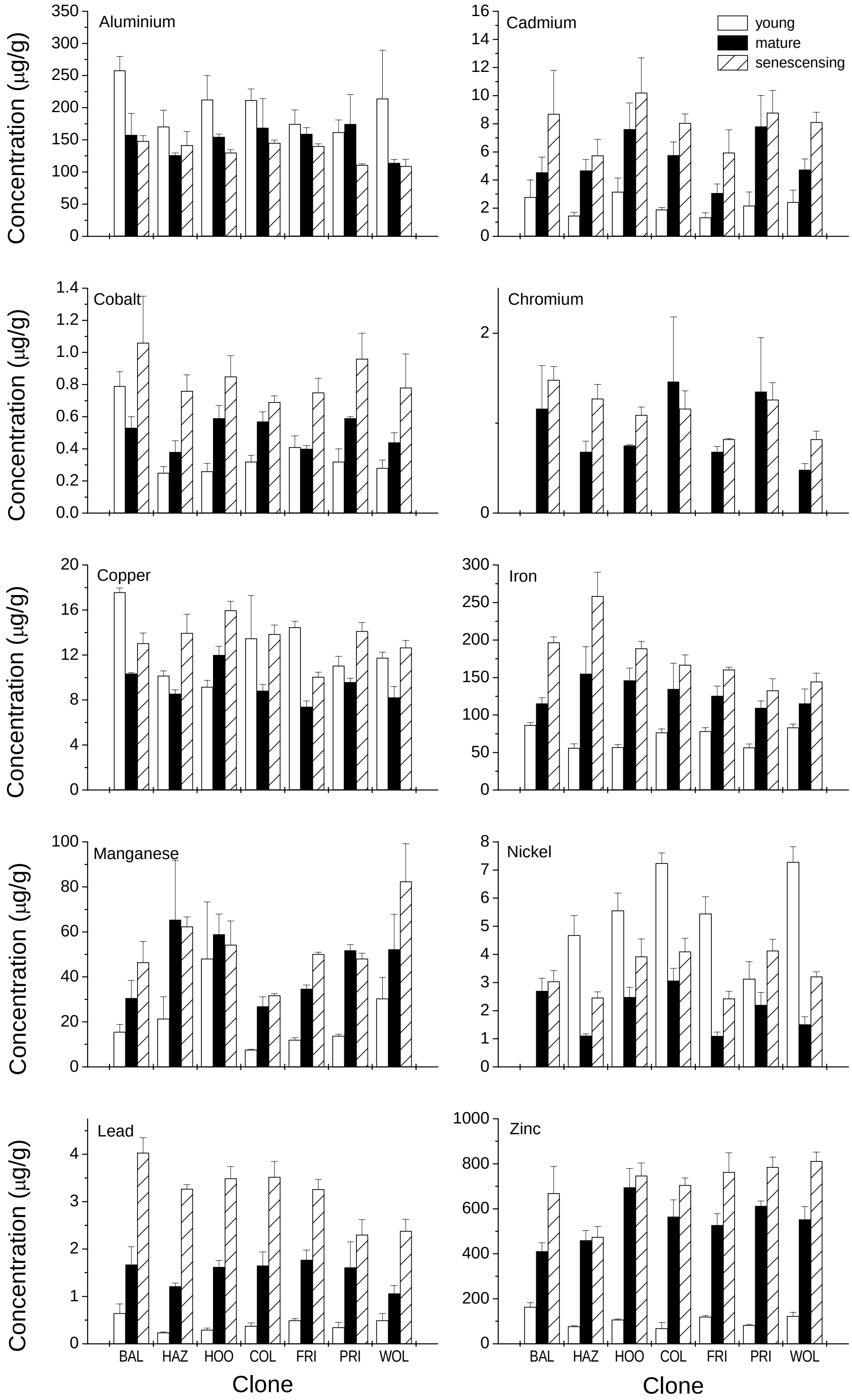
Table 1: Metal concentrations in wood of two-year old poplar stems of different clones harvested in August (Aug) and November (Nov). T: *P. trichocarpa*; B: *P. balsamifera*; D: *P. deltoides*; N: *P. nigra.*

Clone	Parentage	Al (µg/g)		Cd (µg/g)		Fe (µg/g)		Mn (µg/g)		Zn (µg/g)	
		Aug	Nov	Aug	Nov	Aug	Nov	Aug	Nov	Aug	Nov
Balsam Spire	T × B	8.1	11.2	1.11	2.86	6.7	43.6	2.0	1.6	29	39
Beaupré		10.0	16.3	2.36	2.64	10.8	7.1	5.1	1.7	24	32
Hazendans		16.5	15.3	1.63	1.01	31.3	77.3	9.6	7.6	31	33
Hoogvorst	T × D	13.6	15.6	1.94	1.11	8.1	15.8	2.5	3.5	34	37
Raspalje		9.5	10.5	1.74	3.18	8.0	13.9	3.8	5.0	38	26
Unal		8.3	15.5	2.77	2.63	22.0	6.5	2.1	2.3	26	29
Columbia River		18.3	12.7	1.43	2.33	18.4	8.7	2.0	1.8	39	37
Fritzi Pauley	T	13.3	11.1	1.11	0.80	58.7	9.2	2.3	2.2	26	28
Trichobel		7.9	19.9	1.22	0.70	5.3	20.6	1.4	1.9	26	34
Gaver		8.1	20.4	2.77	2.26	4.9	25.8	2.4	7.5	35	31
Gibecq	D × N	8.9	14.2	1.63	0.29	4.5	9.6	1.0	2.4	31	51
Primo		12.6	12.7	2.88	3.29	5.2	11.7	2.3	2.6	34	54
Wolterson	N	13.4	36.8	-	0.91	47.2	59.3	4.6	19.7	42	50

Table 2: Mean metal content (SE) per stool and per hectare for six poplar clones in a short rotation coppice culture. The two-year old shoots were harvested in November.

	Al (µg $stool^{-1}$)	Cd (µg $stool^{-1}$)	Zn (µg $stool^{-1}$)	Al (g ha^{-1})	Cd (g ha^{-1})	Zn (g ha^{-1})
Balsam Spire	976 (116)	64 (7)	2213 (264)	8.7 (1.3)	0.57 (0.09)	19.8 (3.0)
Fritzi Pauley	1578 (190)	14 (2)	1570 (191)	13.9 (2.0)	0.13 (0.02)	13.9 (2.0)
Gaver	188 (12)	55 (8)	740 (58)	1.5 (0.1)	0.43 (0.10)	6.0 (0.3)
Hazendans	370 (64)	17 (9)	1065 (190)	3.2 (0.6)	0.16 (0.09)	9.2 (1.8)
Trichobel	596 (144)	13 (3)	1072 (261)	5.5 (1.6)	0.12 (0.03)	9.8 (2.9)
Wolterson	648 (35)	51 (2)	2641 (81)	5.9 (0.2)	0.47 (0.02)	24.2 (0.5)

Figure 1: Mean metal concentration in young, mature and senescing poplar leaves for clones Balsam Spire (BAL), Hazendans (HAZ), Hoogvorst (HOO), Fritzi Pauley (FRI), Primo (PRI) and Wolterson (WOL). Mean values of replicates and their standard error bars are presented.



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Abstract
This document contains the Proceedings of the Expert Consultation "Short Rotation Forestry, Short Rotation Coppice and perennial grasses in the European Union: Agro-environmental aspects, present use and perspectives" held in Harpenden, United Kingdom, on 17 and 18 October 2007. This meeting was jointly organised by the Joint Research Centre – Institute for Environment and Sustainability and the European Environment Agency in cooperation with Rothamsted Research, United Kingdom.
The cultivation of Short Rotation Coppice (SRC), Short Rotation Forestry (SRF such as poplar, eucalyptus or willow…) and perennial grasses (such as miscanthus…) for heat and power generation is often considered to be an opportunity for agricultural diversification, while at the same time contributing to environmental protection and a greater independency from imports for energy. The main topics of this Expert Consultation dealt with 1) SRC/SRF and perennial grasses in the EU: the implementation stage, 2) SRC/SRF in the European Union: agro-environmental aspects and 3) SRF/SRC: Status of research and perspectives.

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