SARA Maria TRANQUADA BOLÉO

Graduate in Environmental Sciences

Environmental impact assessment of energy crops cultivation in the Mediterranean Europe

Thesis submitted for the Degree of
Master in Energy and Bioenergy

Supervisor:
Doctor Ana Luísa Almaça da Cruz Fernando
Assistant Professor, FCT/UNL
Co-supervisor:
Doctor Maria Paula Amaro de Castilho Duarte
Assistant Professor, FCT/UNL

Jury members:

President: Doctor Benilde Simões Mendes
Examiners: Doctor João Paulo Tavares de Almeida Fernandes
Doctor Ana Luísa Almaça da Cruz Fernando
Doctor Maria Paula Amaro de Castilho Duarte

FACULDADE DE CIÊNCIAS E TECNOLOGIA
UNIVERSIDADE NOVA DE LISBOA

September of 2011

Environmental impact assessment of energy crops cultivation in the Mediterranean Europe

Avaliação do impacte ambiental da produção de culturas energéticas no Mediterrâneo europeu

Parts of the present work have been published:

Fernando A.L.; Duarte M.P., Almeida J., Boléo S., Mendes B. (2011) Environmental Pros and Cons of Energy Crops Cultivation in Europe. In: Faulstich, M., Ossenbrink, H., Dallemand, J.F., Baxter, D., Grassi, A., Helm, P. (eds) *Proceedings of the 19th European Biomass Conference and Exhibition, From Research to Industry and Markets*. 6-10 June 2011, Berlin, Germany, Organized by ETA-Florence Renewable Energies and WIP-Renewable Energies, published by ETA-Florence Renewable Energies, pp 38-42 (ISBN 978-88-89407-55-7)(DOI: 10.5071/19thEUBCE2011-PD1.4)

Fernando A.L.; Duarte M.P.; Almeida J.; Boléo S.; di Virgilio N. and Mendes, B. (2010) The influence of crop management in the environmental impact of energy crops production. In: Spitzer, J., Dallemand, J.F., Baxter, D., Ossenbrink, H., Grassi, A., Helm, P. (eds) *Proceedings of the 18th European Biomass Conference and Exhibition, From Research to Industry and Markets*. 3-7 May 2010, Lyon, France, ETA-Renewable Energies and WIP-Renewable Energies, pp 2275-2279 (ISBN 978-88-89407-56-5).

Fernando, A.L., Duarte, P., Almeida, J., Boléo, S., Mendes, B. (2010) *Final Report on Task 4.1, Environmental impact assessment (EIA) of Energy Crops production in Europe*, July 2010 (4F Crop Project, E.U. Grant Agreement No: 212811, Coordination and Support Actions, FP7-KBBE-2007-1). Grupo de Disciplinas de Ecologia da Hidrosfera, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisboa, 80 p.

Fernando, A.L.; Duarte, M.P.; Almeida, J.; Boléo, S. and Mendes B. (2010). Environmental impact assessment (EIA) of Energy crops production in Europe. *Biofuels, Bioproducts & Biorefining*, 4: 594-604.

ACKNOWLEDGEMENTS

A minha profunda gratidão:

- À Presidente do DCTB - Departamento de Ciências e Tecnologias da Biomassa e Coordenadora do Mestrado em Energia e Bioenergia, Professora Doutora Benilde Mendes, por me ter dado a oportunidade de concretizar o sonho de trabalhar em Ciência; de frequentar o mestrado em Energia e Bioenergia que muito me realizou mas, principalmente, por me ter inspirado com o seu exemplo, personificando numa só pessoa os valores de grande Humanidade, Profissionalismo, Sabedoria, Liderança, Justiça, Persistência, Sensibilidade, Boa-disposição, Combate pelo bem-estar dos seus colaboradores e alunos e pela qualidade de ensino de todos os seus alunos. Diariamente.
- À Professora Ana Luísa Fernando, a minha mestre e tutora, por me ter dado, e continuar a dar, a oportunidade de consigo trabalhar, proporcionando-me estímulo intelectual e a possibilidade de evoluir humana e profissionalmente, constantemente. Mas, principalmente, pela sua Amizade e inspiração através do seu extraordinário exemplo de Humanidade, Profissionalismo, Inteligência, Justiça, Liderança, Força, Trabalho, Dedicação Pedagógica e Humana aos seus alunos, Alegria e Boa-disposição.
- À Professora Ana Luísa Fernando, a minha excepcional orientadora, que me apoiou e estimulou, nos momentos de desânimo. E pelo seu extraordinário esforço e empenho na realização e correcção desta dissertação, sem o qual este documento não teria a mesma qualidade.
- À Professora Paula Duarte, a minha co-orientadora e tutora, por me ter dado e continuar a dar a oportunidade de trabalhar na sua equipa, pelo seu exemplo de Humanidade e Profissionalismo, Força de Trabalho e Dedicação aos seus alunos, por toda a sua colaboração na realização desta dissertação, mas, principalmente pela sua Amizade.
- À minha mãe, por todo o seu incondicional Amor, exemplo, sacrifício e incansável e permanente apoio, sempre em prol da minha felicidade, permitindo perdoar todas as minhas ausências feitas em nome deste projecto.
- À minha família e amigos, pela sua consistente Amizade, apoio e compreensão pelas minhas ausências físicas,

O meu agradecimento:

- À Coordenadora do Mestrado em Energia e Bioenergia Professora Benilde Mendes e ao Professor Nuno Lapa, por todo o esforço e dedicação na concretização de um mestrado com muita qualidade, interesse e actualidade; e por sempre defenderem o interesse dos seus alunos. Bem como a todos os restantes Professores que leccionaram neste mestrado com dedicação, empenho, qualidade e generosidade;

- À Joana Almeida, minha colega no Projecto 4F Crops, pela sua colaboração na recolha e tratamento de dados utilizados nesta dissertação e pelos estimulantes *brainstorms*, que conjuntamente com a Professora Ana Luísa Fernando realizámos durante o projecto.

- A todos os colaboradores do DCTB com que diariamente me encontro, professores, colegas, secretária, técnicas do laboratório e, especialmente, Às minhas companheiras de almoço, por trazerem ao meu quotidiano laboral bom ambiente, alegria e espírito de entreajuda.

This work was supported by the European Union (Project 4F Crops – Future Crops for Food, Feed, Fiber and Fuel, Grant Agreement No: 212811, Coordination and Support Actions, FP7-KBBE-2007-1).

ABSTRACT

Energy crops offer ecological advantages over fossil fuels by contributing to the reduction of greenhouse gases and acidifying emissions. However, there could be ecological shortcomings related to the intensity of agricultural production. There is a risk of polluting water and air, losing soil quality, enhancing erosion and reducing biodiversity. In the scope of the project Future Crops for Food, Feed, Fiber and Fuel (4F Crops), supported by the European Union, an environmental impact assessment study was developed and applied to the cultivation of potential energy crops in the Mediterranean Europe. The categories selected were: use of water and mineral resources, soil quality and erosion, emission of minerals and pesticides to soil and water, waste generation and utilization, landscape and biodiversity. Results suggest that annual cropping systems have a more negative impact on the environment than lignocellulosic and woody species, namely regarding erodibility and biodiversity. Annual systems and woody crops are also more damaging to soil quality than herbaceous perennials. However, differences among crop types are not as evident in the remaining indicators. Impact reduction strategies are limited to crop management options, but, site specific factors should be accurately assessed to evaluate the adequacy between crop and location.

KEYWORDS: Environmental Impact Assessment (EIA), Energy Crops, Sustainability, Agro-Environmental indicators, Mediterranean Europe,

RESUMO

A utilização de culturas energéticas apresenta vantagens ecológicas em relação aos combustíveis fósseis uma vez que contribui para a redução da emissão de gases de efeito estufa e de emissões acidificantes. Contudo, a intensidade da sua produção agrícola pode apresentar desvantagens ecológicas. Existe o risco de poluição da água e do ar, perda de qualidade do solo, aceleração de erosão e redução da biodiversidade. No âmbito do projecto Future Crops for Food, Feed, Fiber and Fuel (4F Crops), financiado pela União Europeia, foi desenvolvido um estudo de avaliação de impacte ambiental aplicado ao cultivo de culturas energéticas potenciais no Mediterrâneo europeu. As categorias seleccionadas foram: utilização de água e minerais, qualidade do solo e erosão, emissão de minerais e pesticidas para o solo e água, produção e utilização de resíduos, paisagem e biodiversidade. Os resultados obtidos evidenciam que os sistemas de culturas anuais apresentam um maior impacte negativo sobre o ambiente que as espécies lenhocelulósicas (herbáceas e árvores de crescimento rápido), nomeadamente no que respeita à erodibilidade e biodiversidade. Os sistemas de culturas anuais e as árvores de crescimento rápido são também mais prejudiciais para a qualidade do solo do que as espécies herbáceas perenes. Porém, diferenças entre os tipos de culturas não foram tão evidentes nos restantes indicadores. As estratégias de minimização de impactes estão limitadas às opções de gestão das culturas, mas factores específicos relacionados com os locais de produção deverão ser detalhadamente analisados de forma a avaliar a adequação entre a cultura e o seu local de produção.

PALAVRAS-CHAVE: Avaliação de Impacte Ambiental (AIA), Culturas Energéticas, Sustentabilidade, Indicadores Agro-ambientais; Mediterrâneo europeu.

TABLE of CONTENTS

TABLE of FIGURES

TABLE of TABLES

LIST OF F ABBREVIATIONS, ACRONYMS AND SYMBOLS

1,3-PDO - 1,3 – Propanediol

A.S. – Active substances

C_2H_4 – Ethylene

CFC-11 – Trichlorofluoromethane, freon-11

CH_4 – Methane

CO - Carbon monoxide

CO_2 – Carbon dioxide

DAISIE - Delivering Alien Invasive Species in Europe

DT_{50} – Half life time of one half

EC – European Commission

EEA – European Environment Agency

EIA – Environmental Impact Assessment

EJ – Exajoules (10^{18} J)

FAO – Food and Agricultural Organization of the United Nation*s*

GHG – Greenhouse gas

GJ – Gigajoule (10^{9} J)

HCl - Hydrochloric acid

HF - Hydrofluoric acid

HNO_3 - Nitric acid

IEA – International Environment Agency

IPCC – Intergovernmental Panel on Climate Change

JRC – Joint Research Centre

K - Potassium

K_{eq} – Potassium equivalent

LC_{50} – Lethal concentration of one half

LD_{50} – Lethal dose of one half

LUC – Land Use Change

Mg – Megagrams (10^{6} g)

MJ – Megajoules (10^{6}J)

MSWC – Municipal Solid Waste Compost

N – Nitrogen

N_2O – Nitrous oxide

NH_3 - Ammonia

NH_4^+ – Ammonium

NO_3 – Nitrate

NO_x – Nitrogen oxides

OECD – Organization for Economic Co-Operation and Development

P – Phosphorous

SO_2 – Sulfur dioxide

SOM – Soil organic matter

SR - Short Rotation

SRF – Short Rotation Forest

WFs – Water Footprints

WS - Weight system

yr – Year

1. INTRODUCTION

1.1. Energy crops

The majority of the contemporary societies are changing their energetic paradigm, by increasing the production of energy from renewable sources, as an alternative to its production from fossil sources. Several motives can be indicated for this change:

- the alleged depletion of the fossil fuels supplies such as petroleum, coal and natural gas which together provide around 80% of the actual energy resources (El Bassam, 2010);
- the oil prices peaking, such as the ones in 2006 (OECD/IEA, 2006), in 2008 and again in 2011 (Jewitt and Kunz, 2011);
- the security of supply and the reduction of the energetic dependence (namely from regions in conflict, such as the Middle East and the Caucasus);
- the increasing world energetic demand. IEA predicts an energy demand growth of 1,6% every year, hence 49% between 2007 and 2035, specially from China, India and Middle Eastern countries (El Bassam, 2010);
- the raise of the environmental consciousness and sensibility, specifically, on the promotion of the reduction of greenhouse gas (GHG) emissions, about which the European Union decreed measures (2009/28/EC) towards the remission of CO_2 by 20% until 2020, comparatively to the levels of 2005.

But, the transition from fossil energy to renewable energy should be smooth and equitable (Best, 2004).

According to EEA (2008), biomass is the fourth largest world energy source, providing around 10% of the demand for energy worldwide (45-55EJ, El Bassam, 2010). But, the potential contribution of bioenergy to the world energy demand may be increased considerably. A range of 200-400 EJ per year in biomass harvested for energy production may be expected during this century. Assuming expected average conversion efficiencies, this would result in 130-260EJ per year of transport fuels, since from biomass it is possible to produce renewable fuels, similar in origin to fossil fuels, allowing its direct substitution (El Bassam, 1998), or 100-20EJ per year of electricity (El Bassam, 2010). Biomass is also seen as a source of biobased materials, which can substitute materials derived from fossil sources (El Bassam, 2010; Rettenmaier *et al*., 2010b; Elbersen *et al.*, 2010), either using traditional or innovative technologies (El Bassam, 1998).

In this context, the use of biomass as raw material for the production of bioenergy, biofuels and high value biobased materials is having a renewed and growing interest, in the form of various biomass categories (Picco, 2010; El Bassam, 2010; Fernando *et al*., 2010a, 2009/28/EC):

- products, by-products, residues and waste from agriculture, forestry and related industries;

- non-fossilized and biodegradable organic fractions of industrial and municipal wastes, including gases and liquids recovered from the decomposition of non-fossilized and biodegradable organic material;
- energy crops or dedicated crops.

The term **energy crops** or **dedicated crops** refers to the industrial cultivation of annual or perennial plant species designed to yield biomass for the production of solid, liquid or gaseous energy sources or biomaterials that traditionally come for fossil sources (e.g. oil). They may be considered in three main categories depending on the main product extracted from them (Picco, 2010; El Bassam, 1998, El Bassam, 2010):

- **Sugar crops**: species characterized by high sugar content for the production of biofuels, e.g. ethanol. Species rich in starch and sucrose, such as sugar cane, sugar beet and corn, are potential feedstocks for the ethanol production through the sugars fermentation.

- **Oil crops**: species with a high oil content, which may be utilized as fuel in the co-generation of heat and electricity, directly in automobile engines or transformed into biodiesel. Examples of these crops are sunflower, soybean and rapeseed.

- **Lignocellulosic crops**: species qualified as high dry matter producers which may be destined to several energetic uses (e.g.: combustion, pyrolysis, gasification, biofuels production, etc.). These species are rich in cellulose, hemicellulose and lignin. Herbaceous and woody crops such as *Miscanthus*, willow and poplar are good examples. Within this category there are species with a high content of good quality fiber – hence designated as **fiber crops -** that may be widely applied on the industrial production of a vast number of goods like paper, textiles, threads, ropes, filters, insulation and structural materials for buildings, automobiles and recipients, fiber boards and composites (Fernando, 2005; Ardente *et al*., 2008; Bös and Elbersen, 2008; Lips *at al*., 2009). The raw materials that produce some of these goods are traditionally obtained from derivatives of the refinement and reform of oil. Hence, substituting oil by plants may reduce this fossil fuel dependency and improves its biodegradability, diminishing its environmental impacts.

Plant species potentially energetic are very diverse and grow practically all over the globe. Its utilization may include roots, tubercles, stems, branches, leaves, fruits, seeds, or even the whole plant. Residues obtained in the production of plants, have a high potential to the production of energy, but cannot be entitled as energy crops (El Bassam, 1998). Figure 1.1 exemplifies some energy crops.

Figure 1.1 – Some examples of energy crops

1 – Sweet sorghum (*Sorghum bicolor* L. Moench); 2 - Sugar cane (*Saccharum officinarum* L.); 3 - Sugar beet (*Beta vulgaris* L.); 4 - Sunflower (*Helianthus annuus* L.); 5 - Soybean (*Glycine max*); 6 - Rapeseed (*Brassica napus* L. var. *oleifera* D.C.); 7 - Poplar (*Populus* spp); 8 - *Miscanthus* (*Miscanthus* × *giganteus* Greef. Et Deu.); 9 - Flax (*Linum usitatissimum* L.).

Sources (all accessed in August 2011):
1 - http://www.biofuelstp.eu/crops.html,
2 - http://ariseasia.blogspot.com/2011/06/sugarcane buddhahood-nirvana-is-not-so.html#!/2011/06/sugarcane-buddhahood-nirvana-is-not-so.html;
3 - http://montanakids.com/agriculture_and_business/crops/sugar_beets.htm;
4 - http://rabiscosdoantenor.blogspot.com/2011/11/girassolalimento-e-combustivel.html;
5 - http://www.wallpaperweb.org/wallpaper/nature/rapeseed-field_56305.htm;
6 - http://www.flickr.com/photos/iita-media-library/4602876447/in/set-72157624038436932;
7 - http://www.msstate.edu/dept/pssfeedstocks/lignocellulosic_crops.html;
8 - http://www.ukagriculture.com/countryside/woodland_ecosystem.cfm?comment=add&attributes.title=woodland%20ecosystems%20and%20habitats%20in%20the%20uk;
9 - http://www.reimersflax.com

Not every plant species are considered energy crops. The inherent criteria applied for the selection of dedicated crops for energy are (Venturi and Venturi, 2003; El Bassam, 1998; Ceotto, 2006; OECD/IEA, 2007; Spiertz and Ewert, 2009; Rentizelas *et al*., 2009):

- suitability to certain pedo-climatic conditions;
- ease of introduction in pre-existing agricultural rotations;
- high, uniform and continuous yield levels with respect to amount and quality, with high dry matter contents at time of harvest;
- efficient conversion of sunlight into plant material (e.g. biofuel);
- radiation interception maximization (i.e. early vigor, frost resistance, canopy closure, leaf traits for efficient light capture);

- high energy density plants/parts of plants (expressed in $MJ.kg^{-1}$, etc.) – e.g. rich in oils, sugars, starches, lignocelluloses, etc.;
- sunlight interception for as much of the growing season as possible;
- competitive income compared to traditional crops;
- a sustainable energy balance, i.e. a positive energy balance with respect to ratio (output/input) and especially net gain (output – input), with minimal external inputs to the production and harvest cycle (seed, fertilizer, machine operations and crop drying) – i.e. low input species, efficient nutrient recycling, root/shoot partitioning;
- efficient water use, since moisture is one of the primary factors limiting biomass production in most parts of the world (e.g., rooting depth);
- growing techniques in harmony with the concept of sustainable agriculture;
- resistance to major biotic and abiotic adversities (e.g. disease and pest resistance; drought avoidance and tolerance);
- availability of genetic sources (seeds, rhizomes, stems) suited to different areas;
- proper machinery (mainly for harvesting operations suited to the crop or usable with slight changes);
- ease of harvesting and storage (e.g., resistance to lodging, low moisture content);
- efficient logistics operations (e.g., transportation and handling activities, storage);
- suitability for thermal and industrial conversion technologies (e.g. emission of reactive N, as oxides of N (NO_x), into the atmosphere caused by the combustion of N-rich biomass was identified as a disadvantage, because it contributes to the acidification, Biewinga and van der Bijl, 1996);
- suitability for biological conversion technologies (e.g. accessibility of carbon in the cell wall, high fraction of energy substrates);
- cropped biomass should be preferably aerial in order to minimize the harvest environmental and economic costs (as is not the case of sugar beet).

Obviously, it is difficult to find a crop that matches the totality of all these criteria. Table 1.1 lists the most representative energy crops, in terms of productivity, adaptability and management, in different regions of the globe.

Table 1.1. – Representative energy crops in different regions of the globe

(adapted from El Bassam, 1998, Picco, 2010, El Bassam, 2010, Curt *et al*., 2006)

Regions	Crop categories	Energy Crops
Temperate	**Sugar crops**	Topinambur (Jerusalem artichoke) (*Helianthus tuberosus*) Sugar beet (*Beta vulgaris*)
	Oil crops	Linseed (*Linum usitatissimum*) Rape (*Brassica napus*) Soya bean (*Glycine max*) Safflower (*Carthamus tinctorius*) Sunflower (*Helianthus annuus*)
	Lignocellulosic crops	Flax (*Linum usitatissimum*) Reed canarygrass (*Phalaris arundinacea*) Hemp (*Cannabis sativa*) Fibre sorghum (*Sorghum bicolor*) Giant knotweed (*Polygonum sachalinensis*) Kenaf (*Hibiscus cannabinus*) *Miscanthus* (*Miscanthus x giganteus*) Fibre sorghum (*Sorghum bicolor*) Switchgrass (*Panicum virgatum*) Poplar (*Populus* spp) Willow (*Salix* spp)
Arid and Semi-Arid	**Sugar crops**	Date palm (*Phoenix dactylifera*) Sweet sorghum (*Sorghum bicolor*)
	Oil crops	Argan tree (*Argania spinosa*) Groundnut (*Arachis hypogaea*) Jojoba (*Simmondsia chinensis*) Rape (*Brassica Napus*) Olive (*Olea europaea)* Safflower (*Carthamus tinctorius*) Salicornia (*Salicornia bigelovii*) Soya bean (*Glycine max*)
	Lignocellulosic crops	Broom (ginestra)(*Spartium junceum*) Cardoon (*Cynara cardunculus*) Eucalyptus (*Eucalyptus* spp) Giant reed (*Arundo donax*) Poplar (*Populus* spp) Sesbania (*Sesbania* spp)
Tropical and Sub-tropical	**Sugar crops**	Banana (*Musa x paradisiaca*) Cassava (*Manihot esculenta*) Sorghum (*Sorghum bicolor*) Sugar cane (*Saccharum officinarum*)
	Oil crops	Babassu palm (*Orbignya oleifera*) Castor oil plant (*Ricinus communis*) Coconut palm (*Cocos nucifera*) Jatropha (*Jatropha curcas*) Neem tree (*Azadirachta indica*) Oil palm (*Elaeis guineensis*) Rubber tree (*Acacia senegal*) Soya bean (*Glycine max*)
	Lignocellulosic crops	Aleman grass (*Echinochloa polystachya*) Bamboo (*Bambusa* spp) Black locust (*Robinia pseudoacacia*) Eucalyptus (*Eucalyptus* spp) Leucaena (*Leucaena leucoceohala*) Sisal (*Agave sisalana*)

As an energetic vector and as raw material to high added value products (some of them traditionally obtained from fossil sources), the use of energy crops is potentially wide and present positive effects, such as (Biewinga and van der Bijl, 1996; Rettenmaier *et al*., 2010b; Best, 2004) :

- the contribution to the reduction of GHG and acidifying emissions;
- the reconversion of deforested or abandoned soils;
- the rehabilitation of degraded land;
- the stimulus to the rural development and industrialization;
- the designing of new opportunities (diversification) in the agricultural and forestry sector;
- the promotion of benefits of energy trade to rural producers;
- the enhancement of food security;
- the substitution of fossil fuels;
- the reduction of energetic dependence from other countries;
- the promotion of the potential of bioenergy in the energy market in terms of trade and exports (e.g. liquid biofuels, carbon Kyoto Protocol funds, bioelectricity).

However, a controversial discussion on the net benefit of biofuels and bioenergy has been ongoing, showing that the use of biomass for energy and bioproducts is not environmentally friendly *per se* (much less sustainable), simply because biomass is a renewable energy carrier (Rettenmaier *et al*., 2010b) or a renewable raw material. The production of energy crops requires an intensive use of soil, contributes to the increase of agrochemicals in the growing areas, may increase the pressure on natural resources (biodiversity, water, soil) and may endanger global and local food security (Best, 2004; Rettenmaier *et al*., 2010b). This discussion gains momentum in the light of increasing competition for agricultural land between the production of food, feed, fiber and fuel. In order to mitigate this competition, its negative side-effects and to promote land use efficiency, benefits and constraints related to the energy crops production and use should be carefully analyzed and balanced.

1.2. Benefits and constraints of energy crops

1.2.1. Energy balance

The main goal of the production of biomass for energy and bioproducts is to produce renewable energy and products with a concomitant reduction of the use of fossil sources.

In order to assess the ecological sustainability of the production and use of energy crops, the energy balance is a criteria that should be assessed. The net energy budget should be positive: the “biomass-energy/bioproduct” provided should be greater than the fossil energy needed to produce it. In this balance, all the energy inputs (direct and indirect) in every part of the process chain should be accounted. The energy output is calculated in terms of saved fossil energy, needed to produce an equal amount of energy or to produce a bioproducts substitute.

Energy balance is strongly dependent on the yields of the energy crops (which are highly dependent on geographical location), their pathway (e.g., conversion technologies) and use for bioenergy, biofuels or bioproducts (Rettenmaier *et al*., 2010b). Energy for cultivation is usually the major input (75-87% according to Biewinga and van der Bijl, 1996). Drying, distillation and powdering are also high energy demanding processes (Biewinga and van der Bijl, 1996).

Regarding the use of energy crops for energy production, in terms of energy savings Rettenmaier *et al*. (2010b) concluded that all of the energy crops being studied in Europe present a positive budget. Nevertheless, they identified herbaceous lignocellulosic crops as the best energy crops within and across all European environmental zones, followed by sugar crops. In contrast, oil crops and woody lignocellulosic crops achieved the lowest performance. And, the best way to use their biomass is for combined heat and power generation, followed by heat generation and second-generation bioethanol. The grounds of these results sets in the fact that herbaceous lignocellulosic crops offer the highest biomass yields both in terms of standing biomass and harvested products (share of the crop which is used for energy purposes). And, the harvested product is converted into biofuels and bioenergy in a rather efficient way.

According to Rettenmaier *et al*. (2010a), biomaterials from energy crops are also superior to their fossil or conventional equivalents in terms of energy savings. Table 1.2 presents an overview of the conversion paths and main products that can be derived from several energy crops groups and that were studied by Rettenmaier *et al*. (2010a).

Table 1.2. – Overview of the conversion paths and main products that can be derived from several energy crops groups (according to Rettenmaier *et al*., 2010a)

Crop group	Conversion path	Main product
Oil crops	Refining	Lubricant
	Transesterification & Hydrogenation	Surfactant
Fiber crops	Fleece production	Fiber composite, insulation mat
Lignocellulosic crops (woody and herbaceous biomass)	Hydrolysis & Fermentation	Chemical ethanol, 1,3 – propanediol (1,3-PDO), ethylene
Sugar crops	Fermentation	Chemical ethanol, 1,3 – PDO, ethylene

Many other studies regarding the energy balance performance of bioenergy carriers and biomaterials (such as the one of Ardente *et al*., 2008) show that in order to maximize environmental benefits, it is not sufficient to choose the environmental zone exhibiting the highest biomass yields, but also to make sure that the biomass is converted and used in an efficient way. In other words: the entire life cycle has to be taken into account.

1.2.2. Gas Emissions

Shifting society's dependence away from fossil energy and materials to renewable biomass resources is generally viewed as an important contributor to provide an effective management of GHG emissions (Ragauskas *et al*., 2006).

The greenhouse effect is mainly due to emissions created by the combustion of fossil fuels. One way of reducing GHG emissions is through the use of (CO_2) reducing fuels (e.g. biomass) for energy and biomaterials production (Oliveira *et al*., 2001). The introduction of energy crops allows the use of bioenergy, biofuels and biomaterials without relevantly increasing the CO_2 content of the atmosphere, contrasting to fossil sources.

Several authors (such as El Bassam, 2010) refer to bioenergy as being CO_2 neutral, as all carbon emitted by direct or indirect combustion of biomass has been taken up from the atmosphere (capturing CO_2) and has been photosynthetically transformed into dry mater beforehand (El Bassam, 2010; Spiertz and Ewert, 2009) using solar radiation and water and external inputs (e.g., fertilizer, pesticides, machinery, fuel for farm vehicles, etc.). But, the budget of bioenergy is not exactly zero (moreover, none of the renewable sources of energy are), since a portion of CO_2 is emitted during the cycle of biomass production, due to the necessary use of these external inputs, mostly manufactured by using fossil fuels, as is also the case for transporting and processing the energy crops production (OECD/IEA, 2007; Atkinson, 2009; Spiertz and Ewert, 2009 and Picco, 2010).

Other gases can also contribute to the greenhouse effect such as N_2O and CH_4 (FMV, 2007), which can be quantified in terms of CO_2 equivalents. Regarding the production and use of energy crops, CH_4 emissions are usually considered as negligible (Kaltshmitt *et al*., 1996).

Substitution of fossil sources in energy and biomaterials production systems with energy crops results in significant avoided GHG emissions (such as been seen in the works of Lewandowski *et al*., 1995, Oliveira *et al*., 2001 and Rettenmaier *et al*., 2010a and b). Herbaceous lignocellulosic crops show the highest advantages in terms of GHG emissions (due to the same reasons pointed out in the energy balance) and stationary energy production (e.g. heat and power generation) usually leads to higher GHG savings than the use as transport fuel (Rettenmaier *et al.,* 2010b). Concerning biomaterials, composite from fiber crops, and chemical ethanol, ethylene and 1,3-PDO from herbaceous lignocellulosic crops and sugar crops presented the best performance (Rettenmaier *et al*., 2010a).

The emission of acidifying gases leads to several harmful effects such as eutrophication, decreased tree vitality, dissolution of metals (e.g. aluminium), and declines in fish populations in lakes (Biewinga and van der Bijl, 1996; Nebel and Wright, 2000). In general major acidifying substances are NH_3, SO_2

and NO_x. Other substances such as HCl and HF play a role as well but are of minor importance (Biewinga and van der Bijl, 1996). The acidification potential is measured in SO_2 equivalents (Oliveira *et al*., 2001).

Concerning energy crops, the main activity leading to release of acidifying substances (especially NO_x and SO_2) is combustion. Acidifying emissions can take place at several other phases in the production and conversion of energy crops such as the production of fertilizers. Nitrogen fertilizer production is a source of NO_x and NH_3 emission (Biewinga and van der Bijl, 1996). Constraints related to this fact will penalize annuals rather than perennials, once perennials generally require lower fertilizers inputs (Zegada-Lizarazu *et al*., 2010). From conversion of energy crops HCl emissions can occur; however, with simple techniques HCl can be removed from exhaust gases easily (Biewinga and van der Bijl, 1996).

SO_2 emissions form a smaller proportion of the total acidification potential of energy crops than NO_x emissions (Hartmann, 1995). This is partly due to the low sulfur content of energy crops compared to fossil fuels, which results in a lower SO_2 formation (Oliveira *et al*., 2001). It has been reported when coal and *Miscanthus* are combusted, the SO_2 emissions decrease as the proportion of *Miscanthus* increase. This is not only attributed to the dilution of the high sulfur containing coal with the low sulfur containing biomass, but also to the increased capture of SO_2 by calcium oxide existent in the biomass ash (Kicherer *et al*., 1995).

On the other end, energy crops can emit higher levels of NO_x, since nitrogen is a main constituent of biomass (Biewinga and van der Bijl, 1996).

The acidification potential through the substitution of fossil sources with biomass for energy and biomaterials production depends on the crop, the conversion technology, the method of biomass cultivation and the fossil source which is substituted (Kaltschmitt *et al*., 1996; Rettenmaier *et al*., 2010b). Globally, the acidifying emissions resulting from the production and use of energy crops have a negative impact because they are higher than those of the corresponding uses obtained from fossil sources (Rettenmaier *et al*., 2010b). For energy purposes, giant reed performed the worst when utilized on the production of fuel ethanol. The best results were observed with poplar, willow, *Miscanthus* and switchgrass when used in for the production of heat and power. Concerning biomaterials, best results were obtained with sugar beet for the production of 1,3-PDO. Worst results were observed with hemp for the production of insulation mats. (Rettenmaier *et al*., 2010a).

El Bassam (2010) refers that comparison of CO, CO_2, SO_x and NO_x emissions with respect to mineral diesel, biodiesel (from rapeseed) and a 30 % biodiesel blend showed higher CO_2 and SO_x emissions when mineral diesel was used and higher NO_x emissions from biodiesel. But similar NO_x emissions were obtained when a blend of 30% biodiesel was used.

Production and use of energy crops may also contribute to the depletion of the ozone layer (measured as CFC-11 equivalent) and to summer smog (measured as C_2H_4 equivalent). According to Rettenmaier *et al.* (2010a and b), production and use of energy crops for energy or biomaterials don't show negative impacts related to summer smog. Production of 2nd generation ethanol from herbaceous lignocellulosic crops presents even a positive effect. Regarding the contribution to the ozone depletion, N_2O is the main responsible. N_2O is mainly emitted during nitrification and denitrification processes occurring during the N-fertilizer application (Biewinga and van der Bijl, 1996; Rettenmaier *et al.*, 2010b). Globally, ozone depletion emissions associated with the production and use of energy crops, have a negative impact (Rettenmaier *et al.*, 2010 a and b). Oil crops presented the worst performance. Best results were obtained with woody crops on the production of heat and power and Fischer-Tropsch diesel (Rettenmaier *et al.*, 2010 a and b).

1.2.3. Effects on the quality of soil and water

The production of biomass can be relatively land-intensive and therefore presents a risk of soil and groundwater pollution with nitrates, phosphates, potassium and pesticides.

Perennial energy crops present agronomical features of considerable environmental effects, such as: the possibility to use extensive techniques with modest use of technical means (e.g., fertilizers and pesticides) (Zegada-Lizarazu *et al*., 2010) and therefore, with positive economic and environmental feedback (lower losses by leaching and atmospheric emissions): giant reed N inputs (70-100 $kg.ha^{-1}.year^{-1}$) and poplar N inputs (50-150 $kg.ha^{-1}.year^{-1}$) represents less than half of that used traditionally for the production of corn (200-300 $kg.ha^{-1}$) (Picco, 2010). Some of these energy crops may use organic nitrogen from nitrogen fixing bacteria, free or associated to root systems. This potential has been observed in some perennial grasses, such as giant reed and switchgrass (Picco, 2010).

Perennial crops appear to be very interesting in areas vulnerable to nitrate water pollution. The cultivation of *Miscanthus*, with N-fertilization medium that provides from 0 to 60 $kg.ha^{-1}.year^{-1}$, shows an extremely low leaching of nitrates, virtually limited to the first year of planting in which the crop is in the adaptation process (Christian and Riche, 1998). Makeschin (1994), shows an average reduction of 50% of nitrates in the leaching water from land cultivated with short rotation forest (SRF, fertilized or not), when compared with control land intensively cultivated with crops. In fact, the nitrogen annually added in limited amounts to the poplar SRF, is immobilized deeply into the ground by the root systems (Stanturf *et al*., 2001).

Energy cropping has also been linked with wastewaters treatment (e.g. Fernando *et al*., 2011; EEA, 2007) and landfill leachates (Börjesson, 1999; Duggan, 2005). The nutrients can be recycled and any possible health concerns from viral and bacterial infections are avoided as the crop is not part of the food chain (OECD/IEA, 2007). Phytodepuration with energy crops can also contribute to lowering the water resources consumption and to improve the water quality. Another important environmental positive aspect connected with perennials is its use as buffer strips, by intercepting the nutrient output from traditional farming systems (Picco, 2010).

Regarding pesticide use, in general, herbicides are the class most applied in energy crops cultivation (Biewinga and van der Bijl, 1996). Since herbicide use can often be replaced by mechanical weeding methods, it is expected that this environmental burden can be lowered. However, mechanical methods are not always a good solution, e.g. on soils susceptible to erosion. When energy crops are incorporated into intensive rotations, they may lead to an increase of the use of pesticides (Biewinga and van der Bijl, 1996).

Constraints related to this fact will penalize annuals rather than perennials, once perennials generally require lower pesticides inputs (Zegada-Lizarazu *et al*., 2010). Perennials usually take advantage of the use of herbicides only during planting phase of the crop, while annual crops require year round applications, with repercussions both in terms of growing and ecological costs, with increasing shares of chemicals that seep into underground water and go to the surface waters via runoff (Picco, 2010). Moreover, some energy crops, such as *Miscanthus* and giant reed, present no major illnesses requiring plant protection measures (Fernando, 2005; Picco, 2010).

Cultivation of energy crops, especially perennials, may also present benefits towards soil quality (erodibility, compaction, fertility, carbon sequestration).

Soil erosion, by wind or water, is considered one of the biggest problems of the agricultural areas of the world and represents a serious threat to the reduction of soil fertility. It also hastens water runoff, retarding ground-water recharge, and contributes to water pollution (Abbasi and Abbasi, 2010; Picco, 2010), since water runoff transports minerals, organic matter, residues of pesticides and sometimes heavy metals present in the top soil to surface waters or nearby nature water reserves (Biewinga and van der Bijl, 1996). Soil erosion in Europe is a particular problem in the Mediterranean region, which is characterized by long drought periods followed by heavy bursts of rainfall falling on steep slopes with unstable soils (EEA, 2006). However, wind erosion can be a problem in the flatter landscapes of northern and central Europe with its intensive agriculture (EEA, 2006).

Several agriculture practices can be applied to control erosion: mulching, contour ploughing, contour planting, cultivation of catch crops, maintaining year round soil coverage, no ploughing and tillage on steep slopes, creating windbrakes in the landscape by introducing different height crops, etc. – Biewinga and van der Bijl., 1996; EEA, 2006). But the choice of crops is also important to reduce erosion risks (Biewinga and van der Bijl,1996; EEA, 2006). Perennial crops, in general, and cereals with short row intervals (Calzoni *et al*., 2000) provide better efficacy in reducing the risk of soil erosion (loss of sediment and sediment bound pollutant) and runoff, than annual crops, especially in slope areas and in particularly sensitive plains (Biewinga and van der Bijl, 1996; EC-JRC *et al*., 2006; Picco, 2010; The Center of Native Grassland Management, 2011). The limitation of soil erosion phenomena by the use of perennial crops is well documented. Risser *et al*. (1981) reported that, during heavy rainfall events, losses of soil by erosion and runoff can be 200 times larger in the annual crops, like corn, than those relating to herbaceous perennial crops. Shifflet and Darby (1985) estimated erosion losses in maize cultivation 70 times greater than in perennial crops. These facts are corroborated by El-Bassam (1996), according to whom perennial species, such as SRF, *Miscanthus,* reed canary grass, giant reed and switchgrass, have a lower soil erosion rate than annual crops with the best results being recorded in herbaceous perennials as shown in table 1.3.

Table 1.3 – Soil erosion rates ($Mg.ha^{-1}year^{-1}$) (El-Bassam, 1996)

Annual Crops		Perennial energy crops	
Corn	Soybeans	Herbaceous	SRF
21,8 [a]	40,9 [a]	0,2	2,0

[a] Based on early 1980s data. New tillage practices used today may lower these values.

The work of van Dam *et al*. (2009) also shows that the soil loss from switchgrass production is limited, ranging from 1 to 2 $Mg.ha^{-1}year^{-1}$, higher than the soil loss from soybean production systems, which varied from 2 to 10 $Mg.ha^{-1}year^{-1}$. This work and the work of Kort *et al*. (1998) also indicate an erosion reduction when cropland is converted to herbaceous biomass production.

Woody crops in SRF have a positive impact on reducing erosion and the loss of chemical substances by runoff. Ranney and Mann (1994) have estimated that the erosion phenomenon of these crops mainly occurs in the first two years of the plantation, decreasing gradually in the following years. The estimated erosion at SRF plantations varies between 2 to 17 $Mg.ha^{-1}year^{-1}$ in the first stages of the plant cycle then declining to 2 to 4 $Mg.ha^{-1}year^{-1}$, values significantly lower than the 18 $Mg.ha^{-1}year^{-1}$ of eroded soil of annual crops such as maize (Pimental and Krummel, 1987).

The anti-erosive action provided by these plants (as illustrated in figure 1.2) is related to the presence of nearly continuous vegetation on the ground, offering a good protection and increasing the organic matter with mulching effect in the superficial layers, and to the development of dense and deep root systems which actively holds earthy masses during the rainier periods (Picco, 2010; The Center of Native Grassland Management, 2011). Herbaceous and woody crops have a high plant density and an enduring year-round soil coverage, since some perennial grasses (such as *Miscanthus* and giant reed) can be harvested annually for decades after planting, and fast-growing trees (such as eucalyptus and poplar) are harvested only every 2-5 years are replanted perhaps every 10-20 years (El Bassam, 2010). Against surface runoff, multiannual crops play a role as filters operated by the superficial roots and the eventually developed turf (soil particles are intercepted and the adsorbed substances are gradually immobilized and eventually transferred or converted during the pedogenic processes) (Picco, 2010).

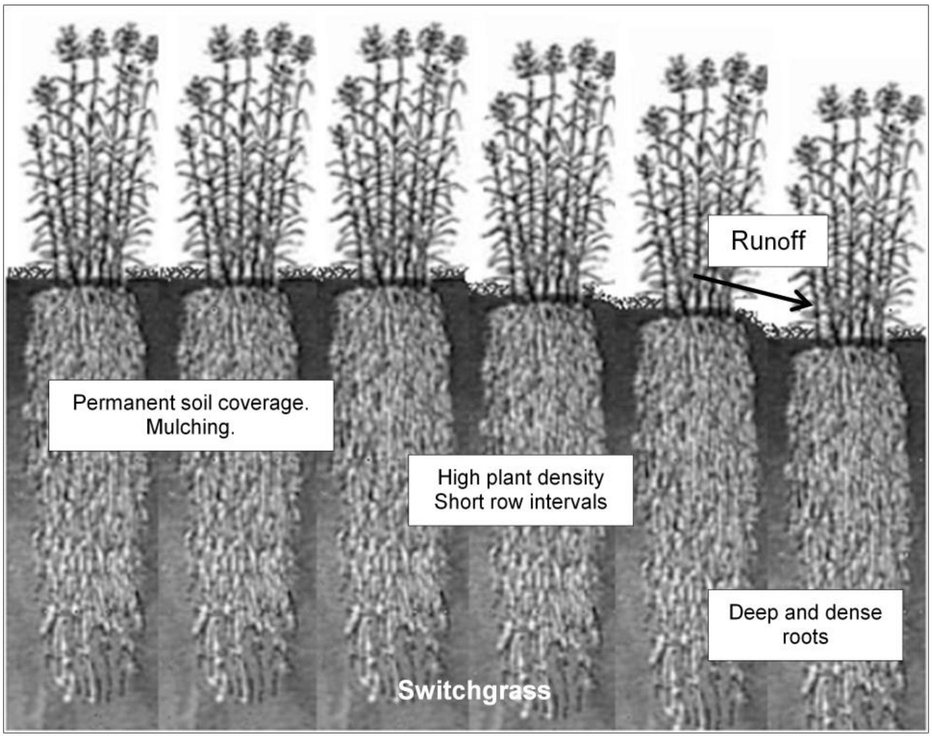

Figure 1.2 – Anti-erosion action of perennial crops plantation.

(adap. from Christopher available at http://www.tva.gov/river/landandshore/stabilization/benefits.htm, accessed September 2011)

Soil compaction results from the use of heavy machinery for activities such as ploughing, spreading of organic manure and harvesting. Soil compaction has adverse effects on soil biodiversity, soil structure and soil aeration (Bowman and Arts, 2000; EEA, 2006). It may also lead to problems such as water logging (EEA, 2006). Once again, some studies indicate that perennial energy crops (e.g. reed canary grass, giant reed, cardoon, *Miscanthus*, switchgrass or SRF) generally reduce soil compaction due to their expanded deep roots and less need of soil disturbance (Christou *et al*., 2004; EEA, 2006; Perlack *et al*., 2005). At the other end, sugar beet, sugar cane and potato expedite soil compaction since they have a high harvesting weight that requires the use of heavy machinery (EEA, 2006; FAO, 2003).

The use of annual crops in soils at risk of erosion may contribute significantly to the soil loss and its associated nutrients (Picco, 2010). It can also lead to the reduction of the organic matter content, thus, reducing the ability to hold water in the soil, altering soil density and aeration and the availability to retain nutrients (Picco, 2010). Woody and herbaceous energy crops show larger amounts of organic carbon in the terrain due to:

- the formation of wide root apparatus; the plant deposits into the rhizosphere (e.g. underground crop residues of the underground culture, root exudates, root turnover materials) and the important contribution of microorganisms and invertebrates populations;
- the reduce tillage or no-tillage systems. (Picco, 2010; Basso *et al*., 2011)

With these features the cultivation of these species provides benefits to soil fertility, such as improving its structure and porosity, increasing the field capacity, extending storage capacity and availability of nutrients. In many studies concerning poplar, the increase on the long run of the organic matter content in the ground is shown (Picco, 2010). Smith *et al*. (2000) indicate that changing from arable land to SRF increases the soil organic carbon at a rate of 1.17% per year. Tolbert *et al*. (2002) have confirmed data from Pimental and Krummel (1987) regarding the positive and essential effect of land cover with vegetation on the minimization of losses of soil organic matter and nutrients.

Soil carbon storage (**carbon sequestration**) increases with the organic matter content. A culture such as switchgrass , for example, has a good aptitude to store carbon in the soil, mainly due to its large and deep root development (70% of the total biomass); this means that most of the organic carbon synthesized during photosynthesis, remains in the ground in the post-harvest (Ma *et al*., 2001). Parrish *et al*. (1997) have observed that the switchgrass root biomass, in the first 30 cm of soil, may exceed 8 $Mg.ha^{-1}$, i.e. about 5 times greater than that of corn. Monti and Zatta (2009) showed that crops such as the giant reed and switchgrass are able to store large quantities of carbon in the soil within their root systems, up to 6 times deeper than fiber sorghum (annual crop). Even the poplar SRF has shown a high capacity for carbon sequestration, due to the limited farming operations that can lead to the mineralization of organic matter (e.g. plowing). Samson *et al*. (1999), although acknowledging the limited development of the root system of poplar (20% of the total biomass produced), assigned to this SRF a good soil carbon storage capacity over 10 years of crop cycles. Brandão *et al*. (2011) compared oilseed rape, *Miscanthus* and willow and concluded that *Miscanthus* is the best option concerning soil quality as it sequesters carbon at a higher rate than the other crops. Ranney and Mann (1994) estimated that SR plantations increase the soil carbon inventories (excluding litter and roots) by about 10 $Mg.ha^{-1}$ over 20-50 years. Börjesson (1999) refers that when perennial energy crops replace annual food crops, mineral soils may accumulate 0.5 $Mg.ha^{-1}year^{-1}$ (C).

Powers *et al*. (2011) modeled the soil quality environmental impacts comparing the production of switchgrass with continuous corn and corn-soybean rotations. According to the model applied, after16 years: switchgrass fields presented less 20% of soil losses by comparison with the corn-soybean conventional tillage and the C content of the soil increased 1.5%, whereas C was lost in all other non-switchgrass scenarios.

1.2.4. Use of resources

Mineral resources

Perennials have shown good potential as low input alternative agricultural crops. In contrast to annual plants, the **fertilizer requirements** of perennials are low (Zegada-Lizarazu *et al*., 2010). This is mainly due to the recycling of nutrients by their rhizome systems (Lewandowski *et al*., 2003b): nutrients are translocated from the aerial to underground parts in the end of the growing season, and these reserves are demobilized in spring for regrowth. Also, their extensive root system can easily immobilize nutrients thus increasing the nutrient use efficiency (Stanturf *et al*., 2001). Some annual energy crops present also nutrient use efficiency, such as sweet sorghum, whose nitrogen fertilization requirements are almost 40% less than those of other ethanol crops such as corn (Zegada-Lizarazu *et al*., 2010). Nitrogen fertilizers are synthesized and need energy to be produced (Biewinga and van der Bijl, 1996). Lower N requirements, consequently will need lower energy inputs. Regarding P and K fertilizers they are usually extracted from mineral ores, which are limited (Biewinga and van der Bijl, 1996). Hence, lower P and K requirements implicate ore conservation and energy savings to mine them.

Water resources

Water scarcity is especially problematic in semi-arid and arid areas as in some parts of the European Mediterranean region, where water availability is low and varies from year to year (EEA, 2006; El Bassam, 2010). Agricultural products account for the largest share of worldwide freshwater demand in the world (FAO, 2010). Effects of increased water abstraction include salinization and water contamination, loss of wetlands and the disappearance of habitats through the creation of dams and reservoirs and the drying-out of rivers (EEA, 2006). So, energy crops cultivation may also contribute to the depletion and spoilage of water resources.

Increases in irrigated land have contributed to water scarcity, with the lowering of water levels in surface (EEA, 2006) and groundwater (Biewinga and van der Bijl, 1996). Usually, energy crops are not irrigated under penalty of reducing, in most cases, its positive net energy balance (Biewinga and van der Bijl, 1996). So, the crop's choice should focus on drought resistance and water use efficiency species (Zegada-Lizarazu *et al.*, 2010), in order to reduce the need of irrigation.

In this respect, EEA (2006) and several other authors, stated that perennial plantations can be designed to minimize negative impacts on water use. Some perennial biomass crops perform better than the conventional arable crops used for biomass production. This fact is due to two main reasons:

- the biomass of perennial crops have a higher lignin and cellulose contents than the biomass of annual crops, allowing the plant to stand upright at low water contents (Lewandowski *et al.*, 2003b);
- perennial herbaceous, such as switchgrass, *Miscanthus* and giant reed, among others, have a high water use efficiency due to their deep and well-developed root system (McLaughlin and Walsh, 1998 and Zegada-Lizarazu *et al*., 2010).

In an energy crops review work, Zegada-Lizarazu *et al.* (2010) considered that sweet sorghum, *Miscanthus* and switchgrass have high water use efficiencies, followed by hemp, giant reed and willow. Studies performed by Biewinga and van der Bijil (1996) across Europe, revealed that most of the energy crops studied have lower evaporation than grass fallow. Exceptions to this are perennials in the South of Portugal, which have higher evaporations than grass fallow, especially eucalyptus, because it is an evergreen crop. Hence its cultivation may contribute to severe problems of groundwater depletion (Biewinga and van der Bijl, 1996). However, in certain cases, energy crops, such as willow and poplar, may work out positively, if they can be cultivated on wet fields, but not waterlogged (Mitchell *et al.*, 1999), and thereby preventing the drainage of those fields (Biewinga and van der Bijl, 1996; OECD/IEA, 2006).

An overview of water footprints (WFs) of bioenergy from several crops was presented in the work of Gerbens-Leenes *et al*. (2009b). According to this study, the WF of bioelectricity is smaller than that of biofuels because it is more efficient to use total biomass (e.g., for electricity or heat) than a fraction of the crop (its sugar, starch, or oil content) for biofuel. The WF of bioethanol appears to be smaller than that of biodiesel. For electricity, sugar beet, maize, and sugar cane are the most favorable crops ($50m^3.GJ^{-1}$). Rapeseed and jatropha are disadvantageous ($400m^3.GJ^{-1}$). For ethanol, sugar beet, and potato (60 and $100m^3.GJ^{-1}$) are the most advantageous, followed by sugar cane (110 $m^3.GJ^{-1}$); sorghum (400 $m^3.GJ^{-1}$) is the most unfavorable. For biodiesel, soybean and rapeseed show to be the most favorable WF (400 $m^3.GJ^{-1}$); jatropha has an adverse WF ($600m^3.GJ^{-1}$). When expressed per L, the WF ranges from 1.400 to 20.000 L of water per L of biofuel.

Land resources

Land used for energy cropping competes with conventional agriculture, forest production and urbanization, as well as for nature protection and conservation (Smeets *et al.*, 2004; OECD/IEA, 2007; Abbasi and Abbasi, 2010; Fritsche *et al*., 2010). Energy crops to be used for bioenergy, biofuels and bioproducts of increased value, should therefore be produced in a sustainable land use way. In other words:

- Using land not required for food, feed and fiber production (Krasuska *et al.*, 2010). In order to avoid the past concerns relating to food security caused by first-generation liquid biofuels production from food crops (such as sugarcane, palm oil, oilseed rape, corn, wheat) grown primarily for energy purposes, and also the case of energy crops (such as *Miscanthus*, switchgrass, willow and eucalyptus) grown specifically as lignocellulosic feedstocks for second-generation biofuels (Fritsche *et al*., 2010).

- Using land in a way that the minimum direct and indirect negative effects are being produced due to Land Use Change (LUC). An example, of a direct LUC effect, is the amount of GHC produced when a rainforest is converted into an energy crop plantation (Fritsche *et al*., 2010). Indirect-LUC effects are the shifting of some of the direct effects of increased biomass production of a single feedstock to outside the system boundaries, so that these effects become indirect (Fritsche *et al*., 2010). It should be noted that indirect-LUC could not only impact GHG emissions, but could also have important effects on biodiversity (Croezen *et al.*, 2010). An example of a negative indirect-LUC effect occurs when rainforest, peatlands, savannas, or grasslands are converted to produce food based biofuels in Brazil, and Southeast Asia, and the United State creates a “biofuel carbon debt” by releasing 17- 429 times more CO_2 than the annual GHG reductions these biofuels provide by displacing fossil fuels (Fargione *et al*., 2008).

Estimates of global biomass potentials vary widely, depending on different assumptions for agricultural yield improvements, trends in food and energy demands, possible dietary changes, and how sustainability is taken into account, among others (Fritsche *et al*., 2010). It takes four times more land to fuel an automobile than to feed one person for one year. The demand for agricultural and forest products is growing rapidly with time, enhancing the already wide gap between demand and supply (Abbasi and Abbasi, 2010).

Krasuska *et al.*, 2010 modeled the surplus land that would be available for non-food crops after satisfying food, and feed demands, considering projections of future agriculture productivity and changes in the population. The total area potentially available for non-food crops in the EU-27 (excluding Cyprus and Malta) is estimated to be 13.2 million ha in the current situation, with fallow land the largest contributor.

Bioenergy from moderately degraded land could additionally deliver ~70 EJ due to the considerable amount of land world-wide low carbon content and low biodiversity (Bauen *et al.*, 2009) which is, in principle, suitable to cultivate bioenergy feedstocks. This could also give the additional benefits of restoring degraded soils and habitats. Recent studies from Fritsche *et al*. (2009) confirm the possibility of sustainable bioenergy production from degraded land, but may be on the lower end of the estimates (100 million to 1 billion, instead of the earlier projected 1-2 billion ha – Dornburg *et al.*, 2008; Lal *et al.*, 2006). Since, crop yields are likely to be relatively low owing to the quality of the soil and its often poorly agricultural management (Fritsche *et al.*, 2010). It should also be taken into careful consideration, especially in developing countries, that even some degraded land, may represent land that have been under communal or traditional customary use, for example as a source of natural medicines to very poor local communities, and are vital for their livelihoods (The Gaia Foundation *et al*., 2008).

1.2.5. Biological and Landscape diversity

Extensive farming systems are important for maintaining the biological and landscape diversity of farmland. However, these systems have been threatened, either by intensification and abandonment (EEA, 2005). At the global level, **biodiversity** has been drastically reduced by continuing specialization in farming practices and a simplification of cropping systems over a preferred few species. This was also associated with a decrease in non-cropped habitats, such as grassland, field boundaries and tree lines (EEA, 2006; Picco, 2010). As a consequence, **landscape diversity** has been substantially reduced, leading to a loss of diversity in farmland habitats, ecotypes, populations, their consistency and associated farmland flora and fauna (EEA, 2005; Picco, 2010). Farmland biodiversity is indirectly affected by a combination of all the previously identified pressures (e.g, soil erosion and compaction, nutrient and pesticide leaching to surface and groundwater and water abstraction). Direct pressures include the loss of habitats and farm and pest management practices (EEA, 2006).

For example, as a consequence of agriculture intensification, the majority of farmland birds have suffered a strong decline from 1908 to 2002, which has leveled off in the 1990s, nevertheless species diversity remains very low in intensively farmed areas (EEA, 2005).

An increased diversification in crop type and the introduction of structural elements can be beneficial for biodiversity, particularly in intensive agricultural systems. More diverse land cover creates a greater number of habitats for species from different *taxa* (EEA, 2006).

Some energy crops, in particular, perennial herbaceous and SRF can add to landscape diversity (hence helping to address the aesthetic concerns sometimes expressed about intensive monocultures) and habitat diversity, due to their different structural characteristics and depending on where the biomass is produced, how much is produced and how it is produced and at what rate it is produced (Faaij and Domac, 2006; Picco, 2010; Sunde *et al.*, 2011).

SRF showed positive impact on the environment, in terms of increased plant and animal biodiversity, especially when compared to traditional crops (EEA, 2006; Picco, 2010). In this regard, several authors have reported an increase in structural diversity of the agricultural landscape, since the introduction of SRF promotes the increase of faunal diversity, acting as vegetation filters, providing wind protection, shelter and improving soil conditions (Perttu, 1998; Börjesson, 1999; Berg *et al.*, 2002; Weih, 2004; Rowe *et al.*, 2009; Picco, 2010). Makeschin (1994) reports that more than 60% of the nutrients can be recycled through the foliage fallen on the ground, which store the organic matter in the topsoil to be gradually released in the circulating solution of the ground, with positive effects within the fauna, microbial activity and soil structure. But SRF, may also have negative pollution effects that affect habitat quality due to use of fertilizers and pesticides in the production (Sunde *et al.*, 2011). The traditional forest mechanical operations may disturb habitat species (especially its matting and nesting areas) to such an extent that species are lost or extinct and other (unwanted) species may appear (Abbasi and Abbasi, 2000; Sunde *et al.*, 2011).

Perennial herbaceous, like switchgrass, giant reed, and cardoon, can also contribute to the ecological value of agricultural production, functioning as elements in a diversifying landscape management and as habitat for different animals (Lewandowski *et al.*, 2003b; El Bassam, 2010). Due to the long-term lack of soil disturbance, the late harvest of the grasses and the insecticide-free production, allows an increase of microorganisms populations and the formation of associative systems (like mycorrhizal, a symbiotic system) e.g.between fungi and plantations of switchgrass (Clark, 1999; Perlack *et al*., 2005; Prochnow *et al.*, 2009; Boehmel *et al.*, 2008). Moreover, plantation of *Miscanthus* and reed canary grass, have been reported to increase the presence of ground flora, invertebrates, mammals and birds when compared to cereal crops (Semere and Slater, 2007a).

1.2.6. Social and economic impact

The major **social** impacts of energy crops cultivation will be:

- The shifts in employment (creation or displacement). Total employment is expected to increase with the energy demand provided by biomass. The labor force will be needed in agricultural and forest production, to cut, harvest, transport biomass resources and in the conversion facilities (Abbasi and Abbasi, 2010);
- Improved access to basic energy services (cooking fuel, pumped water, electric lighting, miling);
- The creation of employment alternative in rural areas, where a new job can be generated by every 540 Mg of dry biomass obtained from dedicated energy crops (Venturi and Monti, 2005).
- The foundation of farmers associations and cooperatives (Sims *et al.*, 2006; Zegada-Lizarazu *et al.*, 2010); and
- Increases in occupational health and safety problems (Abbasi and Abbasi, 2010): associated with the possibilities of increased are greater occupational hazards. Significantly, more production in agriculture and forestry than with either coal (underground mining), oil or gas recovery. Agriculture reports 25% more injuries per man per day, than all other private industries.

Among the **economic** impacts, stands out (Faaij and Domac, 2006; Sims *et al.*, 2006; Zegada-Lizaru *et al.*, 2010):

- The promotion on the development of regional economic structures;
- The macroeconomic benefit of the production of indigenous renewable energy, which in turn increases energy security, improves trade balances, hence increasing the Gross National Product;
- The development of new and profitable markets (biofuels, chemicals, materials, foods and feeds, etc.) that could provide farmers with new sources of income and employment;
- The design of higher value products and co-products and entrepreneur initiatives arising from Research and Development (R&D) activities; and
- The possibility of exporting biomass-derived commodities to the world’s energy markets can provide a stable and reliable demand for rural communities in many (developing) countries, thus creating an important incentive and market access, much needed in many parts of the world.

1.3. Purpose of the study

In essence, as bioenergy carriers, energy crops offer ecological advantages over fossil fuels by contributing to the reduction of greenhouse gases and acidifying emissions. However, there could be ecological shortcomings related to the intensity of agricultural production: there is a risk of polluting air, surface and groundwater, losing soil quality, enhancing erosion and reducing biodiversity. These crops are often compared to other renewable resources and fossil fuels, but the comparison is not easy due to the unfeasibility of considering all the environmental aspects and to the highly variable conditions in which energy crops can be produced. In fact, different groups of crops can be considered, and within these, different species can grow in a great variety of farming environments and pedo-climatic situations with different management technics (Venturi and Venturi, 2003). In any case, it is clear that the cultivation of energy crops must fall within the parameters of sustainable agriculture, hence the need to study and evaluate the environmental impacts associated with it.

Environmental Impact Assessment (EIA) is an evaluation method to explore the possible environmental effects of a proposed project. EIA examines the anticipated environmental effects and determines the importance of these effects, on both the short and the long term. The environmental impact analysis of crop cultivation requires good knowledge of:

- the cultivation operations;
- the requirements and the productivity of the various crops in different climates;
- soil types; and
- methods of cultivation.

There is neither a general list of criteria to assess the environmental impacts nor a general description of methods to be used. Fixing the environmental criteria is part of the EIA process. Usually, criteria address emissions to soil, surface and ground water and air, effects on living environment and health of people in the surroundings, effects on surrounding ecosystems, and effects on cultural assets.

In this framework, the aim of this study is to evaluate the environmental effects due to the cultivation of several non-food crops in the European Mediterranean region, being its ultimate goal to achieve conclusions and to define recommendations, in order:

- to stimulate discussion inside and outside the European Union; and
- to give a contribution towards further development of non-food crops throughout Europe.

This study was carried out in the scope of the project 4F Crops - Future Crops for Food, Feed, Fiber and Fuel (http://www.4fcrops.eu), supported by the EU. This project was designed to survey and analyze all the parameters that will play an important role in successful non-food cropping systems in the agriculture of EU27 alongside the existing food crop systems.

In order to accomplish the goal of this work, an environmental impact assessment study was developed and applied to several crops, considered as promising and suitable to the European Mediterranean region, where the national Portuguese territory is inserted. In this area, the temperature and solar radiation are favorable to the vegetative development, and the growth cycles are long, allowing energy crops to reach maturation phases with high productivities (Fernando, 2005). However, during summer, drought periods occur, forcing farmland irrigation, to avoid water stress, in some crops. In addition, there is a 4 to 20% increase projection of soil availability in the European Mediterranean region, to the energy crops production for the period 2010-2030 (Krasuska *et al.*, 2010).

2. METHODOLOGICAL APPROACH

2.1. Goal and Scope

Goal was primarily to evaluate the environmental effects due to the cultivation of different non-food crops in European Mediterranean.

2.1.1. Choice of the crops to be studied

Thirteen energy crops were selected according to the decisions taken in the framework of the 4F Crops project. Those chosen crops were considered as promising and suitable to the European Mediterranean region:

- **Oil crops**: Rapeseed, Sunflower, Ethiopian Mustard
- **Sugar crops**: Sugar beet, Sweet sorghum
- **Fiber crops**: Hemp, Flax
- **Lignocellulosic crops**: *Miscanthus*, Giant reed, Cardoon
- **Woody crops**: Poplar, Willow, Eucalyptus

Besides the energy crops, two food crops, wheat and potato were also included in the study. These crops are for long well established in the European Mediterranean region, are widespread across the area, represent an important share of the agricultural production and are also reported to present advantages and shortcomings from the environmental point of view. Since wheat and potato are traditional crops, their performance will serve for comparison with the energy crops to be established in the European Mediterranean region.
Grass fallow was the reference system used.

2.1.2. Geographical scope

EU 27 is subdivided into representative regions according to Metzger *et al*. (2005) (Figure 2.1). This study focused on the Mediterranean North and the Mediterranean South regions.

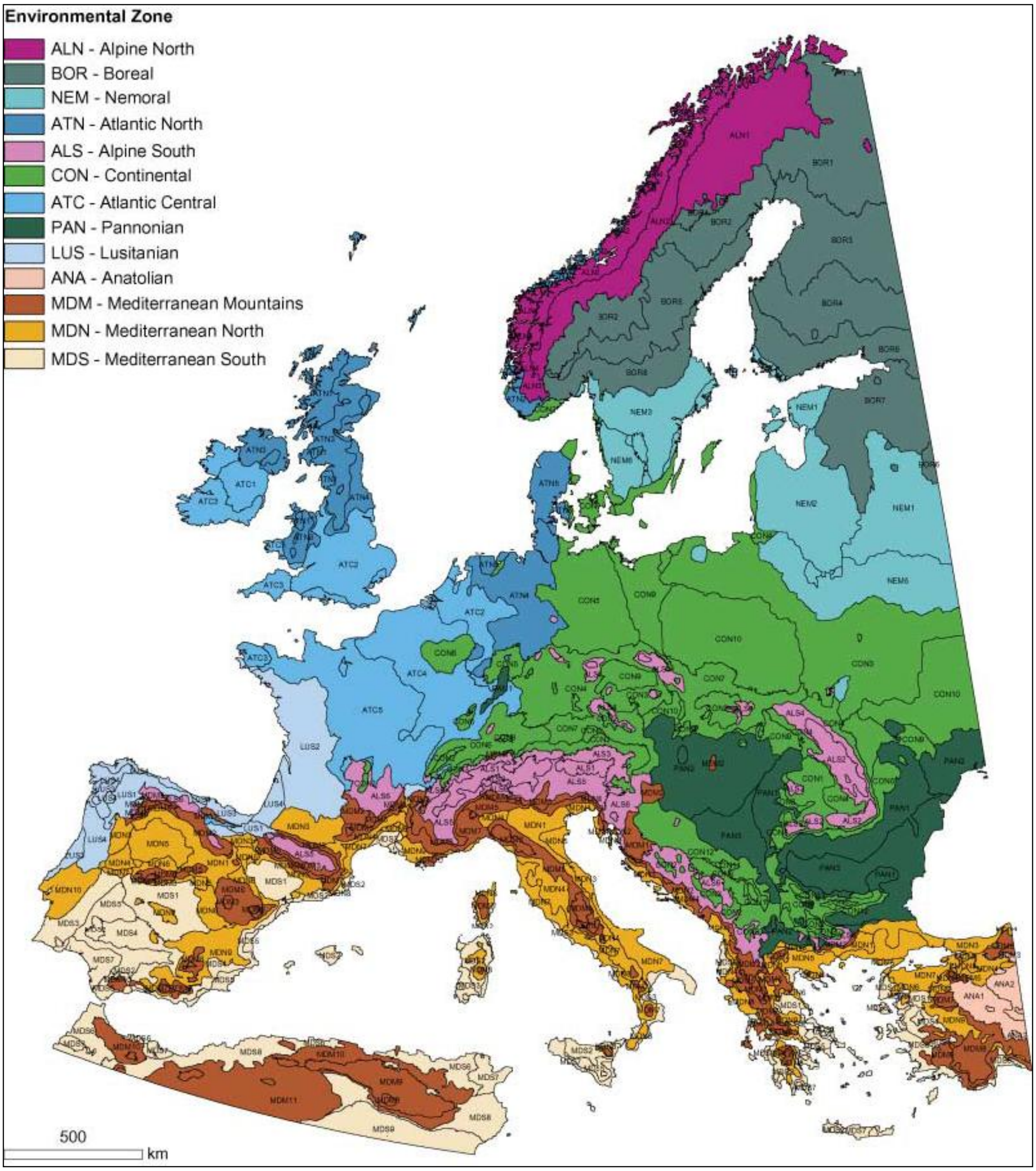

Figure 2.1 - Environmental Stratification of Europe (Metzger *et al*., 2005).

2.2. Data collection

Most energy crops in Europe are cultivated in small-scale and often in experimental sites. Assessment of field data from literature was supplemented with and cross-checked by expert opinions. Some data were acquired as well from national and international organizations such as Food and Agriculture Organization (FAO) and Eurostat. Precipitation data was supplied by Joint Research Centre (EC/JRC, 2010).The complete reference list of the surveyed results and references are available in Annex I.

Assessment of field data revealed the existence of variable inputs. Data analysis often encompasses ranges of inputs for each crop that can be intra-regional and inter-regional. In order to comply with the scope of this study, which aimed at setting an impact trend for each crop, results were displayed as averages (when ranges are available) or single figures (when literature did not provide further data). Thus, variability is not discarded from the analysis. It was decided not to include deviations and error bars in the graphs because it would not reflect actual uncertainty of the results. This study was based on a literature survey, thus the available information on the studied crops varies. More information may induce increased variability on the results. Relating this to uncertainty would give a strong bias towards crops with more available information. For example, fertilizer inputs of potato and wheat are widely documented and this large amount of data comprises wide ranges. On the opposite, crops such as willow or hemp are not so commonly referred thus showing small deviations. Error bars would not accurately show on field variability but reflect the amount of information that could be gathered on each crop.

2.3. Environmental impact assessment

An environmental impact assessment study must be based on data about the impact of a particular crop cultivated at a specific place. Categories such as the impact of a crop on soil need to be selected. In principle, it is possible to quantify the impact by means of chosen indicators.

In this study we followed the approach suggested by Biewinga and van der Bijl (1996), adjusting the methods whenever relevant. The focus is on the impact of cultivation on biotic and abiotic resources, through the analysis of the crop’s interaction with its environment and management practices. This EIA is divided into several categories, which comprise individual impact indicators (Biewinga and van der Bijl, 1996; Börjesson, 1999; Mattson *et al*., 2000):

- **Emission of minerals to soil, water and air** – an estimation of the amounts of minerals (N, P, K) applied to soil and their removal with the crop can show whether there is a mineral build-up in the soil or the reverse. Although high N, P and K content of the soil favors soil fertility, there is the risk that an excess of plant-available nutrients in the soil may be lost through future leaching or erosion, an important fact regarding the long-term fertility of the soil and the eutrophication of soil and water.

- **Emission of pesticides**, concerning the quality of soil, ground and surface water and air, one of the most serious problems is pollution by pesticides. The amount of emission is affected by the amount of pesticides used and characteristics of the pesticide.
- **Soil Erosion** is a serious kind of degradation since it is irreversible. The soil loss also means a loss of plant nutrients and organic matter which can impair the land's productivity.
- **Soil organic matter** plays an important role in several ways. It helps to keep plant nutrients available, contributes to good soil structure, prevents erosion and keeps soil moist.
- **Soil structure** is defined by the amount and distribution of pores. The pores are mainly filled with gas (air), water and plant roots. Soil compaction, i.e. loss of pore space, makes soils less suited for plant production.
- **Soil pH**, a very important factor, controls many chemical and biological activities in the soil, for example availability of plant nutrients and activity of soil microorganisms.
- **Use of Water Resources** – The contribution of a crop to ground water depletion and desiccation correlates with its water use.
- **Hydrology** effects of cultivation occur when the land use alters the flow of water as ground water, stream water, runoff, transpiration, etc.
- **Use of Mineral Resources** – The use of mineral resources, i.e. withdrawal of materials from the environment, can lead to exhaustion. In this study, the use of phosphate and potash fertilizer, as a criterion for the exhaustion of fertilizer ores will be assessed.
- **Waste production and utilization**, an inventory of waste products used and produced during biomass cropping will be performed. In this qualitative approach, each of them will be judge positively or negatively.
- **Biodiversity**, erasing diversified vegetation and replacing it with mono-cultural crops is always a violation against it, but the consequences appear as site-specific factors, such as the number of species affected by the cultivation.
- **Landscape**, the aesthetic value may be affected by the choice of the crops and cultivation systems. Two criteria are considered: effects on the variation of structure and effect on variation of colors.

Table 2.1 indicates the environmental impact assessment methodological steps for each impact category.

Time reference of the study is 2010. Energy savings, greenhouse effects, acidification issues and land use change were not considered in this study.

Table 2.1. - Environmental impact assessment methodological steps for each impact category.

Category	Indicator	Assessment steps
Emissions to soil, air and water	Fertilizer-related emissions	i. Quantification of nitrogen (N) fertilizer applied. ii. Estimation of emissions (IPCC, 2006): a. NH_3 volatilization (10%); b. NH_4/NO_3 leaching and run-off (30%); c. N_2O direct emissions (1%).
	Pesticide-related emissions	i. Quantification of active substances (A.S.) applied. ii. Toxicity evaluation of each A.S. according to its effects on the environment, fauna and human health. (Biewinga and van der Bijl, 1996 and Portaria 732-A/96) iii. Aggregation of *(i)* and *(ii)* in a pesticide score: $Pesticide\ score = \sum\left(amount_{A.S.\ (kgha^{-1})} \times toxicity_{A.S.}\right)$
Impact on soil	Nutrient status	i. Quantification of N, phosphorus (P) and potassium (K) fertilizers applied (input). ii. Quantification of crop N, P and K uptakes and of N emissions. iii. Calculation of nutrient status in the soil as: *Balance = input – uptake – emissions (for N)* *K surpluses may contribute to eutrophication of terrestrial ecosystems and this is accounted in the indicator "Fertilizer related emissions"
	Erosion	i. Division of crop cultivation in development phases from start of growth (A), to closure of crop (B), to start of senescence (C) and harvest (D). ii. Estimation of a soil cover ratio (C-value) and of a regional amount of rainfall in each phase (R-value). iii. Assessment of an erosion control factor (P-value) reflecting the intensity of erosion control in each region. iv. Calculation of the harmful rainfall: $\text{Total harmful rainfall} = \sum (\text{C} \times \text{R})_{\text{stage and region}} \times \text{P}_{\text{region}}$
	Soil properties	Literature survey of the negative and/or positive impacts of each crop on structure, organic matter and pH.
Impact on mineral and water resources	Groundwater depletion	i. Quantification of crop water requirement. ii. Quantification of rainfall available to the crop during its permanence on soil. iii. Calculation of soil water balance: *Groundwater balance = rainfall – water requirement*
	Effects on hydrology	i. Effects on water flow and run-off and on refill of aquifers as influenced by: a. crop permanence on soil; b. crop water needs; c. crop root system.
	Mineral ore depletion	i. Quantification of P and K fertilizers applied. ii. Sum of P and K fertilizers use (P fertilizer is more scarce, thus it will weight five times more than K).
Waste	Literature survey on the possible generation of impactful wastes during cultivation and on the possibility of using each crop to the following waste valorization options: phytoremediation, irrigation with wastewater, soil amendment with sludge, etc.	
Biodiversity	Literature review and evaluation of generic effects of crops regarding: i. biodiversity disturbance as related to management practices and intensity; ii. aggressiveness, nativeness and allelopathy; iii. reported increase or decrease of abundance and diversity of floral and faunal species.	
Landscape	Evaluation of the variation of crop scene in terms of structure (height, density, heterogeneity and openness) and color. Variation was considered to be a benefit when gains in structure and/or color were noticed. Variation implying loss of structure and/or color debited the landscape values.	

2.3.1. Normalization

Although EIA can be more descriptive, it is necessary to aggregate information in order to condense numerous inventory data to more comprehensible information about potential environmental impact. To facilitate a direct comparison, parameters can be normalized: translated into the same measure. A simple form of normalization was used: all parameters were translated into a figure between 0 and 10, with 0 being the lower impact and 10 the highest impact for each category. Five is the score of the reference crop grass fallow. For each quantitative indicator “0” or “10” are determined by the most extreme result among the crops for each environmental zone in the European Mediterranean region (to overcome the inter-regional differences observed, e.g. rainfall, crop productivity). Regarding soil properties and the categories waste, biodiversity and landscape, qualitative evaluation was used to fulfill the lack of quantitative data. Qualitative scoring consisted on the individual evaluation of each crop for a set of pertinent parameters, through expert judgment and literature review.

2.3.2. Weighting

As a last step the scores on the different indicators can be weighted. Defining weighting factors is value-based pronouncement, which brings ambiguity and subjectivity to the study at hand. Some authors agree that, whenever applied, weighting should reflect the relative importance of the impact categories in the organizational context of the study (Schmidt and Sullivan, 2002). Since this study was performed at the European Mediterranean level, the weighting factors were built up according to the relative importance of each indicator studied considering the European Union Environmental Policies, which highlight greenhouse gases emissions, biodiversity and chemical pollution (EC, 2001). Moreover, it was considered that erosion and water availability are of greater concern in the Mediterranean regions (van der Knijff *et al*., 2000; EEA, 2009) while fertilizer emissions have lower impacts in southern European regions (Biewinga and van der Bijl, 1996). In order to assess the influence of a weighting system (WS) on the final results, three different classifications were applied (table 2.2):

- WS1: all indicators have the same weight;
- WS2: greater emphasis on GHG emission drivers, namely N-fertilizer related emissions and soil degradation;
- WS3: greater emphasis on biodiversity.

Table 2.2. - Weighting systems applied.

Category	Indicator	Weighting factors		
		WS1	WS2	WS3
Emissions to soil, air and water	Fertilizer-related emissions	1	2.25	0.75
	Pesticide-related emissions	1	1	1
Impact on soil	Nutrient status	1	0.25	0.25
	Erosion	1	1	1
	Soil properties	1	2	1
Impact on mineral and water resources	Groundwater balance	1	1	1
	Effects on hydrology			
	Mineral ore depletion	1	0.25	0.25
Waste		1	0.25	0.25
Biodiversity		1	1.5	4
Landscape		1	0.5	0.5
Total		10	10	10

After the application of a weighting factor to each category, a weighted average final score for each crop was estimated according to equation 1.

$$Score_{crop} = \frac{\sum\left(score_{indicator} \times weight_{indicator}\right)}{\sum weight_{indicator}} \qquad \textbf{(Eq. 1)}$$

3. RESULTS and DISCUSSION

3.1. Emissions to soil, water and air

3.1.1. Fertilizer-related emissions

Minerals like nitrogen, phosphorus and potassium are largely applied on soils as fertilizers in order to achieve and maximize profitable yields. Consequently, soil, water and air can became polluted by these elements. But, if minerals applied to the soil are lower than the amount removed by the crop, than soil reserves can became depleted.

Nitrogen applied to the soil can contribute to several environmental problems, according to Biewinga and van der Bijl (1996) and IPCC (2006):

- **Volatilization of ammonia (NH_3) and oxides of N (NO_x) to the air** - this contributes to the acidification.
- **Leaching and runoff of ammonium (NH_4^+) and nitrate (NO_3^-) to ground and surface waters** - this contributes to eutrophication and excess of nitrate in drinking water could be a threat to human health.
- **Denitrification to nitrous oxide (N_2O)** - this contributes to the greenhouse effect and to ozone depletion. Some nitrous oxide can be produced during nitrification.

According to IPCC (2006), 10% of the N input can be lost by volatilization and 30% can be lost by leaching/runoff. The emissions of N_2O occur through both a direct pathway (i.e., directly from the N input, 1%), and through two indirect pathways: (i) following volatilization of NH_3 and NO_x from managed soils (1%) and (ii) after leaching and runoff of nitrogen, mainly as NO_3^-, from managed soils (0,75%) (IPCC, 2006).

So, for each crop, nitrogen losses can be estimated by using the IPCC emission factors. As N inputs we only considered fertilizers and not manure. A wide range of N fertilizer application, was witnessed in the review survey, showing that N inputs are not regionally specific. So, N inputs and N emissions were considered at an European level. Figure 3.1 shows average values estimated for N emissions, for all the crops studied. Deposition from air and symbiotic N-fixation were not considered in the study.

According to figure 3.1, run-off and leaching are important fractions and N_2O emissions are a negligible part of the N emissions. When comparing with grass fallow, Eucalyptus is the crop that shows the lowest N emissions. Annual crops showed the higher emissions. This includes the food crops (wheat and potato) and the energy crops (hemp, sweet sorghum, sugar beet, Ethiopian mustard and rape seed). Flax and sunflower were the annual energy crops that showed lower N emissions, similar to those estimated to perennials. Although a perennial crop, cardoon showed also high N emissions, comparable with those estimated for annual crops.

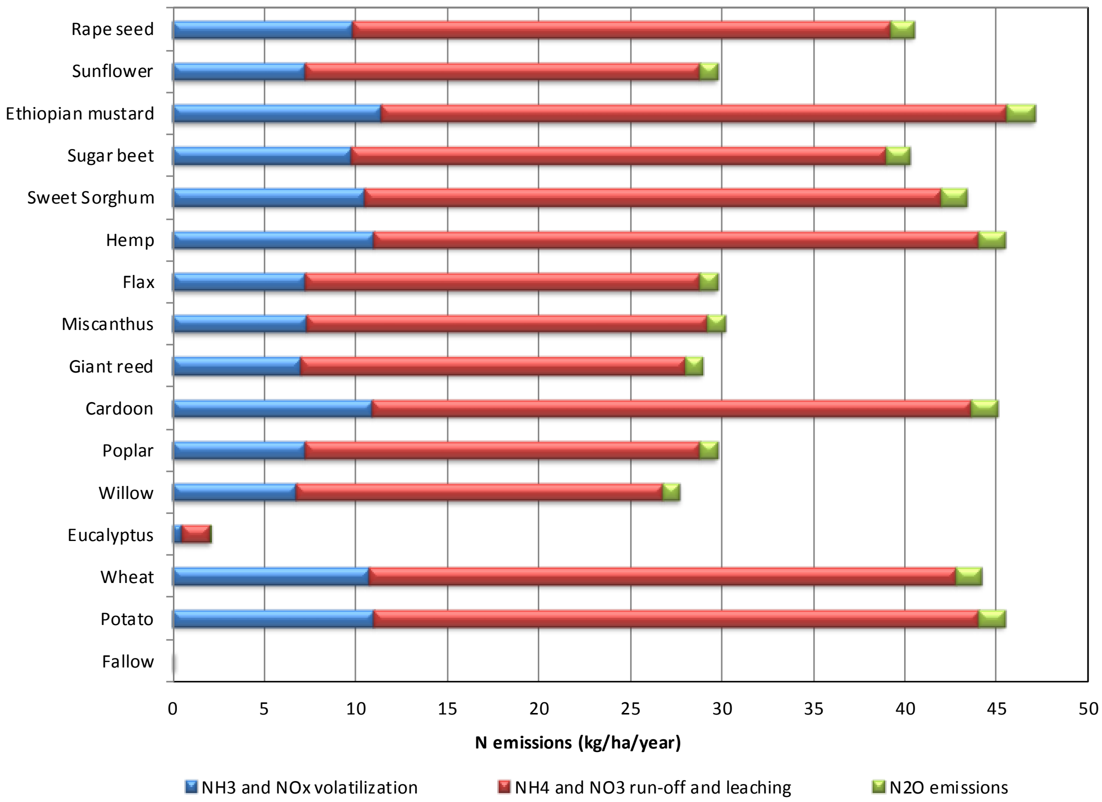

Figure 3.1. - Estimated nitrogen emissions (kg.ha^{-1}.year^{-1}) for all crops, in Mediterranean Europe (for each crop, mean from maximum and minimum results).

Nonetheless, IPCC emission factors don't take into account root and rhizome dynamics and N run-off and leaching can be lower due to the extensive root system of some of the crops studied. Several works on short rotation forestry systems and perennial grasses suggest that nitrate leaching is only of importance during the establishment of the crops, before roots have fully developed (Biewinga and van der Bijl, 1996). Perennial grasses have shown advantage in water and nutrient acquisition because underground standing biomass is massive and rhizome accumulation is significant (El Bassam, 1998, McLaughlin *et al.*, 1999, Bullard and Metcalfe, 2001, Panoutsou, 2007). According to Jørgensen and Schelde (2001), leaching is very limited cause of perennials efficiency at taking up nitrate due to their long growing season and the permanent and deep root system. Extensive root system may also slow the travel of surface water, decreasing run-off and allowing greater water infiltration (Rinehart, 2006). Regarding willow and poplar, but not eucalyptus, they are eligible as vegetable filters for landfill leachates cause of their long growing season and permanent root system (Duggan, 2005).

While a negligible part of the N emissions, estimation of the direct N_2O emissions based on the IPCC 1% factor is still under debate. It is now understood that this factor should be superior (Crutzen *et al.*, 2008).

Concerning P and K emissions, while P from artificial fertilizer remains relatively inert in the soil, provoking no noteworthy effects, K may contribute to eutrophication of terrestrial ecosystems. This issue will be dealt with on the evaluation of the nutrient status of the soil (section 3.2.1.3).

3.1.2 Pesticide-related emissions

Pesticides contribute to ensure the supply of agricultural products. A profitable relation between pest control and agricultural productivity has been verified (Pimentel *et al*., 1992). However, the profit has a liability in terms of agricultural sustainability. The main shortcomings refer noxious human health effects, damage to flora and fauna, contamination of soil and groundwater and unbalacement of pests and diseases (Wilson and Tisdel, 2001).

Pesticides have an impact on the environment at several levels (Biewinga and van der Bijl, 1996):

- Use of energy resources for its production;
- Emissions to the environment during production, transport and storage of pesticides;
- Emissions to the environment during application of pesticides at the farm.

As most of the environmental burden is likely to come from application at the farm, this will be the only aspect to be focused.

Considerable amounts of pesticides end up in soil, water and air due to its application. The relative impact assessment of pesticide use should rely on quantity and harmfulness.

A pesticide score can be determined for each crop resulting from pesticide application. A risk score per crop can be attained through:

- the quantification of active substances applied in each crop;
- a survey on physical specifications, effects on the environment, fauna and human health of each active substance; this will score the toxicity of each pesticide;
- for each crop, a pesticide score can be calculated by multiplying the amount of each pesticide applied per hectare per year by the toxicity score of each pesticide and by adding up the scores (equation 2).

$$\text{Pesticide score}_{\text{crop}} = \sum (\text{amount}_{\text{active substance}(\text{kg ha}^{-1})} \times \text{toxicity score}_{\text{active substance}}) \qquad \textbf{(Eq. 2)}$$

Toxicity data on the substances was compiled from pesticides databases and the relative weight of each characteristic went according to Biewinga and van der Bijl (1996) and Portuguese Decree

Portaria 732-A/96 (1996) (table 3.1). The toxicity score for each substance consisted on the sum of points attributed to each characteristic.

Table 3.1. - Toxicity score calculation framework
(Biewinga and van der Bijl, 1996, Portaria 732-A/96, 1996)

Feature		Ponderation
Application		Yes = 1; No = 0
Water contamination: Solubility and Persistence in the water		Solubility > 1mg.L^{-1} and > 28 days to degrade 70% = 1; Otherwise = 0
Soil contamination: Persistence in soil		DT_{50} > 267 days = 2; 90 days < DT_{50} ≤ 267 days = 1; DT_{50} ≤ 90 days = 0
Acute toxicity for water organisms		LC_{50} ≤ 1mg.L^{-1} = 2; 1 mg.L^{-1} < LC_{50} ≤ 10 mg.L^{-1} = 1; LC_{50} > 10 mg.L^{-1} = 0
Toxicity to terrestrial fauna		Yes = 1; No = 0
Toxicity to humans	Mammals	LD_{50} ≤ 25 mg.kg^{-1}= 2; 25 mg.kg^{-1}< LD_{50} ≤ 200 mg.kg^{-1}= 1 LD_{50} > 200 mg.kg^{-1} = 0
	Carcinogenic / Mutagenic	Yes = 1; Unknown = 0.5; No = 0
	Teratogenic	Yes = 1; Unknown = 0.5; No = 0

A survey on the substances applied, their amounts and traits was carried out thanks to an extensive bibliographic research in peer-reviewed journals, scientific reports and agricultural databases, to expert consulting and own field experience. Multiple references often document for the same crop the application of different pesticides with similar functions, or the application of the same pesticide in different quantities, or the needlessness of pesticide use. As it was observed for the N fertilizer application, pesticide application is not regionally specific. Hence, a range of risks were calculated for each crop in Europe (figure 3.2).

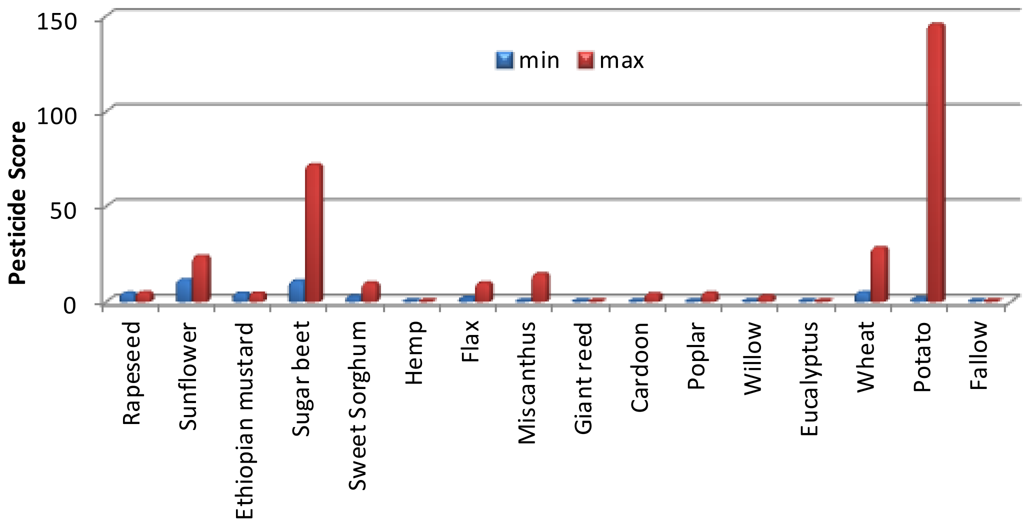

Figure 3.2. - Pesticide scores for each crop in Mediterranean Europe (minimum and maximum risks).

Figure 3.2 shows that most of the energy crops studied present lower pesticide impact, which reflects their apparently low susceptibility to pests and diseases. Crops that pose the least toxicity threat related to pesticide application are, obviously, the ones that do not need disease control and/or chemical weeding. According to literature, these are hemp, the trees (willow, poplar and eucalyptus) and the perennial grasses *Miscanthus*, giant reed and cardoon. Nonetheless, there are reports of pesticide use in poplar, willow, *Miscanthus* and cardoon plantations, which increase their mean pesticide score. Besides the food crop potato, sugar beet crop presents also a high pesticide risk. However, the estimated pesticide risk depends on the intensity level of pest control practices. Large differences between low and high intensity pesticide use exist in different places or according to different sources for the same crop species, such as in sugar beet and potato (figure 3.2). This implies that, although having high mean pesticide-related impact, these crops may have low to moderate impacts if managed in that manner.

3.2. Impact on soil

3.2.1. Nutrient status

3.2.1.1. Nitrogen

N balance can be estimated by subtracting outputs (N volatilization, run-off and leaching, direct N_2O emissions and crop uptake) to inputs (fertilisers). Nitrogen surplus results in soil accumulation. But, a negative value may contribute to the depletion of the soil N reserves. It was assumed that uptake by fallow during its growth is returned to the soil during senescence and decomposition. As already referred in section 3.1.1, N inputs were considered at an European level. Estimation of N emissions was also done at European level, but crop uptake has to be determined at each region due to differences in productivity and biomass composition.

Figure 3.3 shows nitrogen surplus/deficit for all crops, in the Mediterranean (for each crop, average results of Mediterranean North and South). According to Figure 3.3, when comparing with grass fallow, sweet sorghum, flax, poplar, willow and *Eucalyptus* showed the lowest impact regarding N depletion of the soil. Flax, poplar, willow and *Eucalyptus* can even present a contribution to the soil N reserves. Sunflower and cardoon were the crops that showed a higher depletion of the soil N reserves. In the case of sunflower, this negative impact can be reduced if crop residues (straw) are incorporated in the field. The same is valid for cardoon when the seeds are the marketable product.

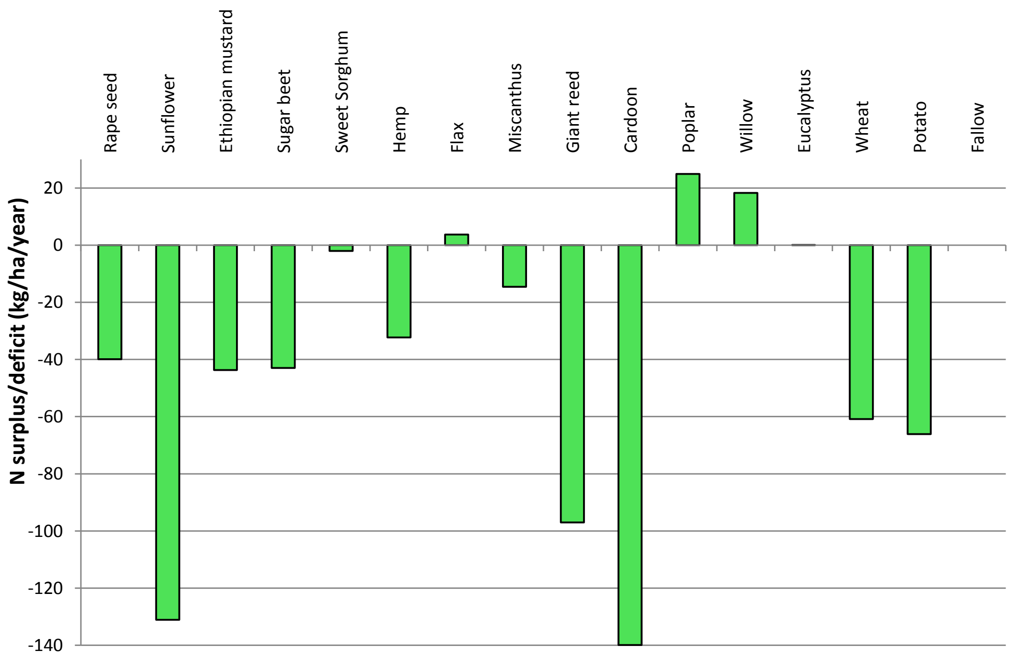

Figure 3.3. - Nitrogen surplus/deficit (kg.ha^{-1}.year^{-1}) for all crops, in the Mediterranean (for each crop, average results of the Mediterranean North and South - Europe)

3.2.1.2. Phosphorus

In Europe, the present phosphate input in agricultural soils poses no threat to the quality of ground water, because soils have a high capacity to bind phosphate (Biewinga and van der Bijl, 1996). Nevertheless the risk is higher when manure is used and continued for a long period. Determination of the phosphorus surplus/deficit is a good indicator of the P soil accumulation or the P soil depletion.

Deposition from air was not considered. As presented for nitrogen, a wide range of P fertilizer application, in each environmental zone studied, was observed, showing that P inputs are not regionally specific. So, P inputs were considered at an European level. P surplus/deficit was estimated by the difference between input (fertilizers) and output (crop uptake). As with N uptake, P uptake was determined at each environmental region due to differences in productivity and biomass composition among regions. It was also assumed that P uptake by fallow during its growth is returned to the soil during senescence and decomposition.

While figure 3.3 shows that most of the crops are soil N depleting, phosphorus balance presented in figure 3.4 shows a soil P surplus for most of the crops. According to these results, a balanced profile is presented: application of phosphorus was equal or superior to the crops uptake. Only *Miscanthus* showed a deficit, although negligible. Sweet sorghum and potato were the crops that contributed largely to the soil P reserves. However, considering that higher P inputs contribute to the exhaustion of mineral resources then, these results suggest that lower P inputs should be applied in those crops.

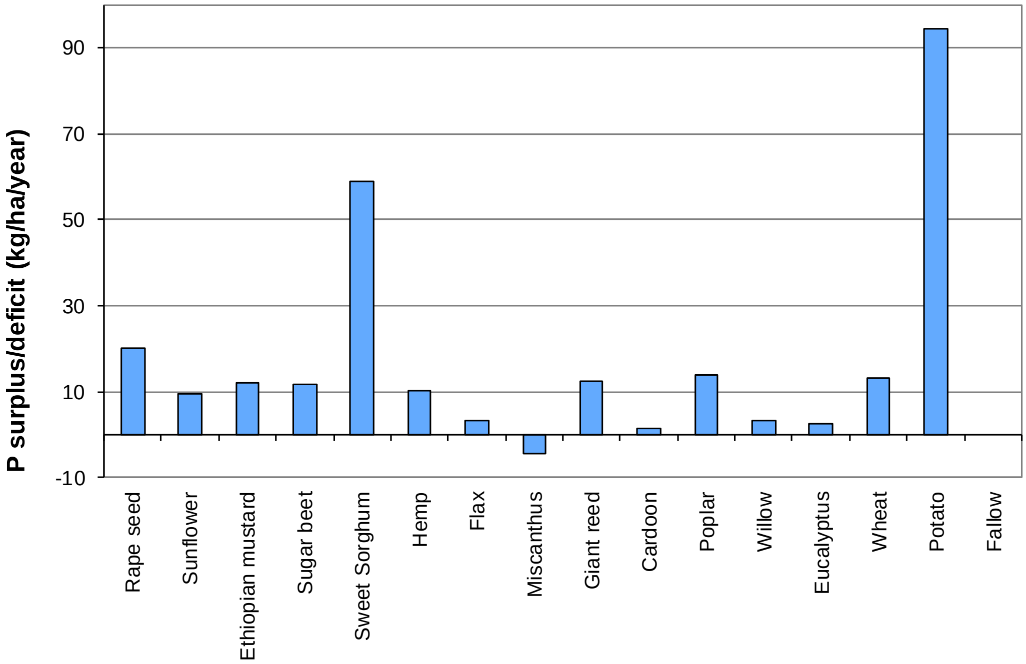

Figure 3.4. - Phosphorus surplus/deficit (kg.ha^{-1}.year^{-1}) for all crops, in the Mediterranean (for each crop, average results of the Mediterranean North and South - Europe)

3.2.1.3. Potassium

Determination of the potassium surplus/deficit is a good indicator of the soil K accumulation and losses to the environment or the soil K depletion. Both aspects have a negative impact: the resulting K surplus may contribute to eutrophication of terrestrial ecosystems (Biewinga and van der Bijl, 1996) but if potassium inputs are lower than potassium crop uptake, K reserves of the soil might be depleted.

Deposition from air was not considered. As it was observed for nitrogen and phosphorus, a wide range of K fertilizer application, in each environmental zone studied, was observed, showing that K inputs are not regionally specific. So, K inputs were considered at an European level. K surplus/deficit was estimated by the difference between input and output (crop uptake). K uptake was determined at each environmental region due to differences in productivity and biomass composition among regions. It also assumed that K uptake by fallow during its growth is returned to the soil during senescence and decomposition.

Figure 3.5 shows potassium surplus/deficit for all crops, in the Mediterranean. According to figure 3.5, most of the crops show a K deficit, especially both sugar crops (sugar beet and sweet sorghum), the perennial grasses giant reed and cardoon and the food crop, wheat. Rapeseed, flax, the woody crops, poplar, willow and *Eucalyptus* and the food crop, potato, showed a K surplus, but this accumulation of K in the soil may contribute to eutrophication of terrestrial ecosystems as referenced before (Biewinga and van der Bijl, 1996).

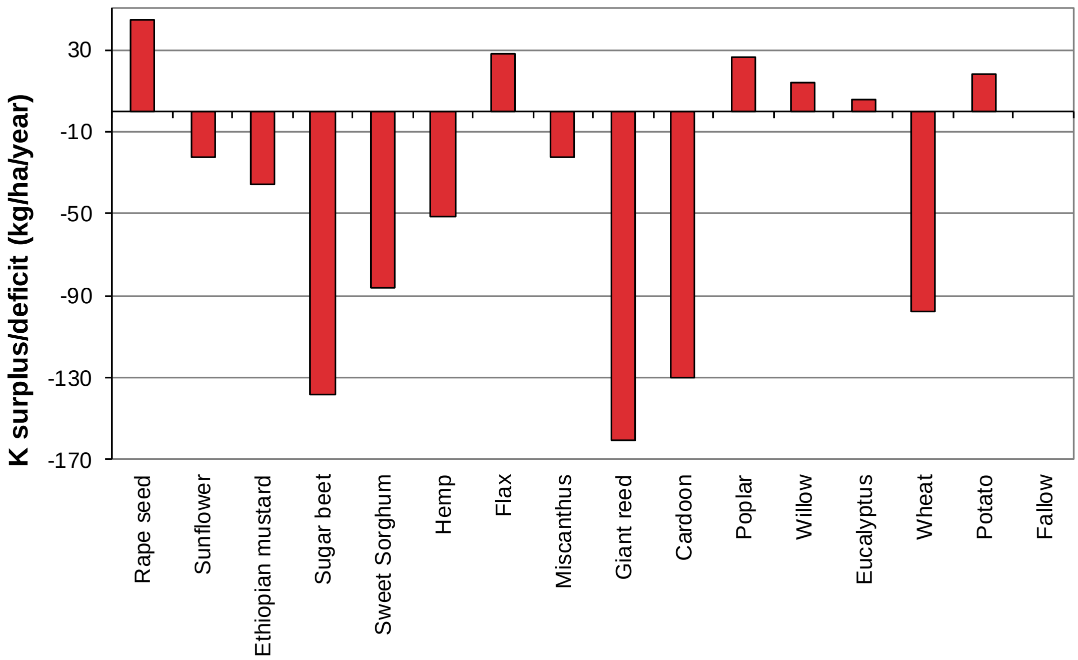

Figure 3.5. - Potassium surplus/deficit ($kg.ha^{-1}.year^{-1}$) for all crops, in the Mediterranean (for each crop, average results of the Mediterranean North and South - Europe)

3.2.2. Soil properties

Soil as an agricultural or natural substrate plays a vital role in structural support and plant nourishment, watering and aeration. Moreover, its part in nutrient cycle, namely organic carbon storage, places soil quality in the basic requirements for enhanced agricultural productivity and environmental preservation (Reeves, 1997). Soil is an important carbon sink and its mismanagement can be a shortcoming for bioenergy systems' sustainability (Cannel, 2003; Brandão *et al*., 2011).

Common cropping management activities such as harvest and site preparation and the sheer prevalence of certain species can affect soil structure, pH and organic matter dynamics. These factors interact with nutrient availability, thus soil fertility.

Assessing the impact of crops on soil organic matter (SOM) content, structure and pH is highly dependent on local conditions. Nonetheless, there are generic trends documented in literature that allow a comparison between trees, perennial grasses and annual crops.

Residue cover left on soil enhances organic matter content, water storage and nutrient recycling and promotes structural integrity (Angers and Caron, 1998; Cannel, 1999; Lal, 1997; Sessiz *et al*., 2008). Litter removal, ploughing and tillage and use of synthetic fertilizers in detriment of organic fertilizers are practices that impoverish soil in terms of organic matter (Lal, 2005; van der Werf, 2004; Sessiz *et al*., 2008; Singh *et al.,* 2009).

Brandão *et al*. (2011) compared soil organic carbon stocks under rapeseed, *Miscanthus* and willow land use. They concluded that rapeseed cultivation reduces soil organic carbon while *Miscanthus* increases it. Willow also has a negative effect, although milder than rapeseed.

Miscanthus had been previously suggested to accumulate organic matter in the soil owing to its permanence, high inputs of residues and rhizome storage (Kahle *et al*., 2001). Long-established unmanaged forests benefit from long time accumulation of soil carbon, both in standing biomass and soil cover (Lal, 2005; Alexandrov, 2007). The same cannot be stated of managed forest species plantations. Much less organic matter is contained in a plantation owing to their smaller average biomass (namely at bottom level) and precocious felling (Cannel, 1999; Alexandrov, 2007). Studies on the particular case of *Eucalyptus* have confirmed the negative effect on soil cover resulting from harvesting options practiced on this crop (Carneiro *et al*., 2008), further enhanced by its allelopathy, which limits the presence of understory vegetation (Sasikumar *et al.*, 2001; Zhang and Fu, 2009).

Soil revolving by tillage and ploughing and litter removal are more intensive in annual systems (Fragoso *et al*., 1997). Thus, annual crops are more likely to induce soil quality depletion through loss of organic matter and structure than perennial grasses and trees (Börjesson, 1999, Zan *et al*., 2001).

Penetrating roots is one of the key points of the influence of plants in soil structure. Root growth promotes the formation of macropores, which are believed to enhance yields (Angers and Caron, 1998). Perennial grasses and trees have deeper roots than annual crops. Accordingly, perennial grasses accumulate more organic matter in the soil, followed by trees and annual crops. Litter deposition should not be higher in annual crops than in fallow. Among annuals, it was assumed that sugar beet harvest depleted the soil from organic matter plus compromising soil physical integrity. The same was assumed with potato crop, but with a minor impact. Rapeseed, Ethiopian mustard and flax benefit from roots and part of the stem left on the ground. Hemp and sweet sorghum have deep roots that improve structure and, being left in the ground after harvest, enhance organic matter content. The same happens with sunflower, although with less extent because of bigger spacing and smaller roots.

Regarding soil pH, forests and forestry crops can significantly increase soil acidity compared to short vegetation (Cannel, 1999), which limits nutrient availability thus crop growth (Bona *et al*., 2008). Soil acidification results from the deposition of atmospheric pollutants absorbed by leafs and branches, such as HNO_3, HCl and NH_3, and of sulfate and nitrate aerosols accumulated in cloud water. These phenomena depend on regional pollution levels and meteorology but have been proven impactful in European regions such as the United Kingdom (Cannel, 1999).

Annual crops have a higher need for soil amendment, which quite often alters soil pH. Use of ammonia fertilizer significantly acidifies the soil (Bohn *et al*., 2001). Although this modification might favor soil fertility for the desired crop, it can inflict a sharp deviation from soil pH native conditions. Perennial herbaceous fields have less fertilizers input and the higher organic matter content also curbs pH variation. Nonetheless, Kenaf – an annual crop – and *Miscanthus* cultivation data indicated negligible fluctuations in pH along the time (Fernando, 2005; Fernando *et al*., 2007).

After an extensive literature review, crops and crop-types were benchmarked towards fallow and towards each other in a qualitative fashion (figure 3.6).

Lignocellulosic crops provide organic matter accumulation and structural enhancement related to permanence, high inputs of residues and vigorous root development. Consequently, these crops present a positive impact regarding SOM and soil structure (figure 3.6). Woody crops are reported to accumulate less SOM than herbaceous perennials, whereas *Eucalyptus* induces further stress through the depletion of ground level vegetation by allelopathy. Annual cropping systems are the most damaging in terms of SOM content and structure due to high soil revolving, short permanence and litter removal. The impact is minor when crops have deep roots (e.g., hemp and sweet sorghum) and if litter is left on field and enhanced when the harvesting process removes a portion of the soil (e.g., sugar beet and potato). Regarding soil pH, woody crops significantly increase soil acidity compared to short vegetation. Intensive soil amendment in annual systems may lead to sharp pH variations from the native status of the soil. The same processes can affect herbaceous perennials systems, but to a lesser extent.

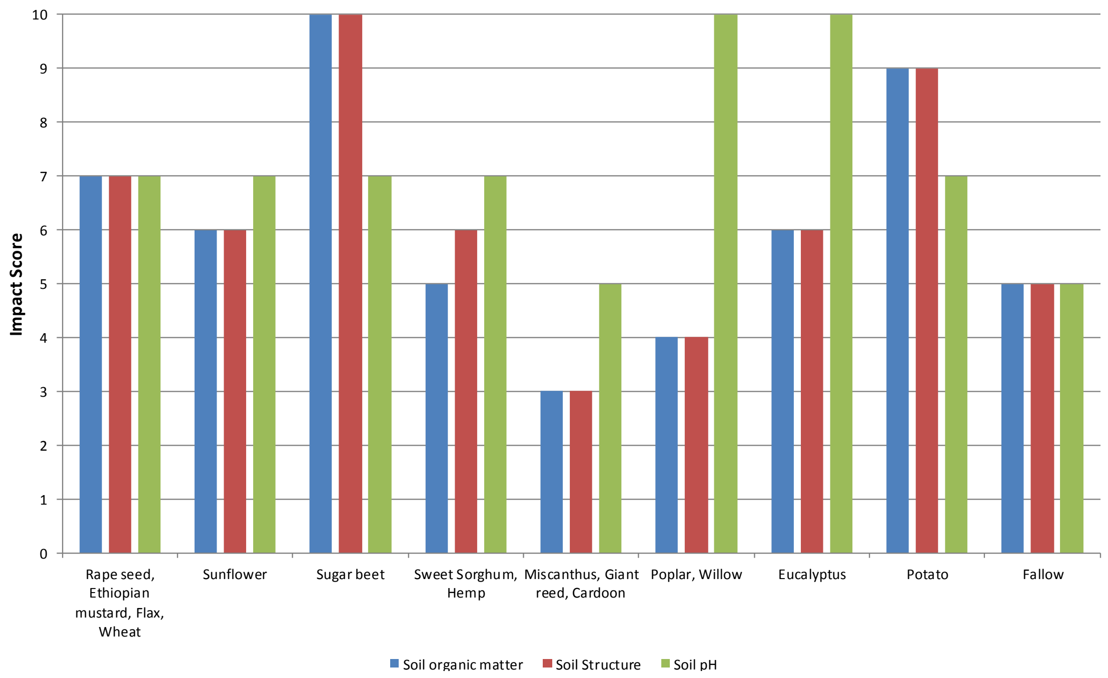

Figure 3.6. - Soil structure, organic matter content and pH impact scores of crops in the Mediterranean Europe.

3.2.3. Erosion

In this study water erosion is assessed by the adaptation of the protocol by Biewinga and van der Bijl (1996) crossing the potential damage caused by rainfall with the soil cover characteristics of the crops during their cultivation cycles.

Each crop growth was divided in four phases comprised between:

- A – start of growth
- B – closure of crop
- C – start of senescence
- D – harvest

Crop management factors (C-values) were defined for each phase of each crop. C-values reflect the soil cover rate of the crop (which depend on canopy development), remaining and buried crop residues and tillage. C-values are between 0 (soil totally covered) and 1 (soil completely uncovered). Definition of growth stages and C-values for each crop at each environmental zone was gathered through own field experience and literature review (Biewinga and van der Bijl, 2006; Fullen, 2003; Poesen and Hooke, 1997; van der Knijff *et al*., 2000; Wilson and Maliszewska-Kordybach, 2000; Calado *et al*., 2008; Harrison and Butterfield, 1996; Harrison *et al*., 2000; Ierna, 2009).

For each crop stage in each region, an accumulated precipitation (R-value) was determined by adding up the monthly average rainfall (mm). For each crop and region, C and R are multiplied and summed up; this sum is then multiplied by P, the erosion control factor, to obtain the total harmful rainfall (equation 3).

$$\text{Total harmful rainfall}_{\text{crop and region}} = \sum (C \times R)_{\text{stage and region}} \times P_{\text{region}} \qquad \textbf{(Eq. 3)}$$

The erosion control factor (P-value) reflects the control of erosion and soil conservation carried out in each region. Values of P are between 0 (well established erosion control) and 1 (no erosion control). European Commission data indicate that areas in Southern and Central Europe as well as in the Baltic region have higher erosion risks than the Atlantic climates (van der Knijff *et al*., 2000). Biewinga and van der Bijl (1996) consider that there are established erosion control systems in Portugal. This can be also identified in other countries of the Mediterranean basin (Poesen and Hooke, 1997). Consequently, it was assumed that erosion control takes place in all Mediterranean. Hence, for all Mediterranean regions it was decided to use a P value of 0.8.

Assessement of the erosion risk is highly site specific, naturally owing to the weight of pluviosity. Mediterranean regions are drier. Hence, the average erosion risk verified there is lower than in climates with higher precipitation, such as atlantic north and lusitanian. Nevertheless, Mediterranean North shows a higher erosion risk than Mediterranean South due to a higher annual precipition (figure 3.7).

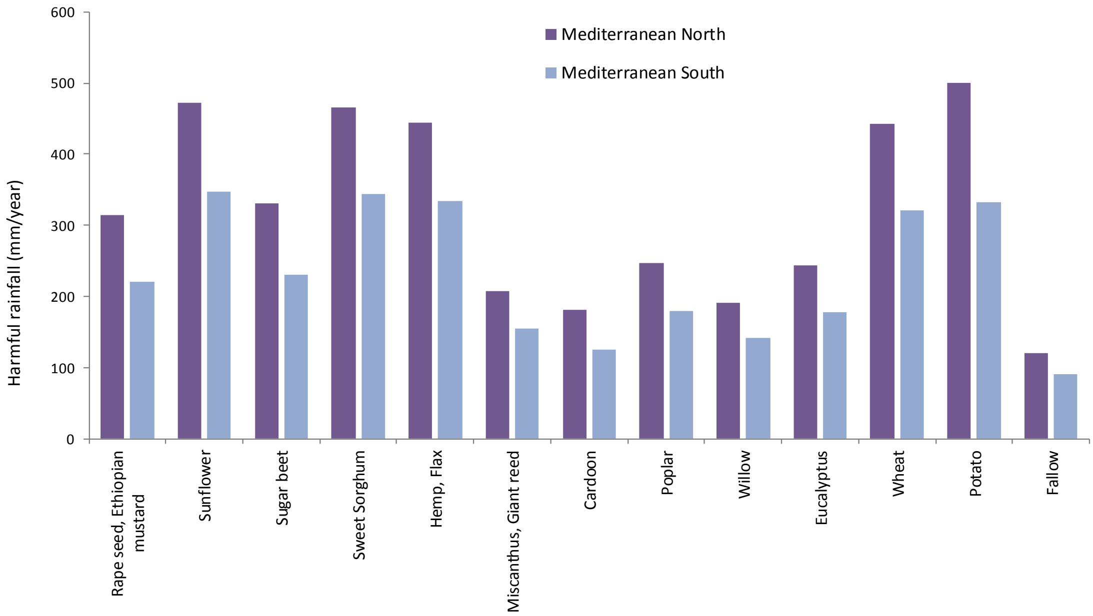

Figure 3.7. – Harmful rainfall for all crops in the Mediterranean Europe.

Results corroborate the suggestions by Kort *et al.* (1998) that lignocellulosic and woody crops exhibit average lower erodibility potential owing to greater interception of rainfall and more surface cover for a longer time period (figure 3.7). The continuous presence of an underground biomass in the soil also contributes to these findings.

In contrast, annual crops pose higher erosion risks, particularly sunflower, sweet sorghum, the fiber crops and the food crops. Rape seed, Ethiopian mustard and sugar beet, however, show a lower impact, owing to the fact that they were considered as winter crops, and their permanence in the soil is long.

Nevertheless, in this erosion impact analysis it was only considered the exposure of the soil to rainfall. Other important factors that might contribute to the erosion potential of each crop, such as wind, SOM and soil structure, which also influence the soils integrity, were not considered in this study.

3.3. Impact on Water and Mineral Resources

3.3.1. Groundwater balance and effects on hydrology

Plant water use is expressed by evapotranspiration. Besides inherent factors, this process is bound to climatic aspects such as solar radiation and relative humidity. Moreover, the water that is in fact obtainable by the rooting system is dependent on local hydrological processes such as drainage and infiltration (Gerbens-Leenes and Nonhebel, 2004).

Lacking site-specific data, a more broad approach was carried out. Crops can either be irrigated or suppress their water needs by accessing aquifers and precipitation water. Whichever way, unless rainfall tops requirements, freshwater must be extracted from surface or groundwater, which depletes natural stocks. Hence, depletion of groundwater resources was determined by comparing the available water provided by rainfall and the water requirements of the crop.

A generic amount of water (mm yr^{-1}) required by each energy crop was determined through literature review (Biewinga and van der Bijl, 1996, Calado *et al*., 2008, Dalianis *et al*., 1995, El Bassam, 1998, Fabeiro *et al*., 2001, Fabeiro *et al*., 2003, FAO, 2010, Fernandez *et al*., 2006, Gasol *et al*., 2007, Gerbens-Leenes *et al*. 2009a, Harrison and Butterfield, 1996, Harrisson *et al*., 2000, Ierna, 2009, LCAinfo, 2009, Luca *et al*., 2003, Luger, 2002, Majumbar, 2004, Pereira and Shock, 2006, Supit *et al*., 2010).

The availability of precipitation water of each climatic region was considered to correspond to the accumulated monthly average rainfall of several Mediterranean locations within each climatic region. For annual crops, the rainfall was only accounted for when lying within the limits of crop growth: from start of growth to harvest. For perennials, it was accounted the annual precipitation, because of its permanent and deep root system efficiency at taking up water (El Bassam, 1998, McLaughlin *et al.*, 1999, Bullard and Metcalfe, 2001, Panoutsou, 2007).

Subtracting water needs to available rainfall would reveal a deficit or a surplus in supply. It was assumed that the resulting calculus would correspond to groundwater depletion/refill, expressed in mm (equation 4).

$$\text{Groundwater depletion/refill} = \text{available rainfall} - \text{water requirement} \quad \textbf{(Eq. 4)}$$

Figure 3.8 shows groundwater depletion/refill results for all the studied crops, in the Mediterranean.

The impact on groundwater is highly site specific (figure 3.8). Mediterranean South with lower rainfall record higher deficits. Globally, perennial grasses and woody species show positive water balances. Even so, in regions with less precipitation, the balance can be negative, such as with poplar and willow in the Mediterranean South regions. Among perennials, *Miscanthus* and *Eucalyptus* performed better, in line with fallow.

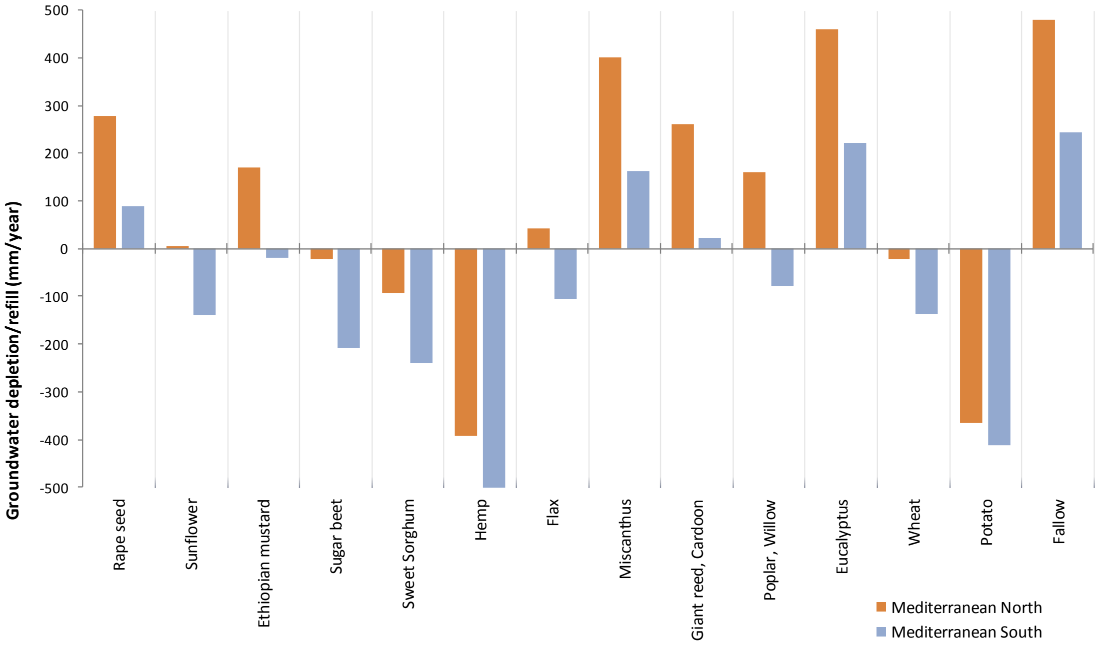

Figure 3.8. - Groundwater balance for each crop in the Mediterranean Europe.

Annual crops are more prone to negative water balances than perennial grasses and trees. Hemp and potato, high water demanding crops, presented the most severe exhaustion potential. Nonetheless, some annual crops can present a balanced amount. Rapeseed and Ethiopian mustard, for example, present positive to neutral water balances due to the fact that the limits of crop growth are coincident with this region highest rainfall period (as winter crops). Crops traits are also highly significant. For example, the high water demanding crop, hemp, in Mediterranean North, shows higher groundwater depletion than flax in Mediterranean South, and both are fiber crops. So, regarding this aspect, interaction between region and crop can also be highly significant and higher water demanding crops should be allocated to regions with higher precipitation in order to lower the depletion rates.

Land use for agricultural practices does not always safeguard the levels and quality of water resources (Gerbens-Leenes *et al*., 2009a; Biewinga and van der Bijl, 1996). Hydrology effects of energy crops cultivation can go beyond their water demand, focusing also on the crops cultivation effects on the flow of ground water, stream water, run-off, etc. These aspects are highly site specific as well as related to crop traits (Hall, 2003).

There are overall conclusions pointing towards neutral to beneficial effects. Tolbert *et al*. (1998) state that soil covering minimize surface run-off and sediment and nutrient losses. Decreased run-off allied to soil drying and increased penetration effects render energy crops useful in flood management when cultivated in wet fields (Rowe *et al*., 2009; Biewinga and van der Bijl, 1996). Hall (2003) claim that the impact of energy crops on water quality is likely to be positive owing to less agrochemical inputs when compared to traditional farming.

On the other hand, shortcomings should be expected from species combining higher growth rates and transpiration rates, longer seasonal growth and deeper and more complex root system (such as SRF and herbaceous C4 plants, but also hemp and sweet sorghum). Deep rooting slows down rainfall refill of aquifers, especially when associated with high evapotranspiration losses (Stephens *et al*., 2001). However, grasses exhibit less transpiration owing to shorter harvest cycles and improved water use efficiency (Hall, 2003).

Figure 3.9 shows the impact on hydrology by the different energy crops studied, in the Mediterranean.

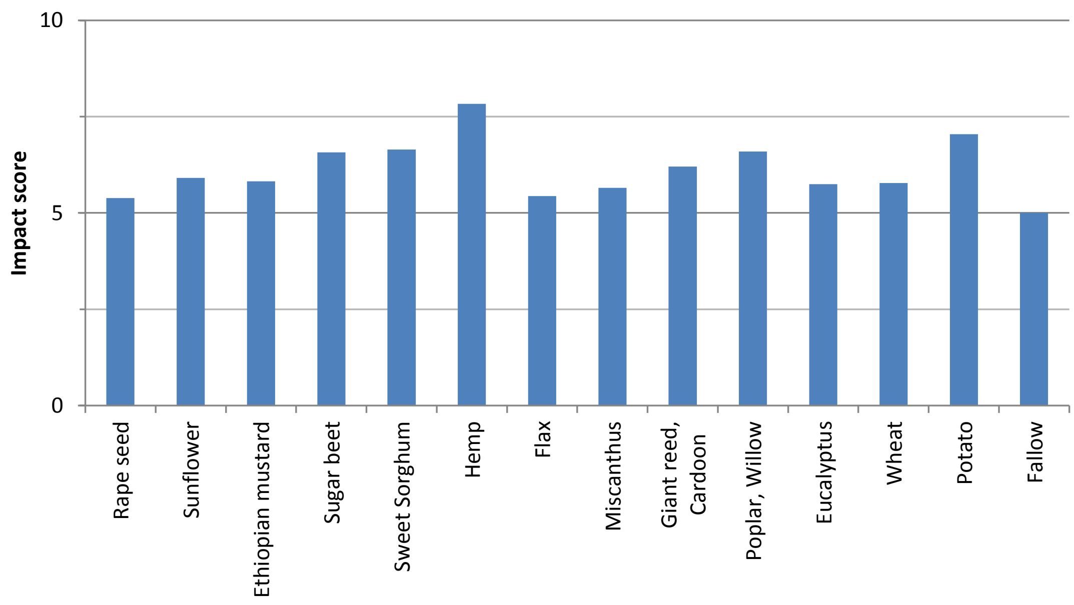

Figure 3.9. – Impact on hydrology of each crop, in the Mediterranean (for each crop, average results of the Mediterranean North and South - Europe)

Effects on water flow and run-off and on refill of aquifers were scored according to the crop permanence on soil, the crop water needs and the crop root system. The longer the crops permanence in the soil (e.g. perennials and fallow) the better the beneficial effect due to minimization of surface run-off. On the opposite, crops with shorter permanence in the soil have a higher impact on hydrology (e.g. potato). Shortcomings concerning aquifer refilling were credited to crops with higher water needs (e.g., sugar beet, hemp, poplar and willow) and deeper root systems (e.g., perennials, hemp and sweet sorghum).

3.3.2. Mineral ore depletion

Agricultural systems rely on a supply of artificial fertilizers that in turn depend on the input of mineral resources (Biewinga and van der Bijl, 1996). Hence, fertilizers use influence the depletion of mineral ores.

This category was assessed according to Biewinga and van der Bijl (1996) who suggest that phosphate and potassium fertilizers should be taken into account, once they are mined as mineral ores, with limited resources. Minimum and maximum P and K fertilizer inputs for the cultivation of each crop were quantified. The exhaustion of mineral ores is expressed as kg K_{eq} ha^{-1} determined according to eq. 5 (as phosphate fertilizer is scarcer, it will weight five times more than the weight of potassium fertilizer).

$$\text{PK fertilizer use (kg } K_{eq}\text{/ha)} = 5 \times \text{P input (kg/ha)} + \text{K input (kg/ha)} \qquad \text{(Eq. 5)}$$

Figure 3.10 show the impact of the energy crops cultivation on the exhaustion of mineral ores. Most crops have a high range of PK fertilizer use. Hence, the different PK use intensities indicate that some crops whose average mineral ore depletion level is high may be cultivated in a lower-impact regime. Rapeseed, sunflower, sugar beet, flax and the food crops fit that case, since their minimum PK input is much lower than the maximum. However, some of these crops showed K depletion of the soil (section 3.2.1.3), so care should be taken to avoid additional impact on soil. Crops like rape seed, flax and potato that showed both P and K positive balances give margin to this lower impact regime. Perennials are less P and K demanding, although differences to most of the annual crops studied are not significant. Lower impact is observed for *Eucalyptus* and willow whereas sweet sorghum and potato present the highest risk concerning mineral resources.

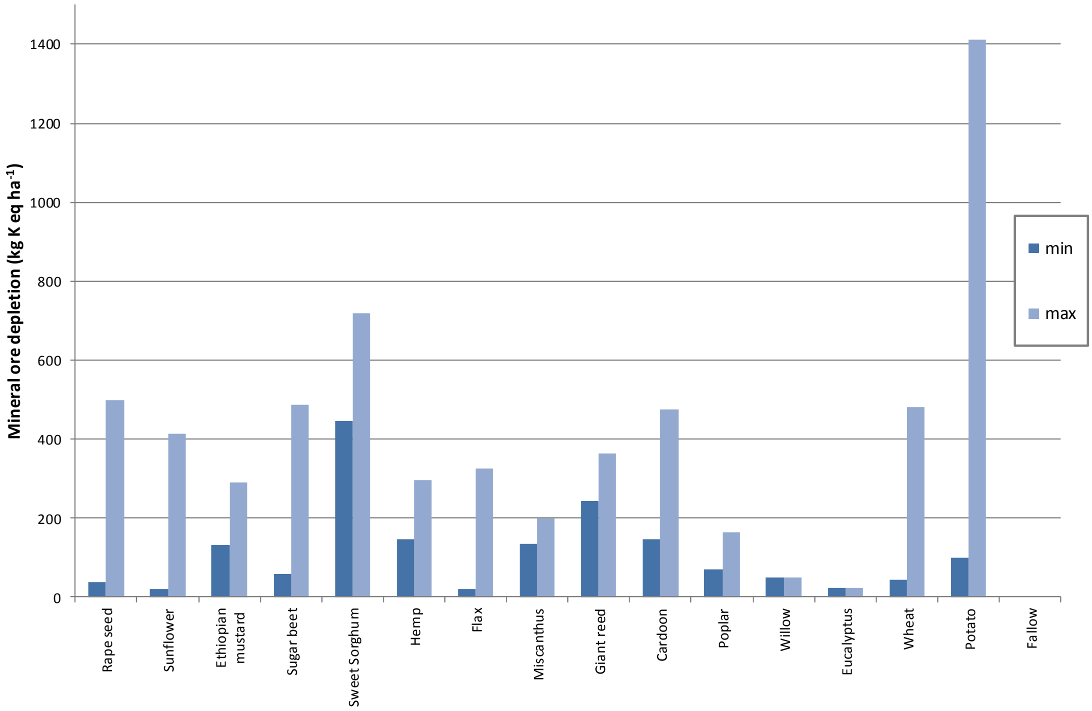

Figure 2.10. – Ranges of mineral ore depletion impact of each crop in the Mediterranean Europe.

3.4. Waste

Though the cultivation of energy crops may produce undesired waste during cultivation, this is partly counterbalanced by the ability to take up contaminants and nutrients from sludge, slurry, landfills, wastewaters and soils (figure 3.11).

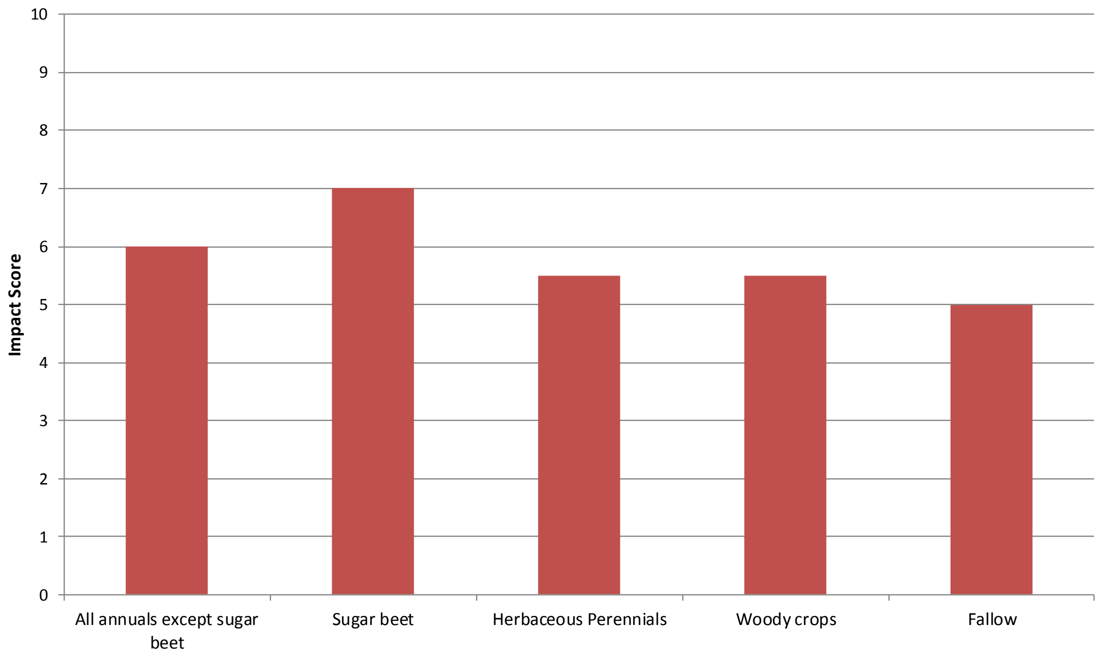

Figure 3.11. – Impact of waste generation and use of each crop in the Mediterranean Europe.

Regarding the generation of waste during cultivation, it was assumed that all crops produce it in the form of pesticide and fertilizer disposed packages and old machinery (Biewinga and van der Bijl, 1996), thus scoring higher impact than fallow fields. Being less management intensive, perennial grasses and trees generate less waste than annual crops. Soil sticking to the sugar beet during the harvest further increases the impact of this crop because this waste cannot return to the field due to phytosanitary reasons (Biewinga and van der Bijl, 1996).

Energy crops have been thoroughly documented as apt remediators of heavy metal contaminated soils and landfill leachates. Irrigation with wastewaters and soil amendment with sewage sludge is reported as well. Thus all crops studied scored the same as fallow fields, where it was assumed that phytorremediation and application of wastewaters and manure is also possible.

Willow and poplar have been documented as efficient landfill caps treating its leachates (Börjesson, 1999; Duggan, 2005). Willow plantations have been irrigated with wastewater and sewage sludge (Heller *et al.*, 2003; Rosenqvist and Dawson, 2005; Hansson *et al.*, 1999). Poplar was tested with success for remediation of soil amended with non-hazardous levels of industrial waste (Giachetti and Sebastiani, 2006). Guo *et al.* (2002) reported the irrigation of *Eucalyptus* plantations with meatworks effluent.

Miscanthus is considered suitable for disposal of sewage sludge in soils (Bullard and Metcalfe, 2001; Fernando, 2005). Irrigation with wastewater from municipal and/or industrial sources are reported cultivation practices alternatives for giant reed (Mavrogianopoulos *et al.*, 2002). The latter is further documented to have high tolerance to metals in the soils treated with sewage sludge (Papazoglou, 2007). Liquid manure application from pig farms as nitrogen substitute is an added value strategy for cardoon and sugar beet cultivation (Luger, 2003a; Draycott, 2006).

Concerning annual crops, rapeseed is documented for phytoextraction of heavy metals (Sheng *et al.*, 2008; Rossi *et al.*, 2002), although Marchiol *et al.* (2004) reported low phytoextraction potential. Batchelor *et al. (*1995) indicate that sewage sludge and animal excreta can be used as fertilizers on the plantations. Niu *et al.*, 2007 successfully used oilseed crops sunflower and Ethiopian mustard for phytoextraction of metals from sewage sludge. Bioremediation capabilities have also been suggested for hemp (Linger *et al*., 2002), flax (Bjelková *et al*., 2001; Grabowska and Baraniecki, 1997) and sweet sorghum (Epelde *et al.*, 2009).

Irrigation of wheat and potato plantations with waste water and sewage sludge was also demonstrated (Antonious *et al*., 2003; Dvořák *et al*., 2003) but may cause accumulation of metals (Abd-El-Fattah *et al.*, 2002; Dvořák *et al*., 2003) and contamination with pathogens (Amahmid, *et al.* 1999) in edible parts, hence compromising food quality. Despite the augmentation of heavy metals and faecal coliforms concentration in soil, treatments with MSWC (municipal solid waste compost) can be effective, with positive gains in wheat yields (Cherif *et al*., 2009). But, edible crops may face the problem of accumulation of chemicals and of biological contamination beyond accepted toxicity limits. In this case, the application of waste can only be taken into account if for non-food purposes, when relevant.

3.5. Biodiversity

Biodiversity impact assessment is highly site-specific once it analyzes the effect of the introduction of a crop and its management on the structure of ecological units and the development and use of an existing population (Biewinga and van der Bijl, 1996; Stlootweg and Kolhoff, 2003; Rodrigues *et al*., 2003). Landscape configuration and habitat richness have an impact on its community's diversity (Dauber *et al*., 2003). It is agreed that more complex structure and heterogeneity of a vegetation system have a positive influence on its cover value for wildlife (Smeets *et al*., 2009). Establishment of a monoculture as a replacement of natural diversified vegetation is a violation against biodiversity (Mattson *et al*., 2000; Bringezu *et al*., 2009). By definition, any natural vegetation type has the best performance concerning the ecosystem services and, consequently, biodiversity (Smeets *et al*., 2009). Hence, compared to a natural system even if fallow land, any energy crop will have negative effects, the more severe the farther the system shifts from the native conditions (Paine *et al*., 1996). The extension of these effects depends on crop traits, plantation location and its management system (McLaughlin and Walsh, 1998; Fragoso *et al*., 1997).

Local onset data and extensive and systematic reference studies for each crop species on biodiversity impact are not abundant. Most of the studies referenced in the literature are the ones related with

Miscanthus, switchgrass and SRF. A generic approach was implemented, although the analysis was subjective and often involved extrapolating knowledge of one species to its similar. Data was compiled through an extensive literature review and crops and crop-types were benchmarked towards fallow and towards each other in a qualitative way. Subsequently, biodiversity impact scores were attributed through the deliberation of the collected data.

In general, establishment of a monoculture (all crops studied) and aggressiveness of species (*Eucalyptus* spp and giant reed) outcome in a higher impact. Conversely, native species (cardoon and rapeseed) and colorful blossomed crops contribute to the biodiversity value. Globally, trees were considered richer in terms of biodiversity value and annual crops poorer. Perennial grasses were scored in between. The remaining variations in scoring are due to characteristics of the plants or of their cultivation practices and also to documented negative or positive impacts, either in the Mediterranean or in other European regions (figure 3.12).

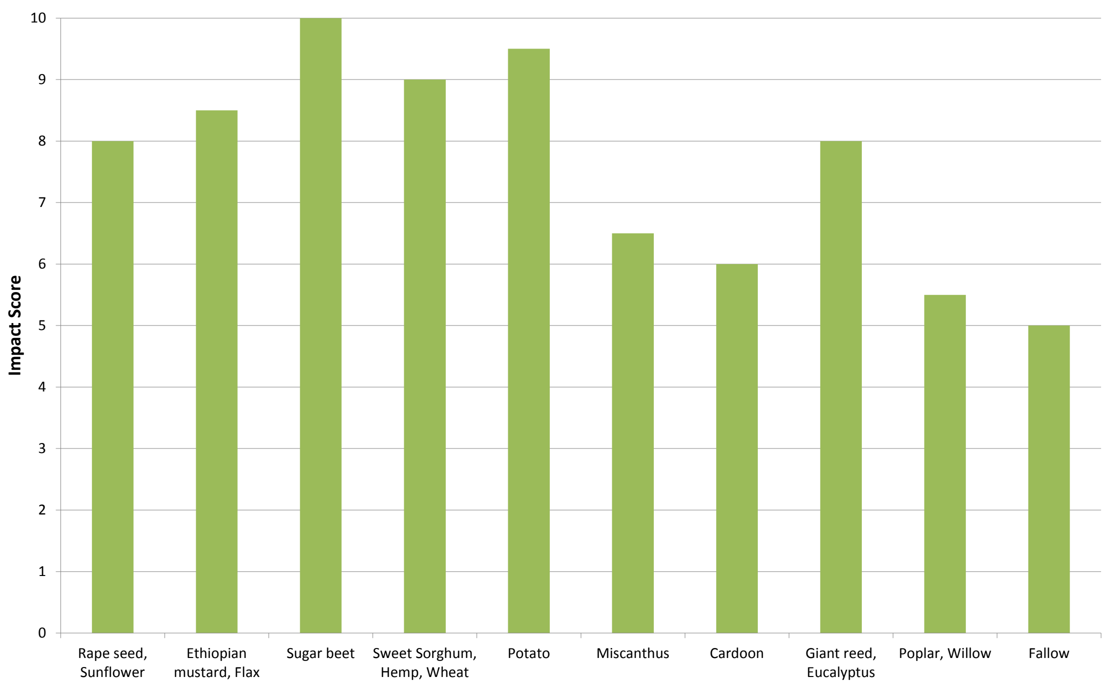

Figure 3.12. - Impact on biodiversity of each crop in the Mediterranean Europe.

Perennial rhizomatous grasses like *Miscanthus*, giant reed and cardoon require a reduced soil tillage and use of agrochemicals (as fertilizers, pesticides and herbicides), as it was abundantly referenced in former chapters. Owing to this little land disturbance compared to annual crops, perennial grasses crops have a high cover value for wildlife (Prochnow *et al*., 2009; Börjesson, 1999; Boehmel *et al*., 2008). These plants have a high above and belowground biomass, and as a consequence high soil organic matter content due to rhizome biomass accumulation and litter deposition. These conditions favor diversity and occurrence of soil microorganisms and soil fauna, especially decomposers such as earthworms, wood lice, harvestmen and carbides (Börjesson, 1999). Moreover, a late harvest, e.g. end of January, may provide an over-wintering site for invertebrates and shelter for birds and small mammals (Bellamy *et al*., 2009; Smeets *et al*., 2009; Semere and Slater, 2007a and 2007b).

Semere and Slater (2007a and 2007b) reported that the weed cover in *Miscanthus* fields increased the general invertebrate diversity of many orders and that *Miscanthus* cultivation supports more diversity and abundance than arable fields within the following biological groups: weed flora, ground beetles, butterflies, and arboreal invertebrates. Nonetheless, there are claims that *Miscanthus* support less biodiversity than SRF plantations (Rowe *et al*., 2009).

The aggressive behavior of giant reed leads to the replacement of other desired indigenous or cultured vegetation (DAISIE, 2009), especially when grown in monoculture and when subject to mismanagement. Hence, this crop was scored with higher impact than *Miscanthus*.

Native crops serve as a biodiversity-friendly feedstock, like the cardoon (native to the Mediterranean region) and rape seed, as they should have more benefits as habitat for native species than foreign options (Groom *et al*., 2008). Cardoon and rape seed further benefits from a period of inflorescence in its scoring.

Literature stresses that perennial grasses and tree plantations support more microfauna, soil fauna and bird species (Fragoso *et al*., 1997; Berg, 2002; Börjesson, 1999) than annuals. The biodiversity loss reported to annuals is due to short permanence on soil and thorough management, including high agrochemical inputs, ploughing and tillage and removal of litter soil cover (Mineau and McLaughlin, 1996; Fragoso *et al*., 1997; Berg, 2002). Consequently, these crops were scored with the highest impact when compared to trees and perennial grasses. However, annual crops that undergo a flowering period should attract insects and birds, increasing their diversity and numbers. Such has been reported in sunflower fields (Jones and Sieving, 2006) and is likely to happen in other colorful blossomed annual crops such as flax, rapeseed and Ethiopian mustard.

Sugar beet has the poorest performance, since it is a ground-hugging crop and its harvesting should be very destructive to soil fauna owing to the total removal of the plant. Wheat and potato share shortcomings of annual crops. Although potato bears inflorescence in its life cycle and is a well structured crop, it has a very short permanence on ground and its harvest is similar to sugar beet.

Poplar and willow increase bird species number and diversity and provide transitional habitats in farmland settings (Börjesson, 1999; Skärbäck and Becht, 2005; Rowe *et al*., 2009; Christian *et al*., 1997; Berthelot *et al*., 2005; Berg, 2002). The presence of SRF cultivation might have negative impact for changing the dynamics of local flora and fauna, increasing pests and creating shelter for predators (Paine *et al*., 1996; Börjesson, 1999). However, the overall effect is stated as negligible at a regional level to being a positive trade-off between productivity and species richness at a local level (Cannel, 1999; Ulrich *et al*., 2004). Their structure and longer life cycle awards these systems with higher biodiversity values than perennial herbaceous plantations (Rowe *et al*., 2009), for which they received a score closer to fallow.

Eucalyptus carries limitations in relation to the other trees, thus being rated with a poor score. Its aggressiveness has been thoroughly debated and results from the DAISIE Project (2009) report many species to be invasive in European countries. Besides, in a management-intensive system, the soil disturbance during preparation and harvest distress understory flora (Carneiro *et al*., 2009). Allelopathy further restricts the development of native vegetation (Sasikumar *et al*., 2001). Even so, some reports point to the prevalence of certain species and deny the reduction of specific diversity (Fabião *et al*., 2007).

3.6. Landscape

Anthropogenic alterations on the landscape may induce visual impact. Whether this impact is an enhancement or degradation determines gain or loss of value of this economical and environmental resource.

Landscape impact assessment was built based on a subjective analysis of know crop traits. By suggestion of Biewinga and van der Bijl (1996), the structure and colour were chosen as criteria to evaluate landscape. Fallow land was considered a standard and variation was assumed to be a deviation in landscape characteristics of the crop towards fallow.

The evaluation of structure included height, density, heterogeneity and openness of the crop. Significant variation of colour of the crop along its life cycle and/or presence of e.g. inflorescences, with distinct coloration, was another characteristic considered on the landscape impact assessment, being valued twice. Variation was considered to be a benefit when it embraced gains in structure and/or colour, consisting of an aesthetical enhancement, and differences implying loss of structure and/or colour debited the landscape values.

The impact on landscape values in even among crops (figure 3.13). The exception is sugar beet, a highly uniform and ground-hugging crop. The variation in structural richness that underlies the variation in biodiversity values motivates variation in landscape values as well. Gains are verified in blossoming crops (oilseed crops, cardoon, flax and potato). Trees and herbaceous perennials lose in openness and heterogeneity what they gain in height variation.

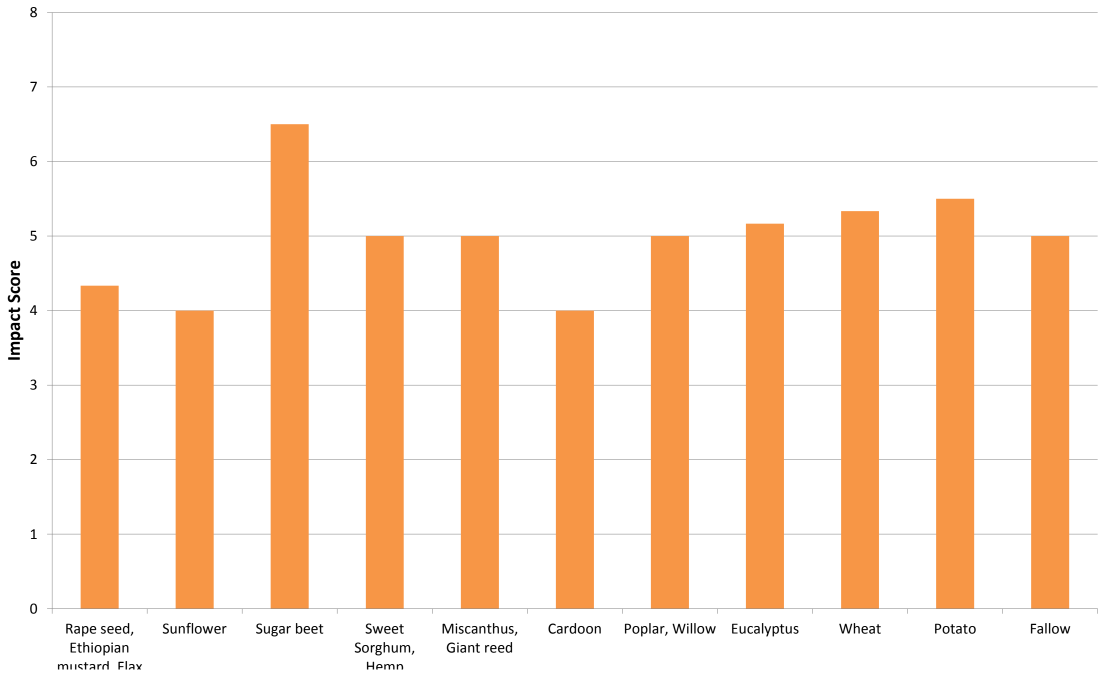

Figure 3.13. – Impact on landscape values of each crop, in the Mediterranean Europe.

3.7. Overall results

Figure 3.14 shows the overall environmental impact of the different energy crops studied, in the Mediterranean.

The most remarkable observation to emerge from the data is the lower overall impact of lignocelullosic and woody crops when comparing to annual species. But annuals can play an important role in crop rotations, for example with cereals, a feature that perennials cannot defend, and this is an important and positive characteristic that was not considered in the assessment. Among perennials no significant differences were observed. Among the annual species, potato and sugar beet present the highest impact. All the other annual systems were more or less even.

All the studied crops present higher overall environmental impact than fallow, but, less impact than potato and, except sugar beet, than wheat as well. Therefore, the results suggest that cultivating energy crops would not cause extra harm on the environment (regarding the studied categories) by comparison with potato and wheat farming. In contrast, cultivating them in fallow land displays an increased impact. Regarding this subject, concerns related to the impact of land use change should also be considered. These and other issues such as socioeconomic analysis and crop rotation fall out of the scope of this study, and would sustain relevant future research.

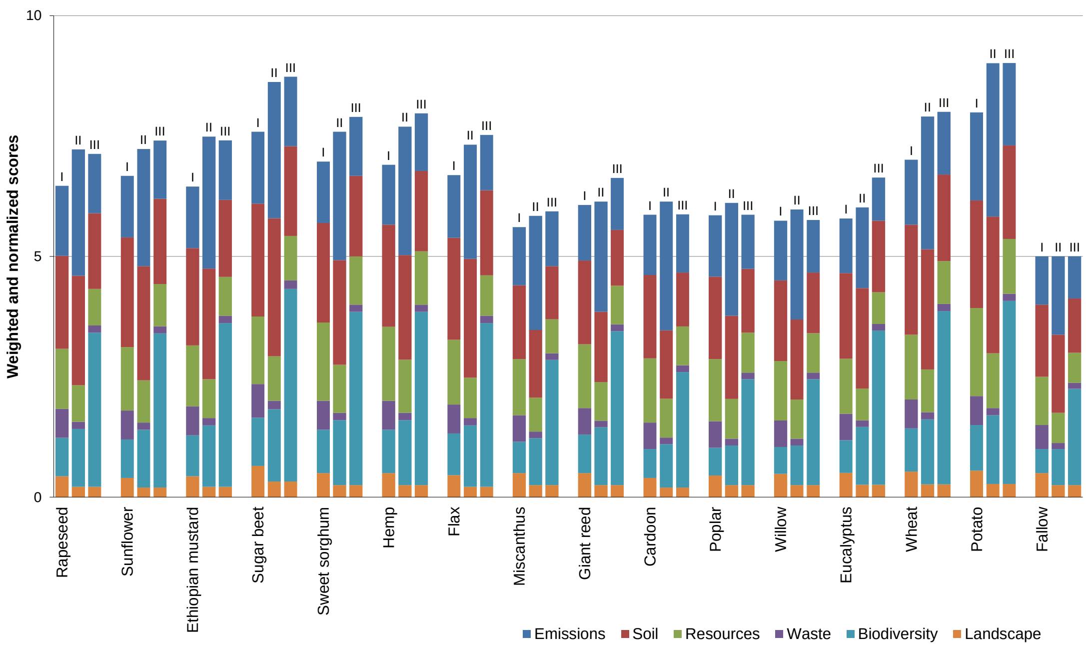

Figure 3.14. - Final environmental impact assessment of energy crops cultivation in the Mediterranean Europe (I – WS1; II – WS2: III – WS3).

Application of the weighting step aggravates the impact of all crops, albeit more evident with annuals. Emphasis on biodiversity (WS3) in detriment to GHG emission drivers (WS2) inflicts a higher impact, except with rapeseed, Ethiopian mustard, cardoon, poplar and willow. Noticeably, the more aggressive crops, giant reed and *Eucalyptus*, showed the most distinct rise between WP2 and WP3. However, if crops were to be sorted according to their performance, weighting would not significantly influence their relative position.

Results on the impact on soil marked the WS1 results, emissions to soil, air and water, the WS2 results and biodiversity the WS3 results, this, of course, due to the influence of the weighting factors applied. Caution must be applied, nonetheless, when the results rely on quantified ranges dependent upon the intensity level of inputs. The wider the range, the more pertinent is the suggestion that impact can be reduced if fertilizers and pesticides are applied in a moderate manner. Still, other than implying less room for optimization, narrower ranges might indicate fewer available data, since the results arise from literature surveys. Further, we verified N and K soil depletion, which indicates that reducing fertilizers would stress nutrient soil reserves. This fact is even more pertinent considering that some of the studied crops have not yet been upscaled to a commercial level in Europe. Upscaling of new crops in Europe can also induce an increment of pesticides use due to the emergence of new pests and diseases. However their impact can be minored if pesticides with reduced toxicity are selected.

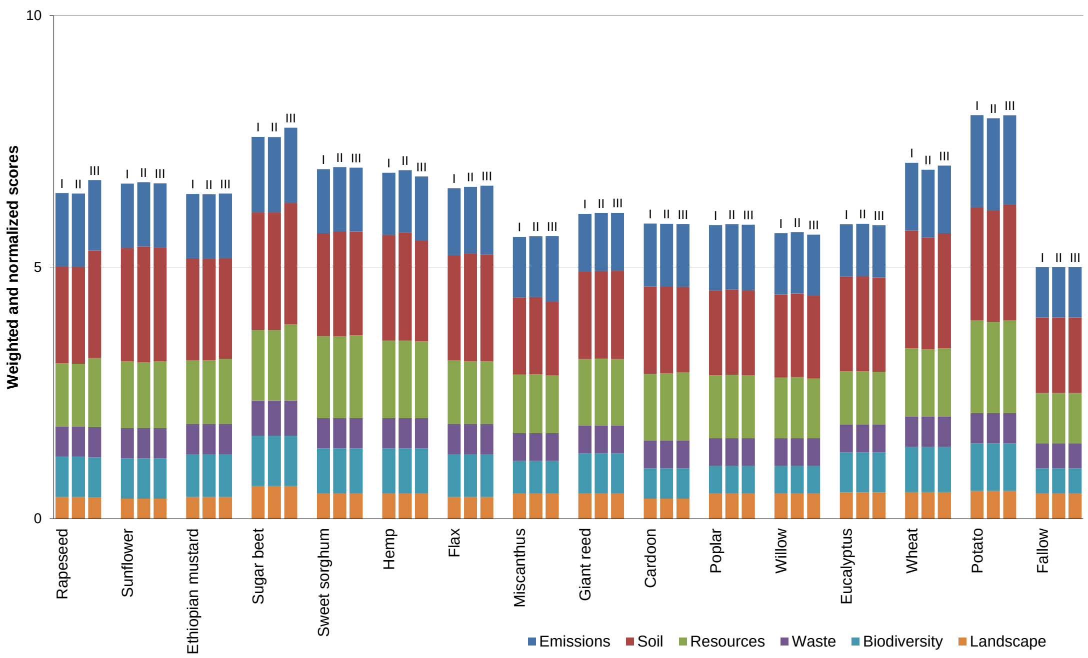

Figure 3.15. – Final environmental impact assessment of energy crops cultivation in the Mediterranean Europe regions studied and in Europe (I – Mediterranean North; II – Mediterranean South; III – Europe, data from Europe withdrawn from Fernando *et al.*, 2010b).

Differences between results obtained in the two Mediterranean regions studied were not significant (figure 3.15). Groundwater balance indicator favors Mediterranean North but soil erosion indicator penalizes the same region, counterbalancing the overall calculus. The higher gap, while minimum, between North and South regions was observed with wheat, a crop that presented a better overall environmental impact in Mediterranean South.

Furthermore, differences between Mediterranean regions and average results obtained in Europe (Fernando *et al.*, 2010b), were not significant either (figure 3.15). Rapeseed and sugar beet were the crops that showed higher, but minimal, differences between Mediterranean regions and Europe. Better results were obtained with these crops in the Mediterranean because they were considered as winter crops, by contrast to the study used for comparison (Fernando *et al.*, 2010b), where these crops were allocated to northern regions and studied as spring crops (except rapeseed that among other regions was also studied in Lusitanian, as a winter crop).

This supports the indication that, although the impact of a crop is site specific, as long as cultivation is allocated properly, the overall environmental impact will differ depending upon crop management options.

4. CONCLUSIONS AND FUTURE WORK

This study provides a generic outline on the expected environmental consequences of cultivating a set of energy crops in the Mediterranean Europe regions. Results suggest that growing energy crops do not cause higher disturbance to the environment comparing to potato and wheat farming (regarding the studied categories). The assessed impact pathways rely mostly on management intensity and crop traits. Annual cropping systems (oil, sugar, fiber and food) are more management intensive than the remaining types, since they require more inputs and land intervention, build up less biomass and have shorter permanence periods. Thus they have a more negative impact on the environment than lignocellulosic and woody species. Annual crops do stand out as being more burdening than the remaining types regarding erodibility and biodiversity. Annual systems and woody crops are also more damaging to soil quality than herbaceous perennials. However, differences among crop types are not as evident in the remaining indicators. Further, each crop type often contains uneven outcomes among species, consequence of the crop traits but also on crop management options.

Impact reduction strategies are limited to crop management choices which can influence emissions, nutrient status and mineral ore depletion. All other impacts are site specific dependent, intertwined with crops traits. Therefore, the implementation of impact-lean agro-energy-systems should be based also on the adequacy between crop and location. For that, adding to the generic trends we hereby set, decision makers and stakeholders should assess site-specific factors (e.g. on-field emission fluxes, quality assessment of soil and groundwater, effect on local biodiversity and landscape).

Some of the indicators used in this analysis have showed significant limitations due to insufficient data, like biodiversity studies and soil quality studies. So, it is suggested by this study that future work on this subject should be anchored on more experimental field data.

5. REFERENCES

Abbasi, T. and Abbasi, S.A. (2010). Biomass energy and the environmental impacts associated with its production and utilization. *Renewable and Sustainable Energy Reviews*, 14, pp 919-937.

Abd-El-Fattah, A.; Shehata S.M. and Talab, A.S. (2002). Evaluation of irrigation with either raw municipal sewage river water on element uptake and yield of lettuce and potato plants. *Egyptian Journal of Soil Science*, 42, pp 705-714.

Ačko, D.K. and Trdan, S. (2008). Influence of row spacing on the yield of two flax cultivars (*Linum usitatissimum* L.). *Acta agriculturae Slovenica*, 91, pp 23-35.

Alexandrov, G.A. (2007). Carbon stock growth in a forest stand: the power of age. *Carbon Balance and Management,* 2 (doi: doi:10.1186/1750-0680-2-4).

Alexopoulou, E.; Chatziathanassiou, A.; Panoutsou, C.; Koutoukidis, A.; Tsakiris, S. and Drimaki, E. (2001). Yields and public perception of sweet sorghum growth in demonstrative fields of northern Greece. In: Kyritsis, S., Beenackers, A.A.C., Helm, P., Grassi, A., Chiaramonti, D. (eds) *Biomass for Energy and Industry - Proceedings of the 1st World Conference*, 5-9 June 2000, Seville, Spain, James & James (Science Publishers) Ltd, London, United Kingdom, 2, pp 1638–1641.

Amaducci, S.; Amaducci, M.T.; Benati, R. and Venturi, G. (2000). Crop yield and quality parameters of four annual fibre crops (hemp, kenaf, maize and sorghum) in the North of Italy. *Industrial Crops and Products*, 11, pp 179-186.

Amaducci, S.; Zatta, A.; Pelatti, F. and Venturi, G. (2008). Influence of agronomic factors on yield and quality of hemp (*Cannabis sativa* L.) fibre and implication for innovative production system, *Field Crops Research,* 107, pp 61-169.

Amahmid, O,; Asmama, S. and Bouhoum, K. (1999). The effect of wastewater reuse in irrigation on the contamination level of food crops by *Giardia* cysts and *Ascaris* eggs. *International Journal of Food Microbiology,* 49, pp 19-26.

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

Angelini, L.G.; Ceccarini, L.; di Nasso, N. and Bonari, E. (2007). Long term evaluation of biomass production and quality of two cardoon (*Cynara cardunculus* L.) cultivars for energy use. In: Maniatis, K, Grimm, H.P., Helm, P., Grassi, A. (eds) *Proceedings of the 15th European Biomass Conference & Exhibition, From Research to Market Development* - 7-11 May 2007, ICC, Berlin, Germany, ETA-Renewable Energies and WIP-Renewable Energies, pp 622-627.

Angelini, L.G.; Ceccarini, L.; Di Nasso, N. N. and Bonari, E. (2009). Comparison of *Arundo donax L.* and *Miscanthus x giganteus* in a long-term field experiment in Central Italy: Analysis of productive characteristics and energy balance, *Biomass and Bioenergy*, 33, pp 635–643.

Angers, D.A. and Caron, J. (1998). Plant-induced changes in soil structure: processes and feedbacks. *Biogeochemistry*, 42, pp 55-72.

Antonious, G.F.; Patterson, M.A .and Snyder, J.C. (2003). Pesticide residues in soil and quality of potato grown with sewage sludge. *Bulletin of environmental contamination and toxicology*, 71, pp 315-322.

Ardente, F.; Beccali, M.; Cellura, M. and Mistretta, M. (2008). Building energy performance: A LCA case study of kenaf-fibres insulation board. *Energy and Buildings* 40, pp 1–10.

Arrobas, M. and Rodrigues, M.A. (2009). Efeito da adubação azotada, fosfatada e potássica na cultura da batata: produtividade e eficiência de uso dos nutrientes. *Revista de Ciências Agrárias*, 32, pp 101-111 (in portuguese).

Atkinson, C.J. (2009). Establishing perennial grass energy crops in the UK: A review of current propagation options for *Miscanthus*. *Biomass and Bioenergy*, 33, pp 752-759.

Basso, B.; Sartori, L.; Bertocco, M.; Cammarano, D.; Martin, E.C. and Grace, P.R. (2011). Economic and environmental evaluation of site-specific tillage in a maize crop in NE Italy. *European Journal of Agronomy*, 35, pp 83-92.

Batchelor, S.E.; Booth, E.J. and Walker, K.C. (1995). Energy analysis of rape methyl ester (RME) production from winter oilseed rape. *Industrial Crops and Products*, 4, pp 193-202.

Bauen, A.; Berndes, G.; Junginger, M.; Londo, M. and Vuille, F. (2009). *Bioenergy - a sustainable and reliable energy source. A review of status and prospects*, IEA Bioenergy. Available at: http://www.ieabioenergy.com/LibItem.aspx?id=6479 (accessed: August 2011).

Bellamy, P.; Croxton, P.; Heard, M.; Hinsley, S.; Hulmes, L.; Hulmes, S.; Nuttall, P.; Pywell, R. and Rothery, P. (2009). The impact of growing miscanthus for biomass on farmland bird populations. *Biomass and Bioenergy*, 33, pp 191 –199.

Berg, Å (2002) Breeding birds in short-rotation coppices on farmland in central Sweden—the importance of *Salix* height and adjacent habitats. *Agriculture, Ecosystems and Environment,* 90, pp 265-276.

Bernesson, S.; Nilsson, D. and Hansson, P.A. (2004). A limited LCA comparing large-and small-scale production of rape methyl ester (RME) under Swedish conditions. *Biomass and Bioenergy,* 26, pp 545-559.

Berthelot, A.; Augustin, S.; Godin, J. and Decocq, G. (2005). Biodiversity in poplar plantations in the Picardie region of France. *Unasylva-FAO*, 221, pp 18-19.

Best, G. (2004). Bioenergy, the key renewable. In: Seventh Central European Initiavive summit Economic Forum. 24-26 November 2004, Portoroz, Slovenia. Available at: http://www.fao.org/sd/dim_en2/bioenergy/docs/policy3_en.pdf (accessed: July 2011).

Biewinga, E.E. and van der Bijl, G. (1996) *Sustainability of energy crops in Europe. A methodology developed and applied*. Centre for Agriculture and Environment, Utrecht, February, CLM 234 - 1996, 209 p.

Bjelková, M.; Tejklová, E.; Griga, M.; Zajíková, I. and Genurová, V., (2001). Flax, linseed and hemp in phytoremediation, *Natural Fibres (Poznan) – Special Edition: Proc. 2nd Global Workshop Bast Plants in the New Millennium*, Borovets, Bulgaria, p. 285.

Boehmel, C.; Lewandowski, I.; Claupein, W. (2008) Comparing annual and perennial energy cropping systems with different management intensities. *Agricultural Systems*, 96, pp 224-236.

Bohn, H.; McNeal, B. and O'Connor, G. (2001). *Soil Chemistry* – second edition. John Wiley & Son, 260 p.

Bona, K.A.; Burgess, M.S.; Fyles, J.W. and Camiré, C. (2008). Weed cover in hybrid poplar (*Populus*) plantations on Quebec forest soils under different lime treatments *Forest Ecology and Management*, 255, pp 2761–2770.

Börjesson, P. (1999). Environmental effects of energy crop cultivation in Sweden—I: identification and quantification. *Biomass and Bioenergy*, 16, pp 137-154.

Bös, H. and Elbersen, W. (2008).WP 1.3 Identification of market demand for non-food crops. In: Kick off meeting, Brussels, 1 April 2008, 4F Crops – Future Crops for Food, Feed, Fiber and Fuel. 29 p.

Bouwman, L.A. and Arts, W.B.M. (2000). Effects of soil compaction on the relationships between nematodes, grass production and soil physical properties. *Applied Soil Ecology*, 14, pp 213–222.

Brandão, M.; Canals, L.M. and Clift, R. (2011). Soil organic carbon changes in the cultivation of energy crops: Implications for GHG balances and soil quality for use in LCA. *Biomass and Energy*, 35, pp 2323-2336.

Bringezu, S.; Schutz, H.; Brien, M.O.; Kauppi, L.; Howarth, R.W.; McNeely, J. and Otto, M. (2009). *Assessing Biofuels*. UNEP, 120 p.

Bullard, M. and Metcalfe, P. (2001) *Estimating the energy requirements and CO_2 emissions from production of the perennial grasses Miscanthus, Switchgrass and Reed canary grass*. ETSU Report Number B/U1/00645/REP. DTI/Pub URN 01/797, Contractor ADAS Consulting Ltd. 94 pp

Calado, J.; Basch, G. and Carvalho, M (2008) Effect of the sowing date on bread wheat (*Triticum aestivum* L.) productivity under mediterranean conditions. *Revista de Ciências Agrárias*, 31, pp 139-151.

Calzoni, J.; Caspersen, N.; Dercas, N.; Gaillard, G.; Gosse, G.; Hanegraaf, M.; Heinzer, L.; Jungk, N.; Kool, A.; Korsuize, G.; Lechner, M.; Leviel, B.; Neumayr, R.; Nielsen, A.M.; Nielsen, P.H.; Nikoalaouf, A.; Panautsou, C.; Panvini, A.; Patyk, A.; Rathbauer, J.; Rienhardt, G.A.; Riva, G.; Smedile, E.; Stettler, C.; Pedersen, B.; Wörgetter and van Zeijts, H. (2000). *Bioenergy for Europe: which ones fit best? – A comparative analysis for the community. Final Report.* IFEU – Institut für Energie und Umweltforschung Heidelberg GmbH, Heidelberg, Germany, 178 p..

Cannell, M.G.R. (1999). Environmental impacts of forest monocultures: water use, acidification, wildlife conservation, and carbon storage. *New Forests*, 17, pp 239-262.

Cannell, M.G.R. (2003). Carbon sequestration and biomass energy offset: theoretical, potential and achievable capacities globally, in Europe and the UK. *Biomass and Bioenergy*, 24, pp 97-116.

Cardone, M.; Mazzoncini, M.; Menini, S.; Rocco, V.; Senatore, A.; Seggiani, M. and Vitolo, S. (2003). *Brassica carinata* as an alternative oil crop for the production of biodiesel in Italy: agronomic evaluation, fuel production by transesterification and characterization. *Biomass and Bioenergy*, 25, pp 623 – 636.

Carneiro, M.; Fabião, A.; Martins, M.C.; Fabião, A.; Abrantes da Silva, M.; Hilário, L.; Lousã, M. and Madeira, M. (2008). Effects of harrowing and fertilisation on understory vegetation and timber production of a *Eucalyptus globulus* Labill. plantation in Central Portugal. *Forest Ecology and Management*, 255, pp 591–597.

Carneiro, M.; Serrão, V.; Fabião, A.; Madeira, M.; Balsemão, I. and Hilário, L. (2009). Does harvest residue management influence biomass and nutrient accumulation in understory vegetation of *Eucalyptus globulus* Labill. plantations in a Mediterranean environment?. *Forest Ecology and Management*, 257, pp 527-535.

Casa, R.; Russell, G.; Lo Cascio, B. and Rossini, F. (1999). Environmental effects on linseed (*Linum usitatissimum* L.) yield and growth of flax at different stand densities. *European journal of agronomy*, 11, pp 267-278.

Ceotto, E. (2006); La canna commune, una piñata adatta per ottenere energia. *Agricoltura,* 6, pp 80-82.

Cherif, H.; Ayari, F.; Ouzari, H.; Marzorati, M.; Brusetti, L.; Jedidi, N.; Hassen, A.and Daffonchio, D. (2009). Effects of municipal solid waste compost, farmyard manure and chemical fertilizers on wheat growth, soil composition and soil bacterial characteristics under Tunisian arid climate. *European Journal of Soil Biology*, 45, pp 138-145.

Christian, D.G. and Riche, A.B. (1998). Nitrate leaching losses under Miscanthus grass planted on a silty clay loam soil. *Soil use and management*, 14, pp 131-135.

Christian, D.G.; Riche, A.B. and Yates, N.E. (2008). Growth, yield and mineral content of *Miscanthus* × *giganteus* grown as a biofuel for 14 successive harvests. I*ndustrial Crops and Products,* 28, pp 320-327.

Christian, D.P.; Collins, P.T.; Hanowski, J.M. and Niemi, G.J. (1997). Bird and Small Mammal Use of Short-Rotation Hybrid Poplar Plantations. *The Journal of Wildlife Management*, 61, pp 171-182.

Christou, M.; Fernandez, J.; Gosse, G.; Venturi, G. Bridgwater, A.; Scheurlen, K.; Obernberger, I.;. van be Beld, B.; Soldatos, P. and Reinhardt, G. (2004) Bio-energy chains from perennial crops in South Europe. In: Van Swaaij, W.P.M., Fjällström, T., Helm, P., Grassi, A. (eds) *Biomass for Energy, Industry and Climate Protection - Proceedings of the 2nd World Biomass Conference*, 10-14 May 2004, Rome, Italy, ETA-Florence e WIP-Munich, pp 604-607.

Clark, R.B.; Zeto, S.B. and Zobel, R.W. (1999). Arbuscolar mycorrhizal fungal isolate effectiveness on growth and root colonization of *Panicum virgatum* in acid soil. *Soil Biology and Biochemistry*, 31, pp 1757-1763.

Colomb, B.; Debaeke, P.; Jouany, C. and Nolot, J.M. (2007). Phosphorus management in low input stockless cropping systems: Crop and soil responses to contrasting P regimes in a 36-year experiment in southern France. *European Journal of Agronomy*, 26, pp 154-165.

Croezen, H.; Bergsma, G.; Otten M. and van Valkengoed, M. (2010). *Biofuels: indirect land use change and climate impact*. Report prepared for BirdLife International, Transport & Environment and European Environment Bureau. Available at: http://www.ce.nl/publicatie/biofuels%3A_indirect_land_use_change_and_climate_impact/1068 (accessed: August 2011).

Crutzen, P.J.; Mosier, A.R.; Smith, K.A. and Winiwarter, W. (2008) N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics,* 8, pp 389–395.

Curt, M. D.; Aguado, P.; Sanz; Sánchez, G. and Fenández, J. (2006). Clone precocity and the use of *Helianthus tuberosus* L. stems for bioethanol. *Industrial Crops and Products*, 24, pp 314–320.

Curt, M. D.; Fernández, J. and Martínez, M. (1995). Productivity and water use efficiency of sweet sorghum (*Sorghum bicolor* (L.) Moench) cv."Keller" in relation to water regime. *Biomass and Bioenergy*, 8, pp 401-409.

DAISIE (2009). *Delivering Alien Invasive Species In Europe Project*: www.europe-aliens.org (accessed: February 2009).

Dalianis, C.; Sooter, C. and Christou, M. (1995). Growth, biomass and productivity of *Arundo donax* and *Miscanthus sinensis 'giganteus'*. In: Chartier et al. (eds) *Biomass for energy, environment, agriculture and industry*. Proceedings of the 8th EU Biomass Conference, Pergamon Press, UK, vol. 1, pp 575-582.

Dauber, J.; Hirsch, M.; Simmering, D.; Waldhardt, R.; Otte, A. and Wolters, V. (2003). Landscape structure as an indicator of biodiversity: matrix effects on species richness. *Agriculture, Ecosystems and Environment*, 98, pp 321-329.

Delogu, G.; Cattivelli, L.; Pecchioni, N.; De Falcis, D.; Maggiore, T. and Stanca, A.M. (1998). Uptake and agronomic efficiency of nitrogen in winter barley and winter wheat. *European Journal of Agronomy*, 9, pp 11-20.

di Muzio Pasta, V.; Negri, M.; Facciotto, G.; Bergante, S. and Maggiore, T.M. (2007). Growth dynamics and biomass production of 12 poplar and 2 willow clones in a short rotation coppice in Northern Italy. In: Maniatis, K, Grimm, H.P., Helm, P., Grassi, A. (eds) *Proceedings of the 15th European Biomass Conference & Exhibition, From Research to Market Development*, 7-11 May 2007, ICC, Berlin, Germany, ETA-Renewable Energies and WIP-Renewable Energies, pp 749-754.

di Nasso, N.; Tozzini, C.; Guidi, W.; Ragaglini, G. and Bonari, E. (2009). Sustainability of energy sustainability of energy cropping system in the Mediterranean area: comparison between giant reed (*Arundo donax* L.) and poplar (*Populus deltoides* Bart.) SRC in a long-term field experiment in Central Italy. In: De Santi, G.F., Dallemand, J.F. Ossenbrink, H., Grassi, A., Helm, P. (eds) *Proceedings of the 17th European Biomass Conference and Exhibition, From Research to Industry and Markets*. 29 June - 3 July 2009, Hamburg, Germany, ETA-Renewable Energies and WIP-Renewable Energies, pp 145-147.

Diamantidis, N.D. and Koukios, E.G. (2000). Agricultural crops and residues as feedstocks for non-food products in Western Europe. *Industrial Crops and Products,* 11, pp 97–106.

Dias, A.S.; Fernando, A.L. and Lidon, F. C. (2009). III. Heat stress in Triticum: kinetics of Na, K and P accumulation. *Brazilian Journal of Plant Physiology*, 21, pp 143-152.

Directive 2009/28/EC (2009). Directive of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union,* L140, pp 16–62.

Dores, J.; Patanita, M.; Parreira, A.; Moura, F. and Muñoz-Guerra, L.M. (2008). Estratégias de fertilização azotada em trigo – adubos convencionais versus adubos com inibidor de nitrificação: www.esab.ipbeja.pt (accessed: March 2010), (in portuguese).

Dornburg, V.; Faaji, A.; Verweij; Langsveld, H.; van de Ven, G.; Wester, F.; van Keulen, H.; van Diepen, K.; Meeusen, M.; Banse, M.; Ros, J.; van Vuuren, D.; van den Born, G.J.; van Oorschot, M.; Smout, F.; van Vliet, J.; Aiking, H.; Londo, M.; Mozaffarian, H.; Smekens, K. (2008). *Biomass Assessment: Assessment of global biomass potentials and their links to food, water, biodiversity, energy demand and economy.* Main report. 108 p.. Available at: Available at: http://www.ieabioenergy.com/LibItem.aspx?id=6479 (accessed: August 2011).

Draycott, A.P. (2006). *Sugar Beet*. Blackwell Publishing, UK.

Draycott, A.P. and Christenson, D.R. (2003). Nutrients for Sugar Beet Production: Soil-Plant Relationships. CABI Publishing, United Kingdom. 272 p.

Duarte, M.P.; Fernando, A.L.; Guimarães, H.; Amparo, V.; Alves, L. and Oliveira, J.F.S. (2001). Study of Sweet and Fibre Sorghum crops in Portugal. Effect of climatic conditions and sowing date on the final productivity and on the quality of biomass. In: Kyritsis, S., Beenackers, A.A.C., Helm, P., Grassi, A., Chiaramonti, D. (eds) *Biomass for Energy and Industry - Proceedings of the 1st World Conference*, 5-9 June 2000, Seville, Spain, James & James (Science Publishers) Ltd, London, United Kingdom, 1, pp 361-364.

Duggan, J. (2005). The potential for landfill leachate treatment using willows in the UK - A critical review. *Resources, Conservation and Recycling*, 45, pp 97–113.

Dvořák, P.; Tlustoš, P.; Száková, J.; Černý, J. and Balík, J. (2003). Distribution of soil fractions of zinc and its uptake by potatoes, maize, wheat and barley after soil amendment by sludge and inorganic Zn salt. *Plant Soil Environment*, 49, pp 203-212.

EAWAG (2009). *Project SEA - Observation of the metabolism of the anthroposphere*: www.sea.eawag.ch (accessed: September 2009).

EC – European Comission (2001). *Environment 2010: Our Future, our choice*. 6th EU Environment Action programme, 2001-2010. European Commission, Luxembourg,14 p.

EC (2001). *Environment 2010: Our Future, our choice*. 6th EU Environment Action programme, 2001-2010. European Commission, Luxembourg, 14 p.

EC/JRC (2010). Interpolated meteorological data Source JRC/MARS - Meteorological Data Base, European Commission – Joint Research Centre.

EC-JRC; EEA;CENER Spain; CIEMAT Spain (2006). Sustainable Bioenergy cropping systems in the Mediterranean. In: Proceedings of the Expert Consultation,9-10 February 2006, Ministry of Environment, Madrid, Spain.Available at: http://acm.eionet.europa.eu/docs/meetings/060209_ExpertConsult_Sust_Bioen_Medit/05_Proceedings_Bioen_Medit_WS060209.pdf (accessed: August 2011).

EEA (2005). *Agriculture and Environment in EU-15 – the IRENA indicator report*. Report No 6/2005. European Environment Agency. Copenhagen, Denmark, 128 p.. Available at: *Agriculture and Environment in EU-15 – the IRENA indicator report*. Report No 6/2005. (accessed: July 2011).

EEA (2006). How much bioenergy can Europe produce without harming the environment? Report No 7/2006. European Environment Agency. Copenhagen, Denmark, 67 p.. Available at: http://www.eea.europa.eu/publications/eea_report_2006_7 (accessed: July 2011).

EEA (2007). Estimating the environmentally compatible bioenergy potential from agriculture, EEA Report 12/2007. European Environment Agency. Copenhagen, Denmark, 134 p.. Available at: http://www.eea.europa.eu/publications/technical_report_2007_12 (accessed: August 2001).

EEA (2008). Maximising the environmental benefits of Europe´s bioenergy potential. EEA Report 10/2008. European Environment Agency. Copenhagen, Denmark, 94 p.. Available at: http://www.eea.europa.eu/publications/technical_report_2008_10 (accessed: August 2011).

EEA (2009). Water resources across Europe — confronting water scarcity and drought. EEA Report 2/2009. European Environment Agency, Copenhagen, Denmark, 55 p.. Available at: http://www.eea.europa.eu/publications/water-resources-across-europe (accessed: August 2011).

El Bassam, N. (1996). Performance of C_4 plant species as energy sources and theirs possible impact on environment and climate. In: Chartier, P.; Ferrero, G.L.; Henius, U.M.; Hultberg, S.; Sachau, J. And Wiinblad, M. (eds.). *Biomass for Energy and the Environment – Proceedings of the 9th European Bioenergy Conference*, 24 – 27 June 1996, Copenhagen, Denmark, Elsevier Science Ltd., Oxford, 1, pp 42-47.

El Bassam, N. (1998). *Energy Crop species: their use ans impact on the environment and development.* James & James (Science Publishers) Ltd, London, United Kingdom, 321 p.

El Bassam, N. (2010). *Handbook of Bioenergy crops - A complete reference to species, development and applications*. London, United Kingdom: Earthscan, Ltd., 516 p.

Elbersen, W.; van der Zee, M. and Bos, H. (2010) Strategies for successful establishment of 4F Crops. In: *Final Workshop of the 4F Crops project*, FCT/UNL, 19 November, Lisbon, Portugal. Available at: http://www.4fcrops.eu/pdf/Lisbon/elbersen.pdf (accessed: July 2011).

Epelde, L.; Mijangos, I.; Becerril, J.M. and Garbisu, C. (2009). Soil microbial community as bioindicator of the recovery of soil functioning derived from metal phytoextraction with sorghum. *Soil Biology and Biochemistry*, 41, pp 1788-1794.

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

Eurostat (2007). *The use of plant protection products in the European Union: Data 1992-2003*. Eurostat Statistical Books, 215 pp

Eurostat (2010). *Statistics database*: http://eppeurostat.ec.europa.eu/portal/page/portal/statistics/search_database (accessed February 2010).

EXTOXNET (2009). *Extension Toxicology Network – Pesticides information profiles*: http://extoxnet.orst.edu/pips/ghindex.html (accessed: September 2009).

Faaij, A.P.C. and Domac, J. (2006). *Emerging international bio-energy markets and opportunities for socio-economic development.* Energy for Sustainable Development, X (1), pp 7 - 19. ERAB. (1980). *Gasohol Report of the Gasohol study group*.

Fabeiro, C, de Santa Olalla, JF and de Juan, JA (2001)Yield and size of deficit irrigated potatoes. *Agricultural Water Management,* 48, pp 255-266.

Fabeiro, C., Martín de Santa Olalla , F., Lopez, R. and Domınguez, A. (2003) Production and quality of the sugar beet (*Beta vulgaris* L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate, *Agricultural Water Management,* 62, pp 215-227.

Fabião, A.; Carneiro, M.; Lousã, M. and Madeira, M. (2007). Os impactes do eucaliptal na biodiversidade da vegetação sob coberto. *In:* Alves, A.M.; Pereira, J.S. e Silva, J.M.N. eds. - *O eucaliptal em Portugal: impactes ambientais e investigação científica*. pp 177 – 206.

Fangmeier, A.; De Temmerman, L.; Black, C.; Persson, K. and Vorne, V. (2002). Effects of elevated CO_2 and/or ozone on nutrient concentrations and nutrient uptake of potatoes. *European Journal of Agronomy*, 17, pp 353-368.

FAO (2003). *Biological management of doil ecosystems for sustainable agriculture*. *Report of the International Technical Workshop.* Londrina, Brazil, 24-27 June 2002. FAO, Rome, Italy, 25 p. Available at: ftp://ftp.fao.org/agl/agll/docs/wsrr101.pdf (accessed: July 2011).

FAO (2010). *FAO Water*. Development Management Unit. Available at: http://www.fao.org/nr/water/# (accessed: February, 2010).

FAO (2007). *FertiStat - Fertilizer use by crops statistics*, Available at: http://www.fao.org/ag/agl/fertistat/fst_fubc_en.asp (accessed February 2010).

FAO (2007a). *Pesticide residues in food 2007:* Joint FAO/WHO Meeting on Pesticide Residues. FAO/WHO, Rome.

FAO (2009). *FAO Specifications and Evaluations for Plant Protection Products*: www.fao.org (accessed: September 2009).

FAO (Food and Agriculture Organization of the United Nations), IFA (International Fertilizer Industry Association), IFDC (International Fertilizer Development Center), IPI (International Potash Institute) and PPI (Phosphate and Potash Institute) (2002). *Fertilizer use by crop*. 5th edition; Rome.

Fargione, J.; Hill, J.; Tilman, D.; Polasky, S. and Harthrone, P. (2008). Land clearing and the biofuel carbon debt. *Science*, 319, pp 1235-1238.

Ferguson, A.W.; Fitt, B.D.L. and Williams, I.H. (1997). Insect injury to linseed in south-east England. *Crop Protection*, 16, pp 643-652.

Fernández, J. (2006). Los cultivos energéticos en España y las tendencias de su desarrollo. *In:* I *International Congress Bioenergia*. Valladolid, Spain, October 2006, pp 18-20.

Fernández, J.; Curt, M. and Aguado, P. (2006). Industrial applications of *Cynara cardunculus L.* for energy and other uses. *Industrial Crops and Products*, 24, pp 222–229.

Fernández, J.; Curt, M.D. and Hidalgo, M. (1996). Nutrient extraction by the harvestable biomass of *Cynara cardunculus* L. In: Chartier, Ph., Ferrero, G. L., Henius, U. M., Hultberg, S., Sachau, J. and Wiinblad, M. (eds) *Biomass for Energy and the Environment - Proceedings of the 9th European Conference*, 24-27 June 1996, Copenhagen, Denmark, Pergamon Press, London, United Kingdom, 1, pp 467-472.

Fernando A.L., Bastos, C. and Mendes, B. (2010a) Can the region ofAlgarve, in Portugal, be self sustained energetically? In: Spitzer, J.,Dallemand, J.F., Baxter, D., Ossenbrink, H., Grassi, A., Helm, P. (eds) *Proceedings of the 18th European Biomass Conference and* Exhibition, from Research to Industry and Markets. 3-7 May 2010, Lyon, France, ETA-Renewable Energies and WIP-Renewable Energies, pp 340-341.

Fernando, A.; Duarte, M.P.; Morais, J.; Catroga, A.; Serras, G.; Lobato, N.; Mendes, B. and Oliveira, J.F.S. (2007). *Final report of FCT/UNL to the Biokenaf project,* FCT/UNL, Lisbon, Portugal, 44 p.

Fernando, A.; Duarte, M.P. and Oliveira, J.F.S. (2001). Some aspects of Environmental Impact assessment of Sweet and Fibre Sorghum crops in Southern areas of Portugal. In: Kyritsis, S., Beenackers, A.A.C., Helm, P., Grassi, A., Chiaramonti, D. (eds) *Biomass for Energy and Industry - Proceedings of the 1st World Conference*, 5-9 June 2000, Seville, Spain, James & James (Science Publishers) Ltd, London, United Kingdom, 1, pp 357-360.

Fernando, A.L. (2005). *Fitorremediação por Miscanthus x giganteus de solos contaminados com metais pesado*s. Dissertação de Doutoramento, Faculdade de Ciências e Tecnologia /Universidade Nova de Lisboa, Lisboa, 502 p.

Fernando, A.L. and Oliveira, J.S. (2001). Some aspects of Environmental Impact Assessment of *Miscanthus* x *giganteus* production in Portugal – Application of a model. *Environmental Aspects of Energy Crops. Latest results and Future direction*. 14th November, Moller Centre, Cambridge, UK. Organized by DTI (now BERR, Department for Business, Enterprise and Regulatory Reform), UK: http://www.berr.gov.uk/files/file20819.pdf (accessed March 2010).

Fernando, A.L.; Barbosa, B.; Boléo, S. and Mendes, B. (2011) Growth, Productivity and Biomass Quality of Kenaf irrigated with wastewaters – the effect of ammonium ion. In: Faulstich, M., Ossenbrink, H., Dallemand, J.F., Baxter, D., Grassi, A., Helm, P. (eds) *Proceedings of the 19th European Biomass Conference and Exhibition, From Research to Industry and Markets.* 6-10 June 2011, Berlin, Germany, Organized by ETA-Florence Renewable Energies and WIP-Renewable Energies, published by ETA-Florence Renewable Energies, pp 68-71.

Fernando, A.L.; Duarte, M.P.; Almeida, J.; Boléo, S. and Mendes, B. (2010b). Environmental impact assessment (EIA) of Energy crops production in Europe. *Biofuels, Bioproducts & Biorefining*, 4, pp 594-604.

Fernando, A.L.A.C. (2005). *Fitorremediação por Miscanthus x giganteus de solos contaminados com metais pesados*, PhD Thesis, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Lisbon, 502 p.

FMW - Swedish Defence Materiel Administration (2007). Listing of GWP Values as per Report IPCC WG1 AR4. Available at: http://www.fmv.se/upload/Bilder%20och%20dokument/English/Environmental%20work/GWP%20ipcc%201_0%20eng.pdf (accessed: September 2010).

Fragoso, C.; Brown, G.G.; Patron, J.C.; Blanchart, E.; Lavelle, P.; Pashanasi, B.; Senapati, B. and Kumar, T. (1997). Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of earthworms. *Applied Soil Ecology*, 6, pp 17-35.

Fritsche U.R.; Hennenberg, K.J.; Hermann, A.; Hünecke, K.; Schulze, F.; Wiegmann; Fehrenbach, H.; Roth, E.; Hennecke, A. and Giegrich, J. (2009).*Sustainable bioenergy: Current Status and Outlook, summary of recent results from the research project: Development of strategies and sustainability standards for the certification of biomass for international trade*. Oeko-Institut/IFEU, Darmstadt, Heidelberg, Germany. Available at: http://www.umweltdaten.de/publikationen/fpdf-l/3741.pdf (accessed: August 2011).

Fritsche, U.R.; Sims, R. E. H. and Monti, A. (2010). Direct and indirect land-use competition issues for energy crops and their sustainable production - an overview. *Biofuels, Bioproducts & Biorefining*, 4, pp 692-704.

Fullen, M.A. (2003) Soil erosion and conservation in northern Europe. *Progress in physical geography*, 27, pp 331-358.

Gasol, C.M.; Gabarrell, X.; Anton, A.; Rigola, M.; Carrasco, J.; Ciria, P. and Rieradevall, J. (2009). LCA of poplar bioenergy system compared with *Brassica carinata* energy crop and natural gas in regional scenario. *Biomass and Bioenergy*, 33, pp 119–129.

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

Gayler, S.; Wang, E.; Priesack, E.; Schaaf, T. and Maidl, F.X. (2002). Modeling biomass growth, N-uptake and phenological development of potato crop. *Geoderma*, 105, pp 367-383.

Gerbens-Leenes, P. W. and Nonhebel, S. (2004). Critical water requirements for food, methodology and policy consequences for food security. *Food Policy*, 29, pp 547-564.

Gerbens-Leenes, P.W.; Hoekstra, A.Y. and van der Meer, T. (2009a) The water footprint of energy from biomass: A quantitative assessment and consequences of an increasing share of bio-energy in energy supply. *Ecological Economics*, 68, pp 1052-1060.

Gerbens-Leenes,W.; Hoekstra, A.Y. and van der Meer, T.H. (2009b). The water footprint of bioenergy. *Proceedings of the Academy of Science of the United States of America*, 106, pp 10219-10223.

Giachetti, G. and Sebastiani, L. (2006). Metal accumulation in poplar plant grown with industrial wastes. *Chemosphere*, 64, pp 446-454.

Göksoy, A.T.; Demir, A.O.; Turan, Z.M. and Dağüstü, N. (2004). Responses of sunflower (*Helianthus annuus* L.) to full and limited irrigation at different growth stages. *Field Crops Research*, 87, pp 167-178.

Grabowska, L. and Baraniecki, P. (1997). Three year results on utilization soil polluted by copper-producing industry. *Proc. of the Flax and other Bast Plants Symp. Natural Fibres, Spec. Ed. INF Poznan*, pp 123-131.

Groom, M.; Gray, E. and Townsend, P. (2008). Biofuels and Biodiversity: Principles for Creating Better Policies for Biofuel Production. *Conservation Biology*, 22, pp 602-609.

Guo, L.B.; Sims, R.E.H. and Horne, D.J. (2002). Biomass production and nutrient cycling in Eucalyptus short rotation energy forests in New Zealand. I: biomass and nutrient accumulation. *Bioresource Technology*, 85, pp 273-283.

Haase, T.; Schüler, C. and Heß, J. (2007). The effect of different N and K sources on tuber nutrient uptake, total and graded yield of potatoes (*Solanum tuberosum* L.) for processing. *European Journal of Agronomy*, 26, pp 187–197.

Hall, R.L. (2003). *Grasses for energy production: hydrological guidelines*. UK Department of Trade and Industry, 15 pp: www.berr.gov.uk/files/file14946.pdf (accessed: January 2010).

Hansson, P.A.; Svensson, S.E.; Hallefält, F. and Diedrichs, H. (1999). Nutrient and cost optimization of fertilizing strategies for Salix including use of organic waste products. *Biomass and Bioenergy*, 17, pp 377-387.

Harrison, P. and Butterfield, R. (1996) Effects of climate change on Europe-wide winter wheat and sunflower productivity. *Climate Research*, 7, pp 225-241.

Harrison, P.; Porter, J. and Downing, T. (2000) Scaling-up the AFRCWHEAT2 model to assess phenological development for wheat in Europe. *Agricultural and Forest Meteorology*, 101, pp 167–186.

Hartmann, H. (1995). Environmental aspects of energy crop use - a system comparison. In: Chartier, Ph., Beenackers, A.A.C.M. and Grassi, G. (eds.). *Biomass for Energy , Environment, Agriculture and Industry - Proceedings of 8th E.C. Conference*, 3-5- October, 1994, Vienna, Austria, Elsevier Science Ltd., Oxford, 3, pp 2250-2255.

HC-SC (2009). *Environmental and Workplace Health*, Health Canada - Santé Canada: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/(accessed: September 2009).

Heller, M.C.; Keoleian, G.A. and Volk, T.A. (2003). Life cycle assessment of a willow bioenergy cropping system. *Biomass and Bioenergy,* 25, pp 147-165.

Hernandez, M. (2006). *Cultivos energeticos*. Cuadernos Didacticos del INEA, Valladolid University Publications, 72 pp

Hocking, P.J.; Randall, P.J. and Pinkerton, A. (1987). Mineral Nutrition of Linseed and Fiber Flax. *Advances in Agronomy*, 41, pp 221-296.

IEA Bioenergy (2010). *IEA Bioenergy Task 32* – Biomass database: http://www.ieabcc.nl/database/biomass.php (accessed March 2010).

Ierna, A (2009) Influence of harvest date on nitrate contents of three potato varieties for off-season production. *Journal of Food Composition and Analysis*, 22, pp 551-555.

INCHEM (2009). *International Program on Chemical Safety – Chemical Safety Information from Intergovernmental Organizations*: www.inchem.org (accessed: September 2009).

IPCC - Intergovernmental Panel on Climate Change (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S; Buendia, L.; Miwa, K.; Ngara, T. and Tanabe, K. (eds). Published: IGES, Japan.

IUPAC (2009). *IUPAC - global availability of information on agrochemicals:* http://sitem.herts.ac.uk/aeru/iupac/index.htm (accessed: September 2009).

Jewitt, G. and Kunz, R. (2011). The impact of biofuel feedstock production on water resources: a developing country perspective. *Biofuels, Bioproducts & Biorefining*, 5, pp 387–398.

Johnson, H. (1991). *Simulation of Nitrogen Losses Using the SOILN Model*. Miljoministeriet Miliojstyrelsen, Denmark, 48 pp

Jones, G.A. and Sieving, K.E. (2006). Intercropping sunflower in organic vegetables to augment bird predators of arthropods. *Agriculture, Ecosystems and Environment*, 117 , pp 171-177.

Jones, M.B. and Walsh, M. (2001). Miscanthus *for energy and fibre*, James & James (Science Publishers) Ltd, London, United Kingdom.

Jørgensen, U. and Schelde, K. (2001) *Energy crop water and nutrient use efficiency*. The International Energy Agency. IEA Bioenergy Task 17, Short Rotation Crops. Danish Institute of Agricultural Sciences (DIAS), Department of Crop Physiology and Soil Science, Research Centre Foulum, Tjele, Denmark, 38 p.

Kahle, P.; Beuch, S.; Boelcke, B.; Leinweber, P. and Schulten, H.R. (2001). Cropping of *Miscanthus* in Central Europe: biomass production and influence on nutrients and soil organic matter. *European Journal of Agronomy*, 15, pp 171-184.

Kaltschmitt, M.; Reinhardt, G.A. and Stelzer, T. (1996). LCA of biofuels uner different environmental aspects. In: Chartier, P., Ferrero, G.L.; Henius, U.M; Hultberg, S.; Sachau, J. and Wiinblad, M. (eds.), *Biomass for energy and the environment - Proceedings of the 9th European Bioenergy Conference*, 24-27 June 1996, Copenhagen, Denmark, Elsevier Science Ltd., Oxford, 1, pp 369-386.

Kicherer, A.; Görres, J.; Spliethoff, H. and Hein, K.R.G. (1995). Biomass co-combustion for the pollutant control in pulverized coal units. In: Chartier, Ph., Beenackers, A.A.C.M. and Grassi, G. (eds.). *Biomass for Energy , Environment, Agriculture and Industry - Proceedings of 8th E.C. Conference*, 3-5- October, 1994, Vienna, Austria, Elsevier Science Ltd., Oxford, 2, pp 926-935.

Kort, J.; Collins, M. and Ditsch, D. (1998). A review of soil erosion potential associated with biomass crops. *Biomass and Bioenergy*, 14, pp 351–359.

Krasuska, E.; Cadórniga, C.; Tenorio, J.; Testa, G. and Scordia, D. (2010). Potencial land availability for energy crops production in Europe. *Biofuels, Bioproducts & Biorefining, 4*, pp 658-673.

Labalette, F.; Laboubee, C. and Jacquin, C. (2009). The composition of the linseed straw in France: properties for combustion. In: De Santi, G.F., Dallemand, J.F. Ossenbrink, H., Grassi, A., Helm, P. (eds) *Proceedings of the 17th European Biomass Conference and Exhibition, From*

Research to Industry and Markets. 29 June - 3 July 2009, Hamburg, Germany, ETA-Renewable Energies and WIP-Renewable Energies, pp 154-158.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. *Soil and Tillage Research*, 43, pp 81-107.

Lal, R. (2005). Forest soils and carbon sequestration. *Forest Ecology and Management*, 220. pp 242-258.

Lal, R. (2006). Land area for establishing biofuel plantations. *Energy for Sustainable Development,* 10; pp 67-69.

Landi, S. (1997). Mineral nutrition of *Cannabis sativa* L. *Journal of plant nutrition*, 20, pp 311-326.

LCAinfo (2009). *Life cycle activities in Switzerland*: www.lcainfo.ch (accessed: November 2009).

Lewandowski, I. and Kicherer A. (1997). Combustion quality of biomass: practical relevance and experiments to modify the biomass quality of *Miscanthus x giganteus. European Journal of Agronomy*, 6, pp 163-177.

Lewandowski, I.; Clifton-Brown, J.; Andersson, B.; Basch, G.; Christian, D.; Jørgensen, U.; Jones, M.; Riche, A.; Schwarz, K.; Tayebi, K. and Teixeira, F. (2003a). Biofuels - Environment and Harvest Time Affects the Combustion Qualities of *Miscanthus* Genotypes. *Agronomy Journal*, 95, pp 1274–1280.

Lewandowski, I.; Kicherer, A. and Vonier, P. (1995). CO_2 - balance for the cultivation and combustion and *Miscanthus*. *Biomass and Bioenergy*, 8, pp 81-90.

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

Lima, H.; Chambel, A.; Alves, J. and Francisco, P. (1998). Impacte da cultura de eucaliptos sobre os recursos hídricos subterrâneos da Serra da Ossa. In: *Actas do 4º Congresso da Água*, 23 – 27 Março 1998, Lisboa, Portugal, Associação Portuguesa dos Recursos Hídricos, pp 259 – 260 (in portuguese).

Linger, P.; Müssig, J.; Fischer, H. and Kobert, J. (2002). Industrial hemp (*Cannabis sativa* L.) growing on heavy metal contaminated soil: fibre quality and phytoremediation potential. *Industrial Crops and Products*, 16, pp 33-42.

Lips, S.; de Heredia, G.; Op den Kamp. G, and van Dam, J, (2009). Water absorption characteristics of kenaf core to use as animal bedding material. *Industrial crops and Products*, 29, pp 73-79.

Llorente M.J.F.; Laplaza, J.M.M.; Cuadrado, R. E. and García J.E.C. (2006). Ash behaviour of lignocellulosic biomass in bubbling fluidized bed combustion. *Fuel*, 85, pp 1157-1165.

López-Bellido, R.J. and López-Bellido, L. (2001). Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Research,* 71, pp 31-46.

Luca, E.; Nagy, Z. and Berchez, M. (2003) Water requirements of the main field crops in Transylvania (1964-2002), *Journal of Central European Agriculture*, 4, pp 98-102.

Luger, E. (2002). *Energy crop species in Europe*, BLT Wieselburg, Austria: http://www.blt.bmlf.gv.at/vero/veroeff/0732_Energy_crops_species_e.pdf (acessed November 2009).

Luger, E. (2003a). Cardoon: introduction as an energy crop. BLT. http://blt.josephinum.at/ (accessed: November 2009).

Luger, E. (2003b). *Eucalyptus: introduction as an energy crop*. BLT Wieselburg, Austria: http://www.blt.bmlf.gv.at/vero/veroeff/0797_Eucalypt_introduction_e.pdf (acessed November 2009).

Ma, Z.; Wood, C.W. and Bransby, D.I. (2001). *Impact of row spacing, nitrogen rate, and time on carbon partitioning of switchgrass.* Biomass and Bioenergy, 20, pp413-419.

Madéjon, P.; Murillo, J.; Marañón, T.; Cabrera, F. and Soriano, M. (2003). Trace element and nutrient accumulation in sunflower plants two years after the Aznalcóllar mine spill. *The Science of the Total Environment*, 307, pp 239–257.

Majumbar, D.K. (2004) *Irrigation Water Management: Principles and Practice.* Prentice Hall, India.

Makeschin, F. (1994). Effects of energy forestry on soils*. Biomass and Bioenergy*, 6, pp 63-79.

MAL (2009). *Ministry of Agriculture and Lands, Government of British Columbia*: www.agf.gov.bc.ca (accessed: September 2009).

Marchiol, L.; Assolari, S.; Sacco, P. and Zerbi, G. (2004). Phytoextraction of heavy metals by canola (*Brassica napus*) and radish (*Raphanus sativus*) grown on multicontaminated soil. *Environmental Pollution,* 132, pp 21-27.

Mastrorilli, M.; Katerji, N.; Rana, G. and Steduto, P. (1995). Sweet sorghum in Mediterranean climate: radiation use and biomass water use efficiencies. *Industrial Crops and Products*, 3, pp 253-260.

Mattsson, B.; Cederberg, C. and Blix, L. (2000). Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. *Journal of cleaner production*, 8, pp 283-292.

Mavrogianopoulos, G.; Vogli, V. and Kyritsis, S. (2002). Use of wastewater as a nutrient solution in a closed gravel hydroponic culture of giant reed (*Arundo donax*). *Bioresource technology*, 82 (2) pp 103-107.

McLaughlin, S. and Walsh, M (1998). Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass and Bioenergy*, 14, pp 317-324.

McLaughlin, S.; Bouton, J.; Bransby, D.; Conger, B.; Ocumpaugh, W.; Parrish, D.; Taliaferro, C.; Vogel, K.; Wullschleger, S. (1999). Developing Switchgrass as a Bioenergy Crop*. In: Perspectives on New Crops and New Uses - Proceedings of the Fourth National Symposium New Crops and New Uses: Biodiversity and Agricultural Sustainability*, pp 282-299.

McLaughlin, S.B. and Walsh, M.E. (1998). Evaluating environmental consequences of producing herbaceous crops foi bioenergy. *Biomass and Bioenergy* 14, pp 317-324.

Metzger, M. J.; Bunce, R. G. H.; Jongman, R. H. G.; Mücher, C. A.; Watkins J. W. (2005) A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, 14, pp 549–563.

Mineau, P. and McLaughlin, A. (1996). Conservation of biodiversity within Canadian agricultural landscapes: integrating habitat for wildlife. *Journal of Agricultural and Environmental Ethics*, 9, pp 93-113.

Mitchell, C.P.; Stevens, E.A. and Watters. M.P. (1999). Short-rotation forestry - operations, productivity and costs based on experience gained in the UK. *Forest Ecology and Management*, 121, pp 123-136.

Monti, A. and Zatta, A. (2009). Root distribution and soil moisture retrieval in perennial and annual energy crops in Northern Italy. *Agriculture, Ecosystems and Environment*, 132, pp 252–259.

Nebel, B.; Wright, R.T. (2000) *Environmental Science: the way the world works*, 7th Ed. Prentice Hall, New Jersey, EUA, 664 p.

Niu, Z.; Sun, L.; Sun, T.; Li, Y. and Wang, H. (2007). Evaluation of phytoextracting cadmium and lead by sunflower, ricinus, alfalfa and mustard in hydroponic culture. *Journal of Environmental Sciences*, 19, pp 961-967.

OECD/IEA - Organization for Economic Co-Operation and Development / International Energy Agency (2006). *World Energy Outlook, 2006.* IEA, Paris, France, pp 596. Available at: http://www.iea.org/textbase/nppdf/free/2006/weo2006.pdf.(accessed: July 2011).

OECD/IEA - Organization for Economic Co-Operation and Development / International Energy Agency (2007). *Good Practice Guidelines - Bioenergy Project Development & Biomass Supply*. IEA, Paris, France, 61p.. Availabe at: http://www.iea.org/textbase/nppdf/free/2007/biomass.pdf (accessed: June 2011).

Oliveira, J.S.; Duarte, M.P.; Christian, D.G.; Eppel-Hotz, A. and Fernando, A.L. (2001) Environmental aspects of *Miscanthus* production. In: Jones, M.B and Walsh, M.(eds.), *Miscanthus for energy and fibre*. James & James(Science Publishers) Ltd, Londres, Reino Unido, pp 172-178.

Özcan, M.M. (2006). Determination of the mineral compositions of some selected oil-bearing seeds and kernels using Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). *Grasas y Aceites*, 57, pp 211-218.

Page, M.; Smalley, J. and Talibudeen, O. (1977). The growth and nutrient uptake of winter wheat; *Plant and Soil*, 49, pp 149-160.

Paine, L.K.; Peterson, T.L.; Undersander, D.J.; Rineer, K.; Bartelt, G.; Temple, S. and Klemme, D.W.S. (1996). Some ecological and socio-economic considerations for biomass energy crop production. *Biomass and Bioenergy,* 10, pp 231-242.

PAN (2009). *Pesticide Action Network (PAN) Pesticide Database*: www.pesticideinfo.org (accessed: September 2009).

Panoutsou, C. (2007) Socio-economic impacts of energy crops for heat generation in Northern Greece. *Energy Policy*, 35, pp 6046-6059.

Panoutsou, C.; Kavadakis, G. and Namatov, E. (1999). *Brassica carinata, a promising crop for non-food oil and biomass production in the mediterranean regions*. European Energy Crops InterNetwork.

Papazoglou, E.G. (2007). *Arundo donax* L. stress tolerance under irrigation with heavy metal aqueous solutions. *Desalination*, 211, pp 304-313.

Parrish, D. J.; Wolf, D. D. and Daniels, W. L. (1997). *Switchgrass as a biofuel crop for the upper Southeast: Varieties trials and cultural improvements. Five year report*. Oak ridge National Laboratory, Oak Ridge.

Pereira, AB and Shock, CC (2006) Development of irrigation best management practices for potato from a research perspective in the United States. *Sakia.org e-publish*, 1, pp 1-20.

Pereira, H. (1999). *Cynara cardunculus* cultivation in Portugal. European Energy Crops InterNetwork Report.

Perlack, R.; Wright, L.; Turhollow, A.; Graham, R.; Stokes, B. and Erbach, D. (2005) *Biomass as feedstock for bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply*. United States Department of Energy / United States Department of Agriculture. pp 60. Available at: http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf (accessed: September 2011).

Perttu, K.L. (1998). Environmental Justification for short-rotation forestry in Sweden. *Biomass and Bioenergy* 15, pp 1–6.

Picco, D. (2010). *Colture Energetiche per il didinquinamento della laguna di Venezia. Progetto Biocolt.* C.E.T.A. - Centro di Ecologia Teorica ed Applicata. Venetto Agricultura- Azienda Regionale per i Settori Agricolo, Flrestale e Agroalimentare, Legnaro, Italia, 223 p.

Pimental, D. and Krummel, J. (1987). Biomass energy and soil erosion: assessment of resource costs. *Biomass,*14, pp 15-38.

Pimentel, D.; Acguay, H.; Biltonen, M.; Rice, P.; Silva, M.; Nelson, J.; Lipner, V.; Giordano, S.; Harowitz, A. and D'Amore, M. (1992) Environmental and Economic Costs of Pesticide Use. *BioScience*, 42, pp 750-760.

PMEP (2009). *Cornell University – Pesticide Management Education Program*: http://pmep.cce.cornell.edu (accessed: September 2009).

Pocock, T.O.; Milford, G.F.J. and Armstrong, M.J. (1990). Storage root quality in sugar beet in relation to nitrogen uptake. *The Journal of Agricultural Science*, 115, pp 355-362.

Poesen, J.W.A. and Hooke, J.M.(1997). Erosion, flooding and channel management in Mediterranean environments of southern Europe. *Progress in Physical Geography*, 21, pp 157-199.

Portaria 732-A/96 (1996). Regulamento para a notificação de substâncias químicas e para a classificação, embalagem e rotulagem de substâncias perigosas. *Diário da República*, I Série – B, 286, 4434 – (2-693).

Powers, S.E.; Ascough II , J.C.; Nelson, R.G. and Laroque, G.R. (2011). Modeling water soil quality environmental impacts associated with bioenergy crop production and biomass removal in the Midwest USA. *Ecological Modelling*. pp 2430-2447.

Prochnow, A.; Heiermann, M.; Plöchl, M.; Linke ,B.; Idler, C.; Amon, T.; and Hobbs, P.J. (2009). Bioenergy from permanent grassland – A review 2: Combustion; *Bioresource Technology*, 100, pp 4945–4954.

Raccuia, S. and Melilli, M. (2007). Biomass and grain oil yields in *Cynara cardunculus* L. genotypes grown in a Mediterranean environment. *Field Crops Research*, 101, pp 187–197.

Rafaschieri, A.; Rapaccini, M. and Manfrida, G. (1999). Life Cycle Assessment of electricity production from poplar energy crops compared with conventional fossil fuels. *Energy Conversion and Management*, 40, pp 1477-1493.

Ragauskas, A.J.; Williams, C.K.; Davidson, B.H.; Britovsek, G.; Cairney, J.; Eckert, C.A.; Frederick jr., W.J.; Hallett, J.P.; Leak, D.J.; Liotta, C.L.; Mielenz, J.R.; Murphy, R.; Templer, R. and Tschaplinskl, T. (2006). The path forward for biofuels and biomaterials. *Science,* 311, pp 484-489.

Rahil, M.H. and Antonopoulos, V.Z. (2007). Simulating soil water flow and nitrogen dynamics in a sunflower field irrigated with reclaimed wastewater. *Agricultural water management*, 92, pp 142-150.

Ranney, J. W. and. Mann, L. K. (1994). Environmental considerations in energy crop production. *Biomass and Bioenergy*, 6, pp 211-228.

Rathke, G.W.; Behrens, T. and Diepenbrock, W. (2006). Integrated nitrogen management strategies to improve seed yield, oil content and nitrogen efficiency of winter oilseed rape (*Brassica napus* L.): A review. *Agriculture, Ecosystems and Environment*, 117, pp 80-108.

Reeves, D.W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil and Tillage Research*, 43, pp 131-167.

Rentizelas, A.; Tolis, A. and I. Tatsiopoulos (2009). Logistics issues of biomass: The storage problem and the multi-biomass supply chain. *Renewable and Sustainable Energy Reviews*, 13, pp 887–894.

Rettenmaier, N., Köppen, S., Gärtner, S., & Reinhardt, G. (2010a). *Life cycle analysis - Final Report on Tasks 4.2 & 4.3 of the 4F Crops Project: Future Crops for Food, Feed, Fiber and Fuel*. IFEU - Institute for Energy and Environmental Research Heidelberg GmbH, Heidelberg, Germany, 99 p.

Rettenmaier, N., Köppen, S., Gärtner, S., & Reinhardt, G. (2010b). Life cycle assessment of selected future energy crops for Europe. *Biofuels, Bioproducts & Biorefining, 4*, pp 620-636.

Rinaldi, M. (2004). Water availability at sowing and nitrogen management of durum wheat: a seasonal analysis with the CERES-Wheat model. *Field Crops Research*, 89, pp 27-37.

Rinehart, L. (2006) *Switchgrass as a Bioenergy Crop*. National Sustainable Agriculture Information Service. Available at: http://attra.ncat.org/attra-pub/switchgrass.html (accessed: January, 2010).

Risser, P. G.; Birney, E. C.; Blocker, H. D.; May, S. W.; Parton, W. J. and Wiens, J.A. (1981). *The true prairie ecosystem*. U.S/IBP Synthesis, Series 16. Hutchinson Ross, Stroudsburg, PA. In: Picco, 2010.

Rodrigues, G.S.; Campanhola, C. and Kitamura, P.C. (2003). An environmental impact assessment system for agricultural R&D. *Environmental Impact Assessment Review*, 23, pp 219-244.

Rosenqvist, H. and Dawson, M. (2005). Economics of using wastewater irrigation of willow in Northern Ireland. *Biomass and Bioenergy* , 29, pp 83-92.

Rossi, G.; Figliolia, A.; Socciarelli, S. and Pennelli, B. (2002). Capability of Brassica napus to Accumulate Cadmium, Zinc and Copper from Soil. *Acta Biotechnologica*, 22, pp 133-140.

Rowe, R.L.; Street, N.R. and Taylor, G. (2009) Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. *Renewable and Sustainable Energy Reviews*, 13, pp 271-290.

Samson, R.; Girourard, P.; Zan, C., Mehdi, B.; Martin, R. and Henning, J. (1999). T*he implications of growing short-rotation tree species for carbon sequestration in Canada*. *Final Report*. R.E.A.P. Canada.91 p.

Sasikumar, K.; Vijayalakshmi, C. and Parthiban, K.T. (2001). Allelopathic effects of four *Eucalyptus* species on redgram (*Cajanus cajan* L.). *Journal of Tropical Agriculture*, 39, pp 134-138.

Schimdt, W.P.; Sullivan, J. (2002). Weighting in Life Cycle Assessments in a Global Context. *International Journal of Life Cycle Assessment*, 7, pp 5-10.

Semere, T. and Slater, F.M. (2007a). Ground for a, small mammal and bird species diversity in miscanthus (*Miscanthus × giganteus*) and reed canary-grass (*Phalaris arundicacea*) fields. *Biomass and Bioenergy*, 31, pp 20-29.

Semere, T. and Slater, F. (2007b). Invertebrate populations in Miscanthus (Miscanthus × giganteus) and reed canary grass (*Phalaris arundinacea*) fields. *Biomass and Bioenergy*, 31, pp 30–39.

Sessiz, A.; Sogut, T.; Alp, A. and Esgici, R. (2008). Tillage effects on sunflower (*Helianthus annuus* L.) emergence, yield, quality and fuel consumption in double cropping system. *Journal of Central European Agriculture*, 9, pp 697-710.

Shahnazari, A.; Ahmadi, S.H.; Laerke, P.E.; Liu, F., Plauborg, F.; Jacobsen, S.E.; Jensen, C.R. and Andersen, M.N. (2008). Nitrogen dynamics in the soil-plant system under deficit and partial root-zone drying irrigation strategies in potatoes. *European Journal of Agronomy*, 28, pp 65-73.

Sheng, X.F.; Xia, J.J.; Jiang, C.Y.; He, L.Y. and Qian, M. (2008). Characterization of heavy metal-resistant endophytic bacteria from rape (*Brassica napus*) roots and their potential in promoting the growth and lead accumulation of rape. *Environmental Pollution,* 156, pp 1164-1170.

Shifflet T. N. and G. M. Darby (1985). Forages and soil conservation. In: *Forages: the science of grassland agriculture.* Heat, M. E.; Barnes, R. F and. Metcalfe, D. S. (eds). Iowa State University Press, Ames, IA, pp 21-32.

Sims, R.E.H.; Hastings, A.; Schlamadinger, B.; Taylor, G and Smith, P. (2006). Review – Energy crops: current status and future prospects. *Global Change Biology*, 12, pp 2054-2076.

Singh, S.; Mishra, R.; Singh, A.,;Ghoshal, N. and Singh, K.P. (2009). Soil Physicochemical Properties in a Grassland and Agroecosystem Receiving Varying Organic Inputs. *Soil Science Society of America Journal*, 73, pp1530-1538.

Skärbäck, E. and Becht, P. (2005). Landscape perspective on energy forests. *Biomass and Bioenergy*, 28, pp 151-159.

Slootweg, R. and Kolhoff, A .(2003). A generic approach to integrate biodiversity considerations in screening and scoping for EIA. *Environmental Impact Assessment Review*, 23, pp 657-68.

Smeets, E.; Faaji, A. and Lewandowski, I. (2004). *A quickscan of global bio-energy potencials to 2050 - An analysis of the regional availability of biomass resources for export in relation to underlying factors.* Report NWS-E-2004-109, 122 .. Available at: http://www.bioenergytrade.org/downloads/smeetsglobalquickscan2050.pdf (accessed: July 2011).

Smeets, E.; Lewandowski, I. and Faaij, A. (2009). The economical and environmental performance of miscanthus and switchgrass production and supply chains in European setting. *Renewable and Sustainable Energy Reviews*, 13, pp 1230-1245.

Smith P.; Powlson D. S.; Smith J. U., Falloon P. and K.Coleman (2000). Meeting Europe's climate change commitments: quantitative estimates of the potential carbon mitigation by agriculture. *Global Change Biology*, 6, pp 525-539.

SpecLab (2009). *Spectrum Laboratories*: www.speclab.com (accessed: September 2009).

Spiertz, J.H.J. and Ewert, F. (2009). Crop production and resource use to meet the growing demand for food, feed and fuel: opportunities ans constraints. *NJAS - Wageningen Journal of Life Sciences,* 56, pp 282-300.

Stanturf, J. A.; van Osten, C.; Netzer, D. A.; Coleman, M. D. and Portwood, C. J. (2001). Ecology and silviculture of poplar plantations. In: Dickmann, D. I.; Isebrands, J. G.; Eckenwalder, J. E. and Richardson, J. (eds.). *Poplar culture in North America*. NRC Research Press, National Research Council of Canada, Ottawa, Canada, pp 13-206.

Stenberg, B.; Jonsson, A. and Börjesson, T. (2005). Use of near infrared reflectance spectroscopy to predict nitrogen uptake by winter wheat within fields with high variability in organic matter. *Plant and Soil*, 269, pp 251-258.

Stephens, W.; Hess, T. and Knox, J. (2001). Review of the effects of energy crops on hydrology. Cranfield University, 71 pp

Struik P.; Amaducci, S.; Bullard M.; Stutterheim N.; Venturi ,G. and Cromack, H. (2000). Agronomy of fibre hemp *(Cannabis sativa* L.) in Europe. *Industrial Crops and Products*, 11, pp 107–118.

Sunde, K; Brekke, A. and Solberg, B. (2011). Environmental impacts and costs of woody Biomass-to-Liquid (BTL) production and use - A review. *Forest Policy and Economics*, 13, pp 591-602.

Supit, I.; van Diepen, C.A.; Boogaard, H.L.; Ludwig, F. and Baruth, B. (2010) Trend analysis of the water requirements, consumption and deficit of field crops in Europe. *Agriculture and Forest Meteorolology*, 150, pp 77–88.

The Center for Native Grasslands Management (2011). *Herbaceous Perennials Grass White Paper: a brief overview of Gramineae bebefits and utilization*. Department of Wildlife and Ficheries, University of Tennesee, 35 p..

The Gaia Foundation, Biofuelwatch, The African Biodiversity Network, Salva La Selva, Watch Indonesia and EcoNexus (2008) *Agrofuels and the Myth of the Marginal Lands*. 8pp. Available at: http://www.econexus.info/publication/agrofuels-and-myth-marginal-lands (accessed: September 2011).

Thingstrup, I.; Rubaek, G.; Sibbesen, E. and Jakobsen, I. (1998). Flax (*Linum usitatissimum* L.) depends on arbuscular mycorrhizal fungi for growth and P uptake at intermediate but not high soil P levels in the field. *Plant and Soil*, 203, pp 37-46.

Tolbert, V. R.; Todd Jr., D. E.; Mann, L. K.; Jawdy, C. M.; Mays, D. A.; Malik, R.; Bandaranayake, W.; Houston, A.; Tyler, D. and Pettry, D. E. (2002). Changes in soil quality and below-ground carbon storage with conversion of traditional agricultural crop lands to bioenergy crop production. *Environmental Pollutio*n,116, pp 97-106.

Tolbert, V.; Thornton, F.C.; Joslin, J.; Bock, B.; Bandaranayake, W.; Tyler, D.; Pettry, D.; Green, T.; Makik, R.; Bingham, L.; Houston, A.; Shires, M.; Dewey, J. and Schoenholtz, S. (1998). Soil and Water Quality Aspects of Herbaceous and Woody Energy Crop Productions: Lessons from Research-Scale Comparisons with Agricultural Crops. In:BioEnergy '98: Expanding Bioenergy Partnerships, Madison, USA, 4-8 Oct 1998. http://bioenergy.ornl.gov/papers/bioen98/tolbert.html (accessed: January 2010).

TU Wien (2010).: http://www.vt.tuwien.ac.at/Biobib/search.html (accessed March 2010).

Tzilivakis, J.; Warner, D.J.; May, M.; Lewis, K.A. and Jaggard, K. (2005). An assessment of the energy inputs and greenhouse gas emissions in sugar beet (*Beta vulgaris*) production in the UK. *Agricultural Systems*, 85, pp 101-119.

Ulrich, W.; Buszko, J. and Czarnecki, A. (2004). The contribution of poplar plantations to regional diversity of ground beetles (*Coleoptera: Carabidae*) in agricultural landscapes. *Annales Zoologici Fennici*, 41, pp 501-512.

UNDP and GEF (2004). *Inventory of Agricultural Pesticide Use in the Danube River Basin Countries*. UNDP/GEF Danube Regional Project. http://www.undp-drp.org/drp/en/activities_1-2_-3_agriculture_fr_phase1.html (accessed: October, 2009).

van Dam, J.; Faaij, A.P.C.; Hilbert, J.; Petruzzi, H. and Turkenburg, W.C. (2009). Large-scale bioenergy production from soybeans and switchgrass in Argentina. Pat B - Environmental and socio-economic impacts on a regional level. *Renewable and Sustainable Energy Reviews*, 13, pp 1679-1709.

van der Knijff, J.M.; Jones, R.J.A. and Montanarella, L. (2000) S*oil Erosion Risk: Assessment in Europe. European Soil Bureau - European Commission*, 38 p.

van der Werf, H.M.G. (2004). Life Cycle Analysis of field production of fibre hemp, the effect of production practices on environmental impacts. *Euphytica*,140, pp 13-23.

van der Werf, H.M.G. and Turunen, L. (2008). The environmental impacts of the production of hemp and flax textile yarn. *Industrial Crops and Products*, 27, pp 1-10.

Venendaal, R.; Jørgensen, U. and Foster, C. A. (1997). European energy crops: A synthesis. *Biomass and Bioenergy*, 13, pp 147-185.

Venturi, G. and Monti, A. (2005). Energia da colture dedicate: aspetti ambientali ed agronomici. In: *Conferenza Nazionale sulla Politica Energetica in Italia.* 18-19 April 2005, Bologna, Italy, 5 p.. Available at: http://www.tecnosophia.org/documenti/Articoli/SessioneII/Venturi.pdf (accessed: September 2011).

Venturi, P. and Venturi, G. (2003). Analysis of energy comparison for crops in European agricultural systems. *Biomass and Bioenergy, 25*, pp 235-255.

WDA (2009). A definitive study of the economic potential of plants and animals not currently fully exploited by the Welsh agricultural sector, University of Wales : http://safs.csl.gov.uk (accessed: October, 2009).

Weih, M. (2004). Intensive short rotation forestry in boreal climates: present and future perspectives. *Canadian Journal of Forest Research,* 34, pp 1369–1378.

Wilson, C.and Tisdell, C. (2001) Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics*, 39, pp 449-462.

Wilson, M.J. and Maliszewska-Kordybach, B. (2000) *Soil Quality, Sustainable Agriculture and Environmental Security in Central and Eastern Europe*. NATO Science Series, 2 – Environmental Security, 69. Kluwer Academic Publishers, the Netherlands, 375 pp

Zan, C.S.; Fyles, J.W.; Girouard, P. and Samson, R.A. (2001). Carbon sequestration in perennial bioenergy, annual corn and uncultivated systems in southern Quebec. *Agriculture, Ecosystems and Environment*, 86, pp 135-144.

Zegada-Lizarazu, W.; Elbersen, H. W.; Cosentino, S. L.; Zatta, A.; Alexopoulou, E. and Monti, A. (2010). Agronomic aspects of future energy crops in Europe. *Biofuels Bioproducts & Biorefining, 4*, pp 674-691.

Zhang, C. and Fu, S. (2009). Allelopathic effects of eucalyptus and the establishment of mixed stands of mixed stands of eucalyptus and native species. *Forest Ecology and Management*, 258, pp 1391–1396.

6. ANNEX I

Table A.1. - Range of nitrogen, phosphorus and potassium inputs and uptakes (kg.ha^{-1}.year^{-1}) for all crops, in the Mediterranean Europe.

Type of crop	Crop	Fertiliser[1)]			Uptake[2)]		
		N	P	K	N	P	K
Oil crops	Rapeseed	11-185	5-70	12-150	88 - 108	12-23	8-65
	Sunflower	14-130	3-53	4-149	71-276	18	27-170
	Ethiopian Mustard	76-152	22-42	23-80	95-127	20	87
Sugar crops	Sugar beet	15-180	8-57	18-203	65-136	9-33	249
	Sweet sorghum	60-150	65-120	120	27–96	14-52	77-332
Fiber crops	Hemp	60-160	13-40	83-95	97	16	139-142
	Flax	14-130	3-35	5-150	39	16	49
Lignocellulosic crops	*Miscanthus*	46-100	7-12	99-140	21– 94	7-20	59-224
	Giant reed	40-100	44	83	112-165	32	244
	Cardoon	50-168	12-46	87-245	176-232	21-34	242-350
Woody crops	Poplar	26-118	9-24	25-45	9 – 26	0.5-4	6-12
	Willow	64-70	6	20	21	3	4-9
	Eucalyptus	5	3	7	3	0.2-0.3	0.8
Food crops	Wheat	24-190	9-80	0-80	103–177	13-56	58-250
	Potato	20-200	16-225	21-288	131	26	136
Reference crop	Grass fallow	0	0	0	0	0	0

[1)] Amaducci *et al.* (2008), Angelini *et al*. (2009), Cardone *et al*. (2003), Carneiro *et al*., (2008), Christian *et al.* (2008), Diamantidis and Koukios (2000), Duarte *et al.* (2001), Ericsson *et al.* (2006), FAO (2007), FAO *et al*. (2002), Fernandez *et al*. (1996, 2006), Fernando and Oliveira (2001), Gasol *et al*. (2007, 2009), Hernandez (2006), Landi (1997), Lewandowski e Kicherer (1997), Lewandowski *et al*. (2003b), Mastrorilli *et al*. (1995), Raccuia and Melili (2007), Rafaschieri *et al*. (1999), Smeets *et al.* (2009), Struik *et al*. (2000), van der Werf and Turunen (2008), Venendaal *et al*. (1997), Venturi e Venturi (2003).

[2)] Ačko and Trdan (2008), Alexopoulou *et al.* (2001), Amaducci *et al.* (2000), Angelini *et al.* (2005, 2007), Arrobas and Rodrigues (2009), Biewinga and van der Bijl (1996), Casa *et al.* (1999), Christian *et al*. (2008), Colomb *et al*. (2007), Curt *et al.* (1995), Delogu *et al*. (1998), Di Muzio Pasta *et al*. (2007), Di Nasso *et al*. (2009), Diamantidis and Koukios (2000), Dias *et al.* (2009), Dores *et al*. (2008), Draycott and Christenson (2003), El Bassam (1998), Eurostat (2010), Fangmeier *et al*. (2002), Fernandez (2006), Fernandez *et al*. (1996, 2006), Fernando (2005), Fernando and Oliveira (2001), Fernando *et al.* (2001), Gasol *et al.* (2007, 2009), Gayler *et al.* (2002), Haase *et al*. (2007), Hall (2003), Hocking *et al.* (1987), IEA Bioenergy (2010), Johnson (1991), Jones and Walsh (2001), Labalette *et al*. (2009), Lewandowski *et al.* (2003a and b), Llorente *et al.* (2006), López-Bellido and López-Bellido (2001), Luger (2002, 2003b), Madéjon *et al*, 2003, Mattsson *et al.* (2000), Özcan (2006), Page *et al*. (1977), Panoutsou *et al*. (1999), Pereira (1999), Pocock *et al.* (1990), Raccuia and Melilli (2007), Rahil and Antonopoulos (2007), Rathke *et al.* (2006), Rinaldi (2004), Shahnazari *et al.* (2008), Stenberg *et al.* (2005), Thingstrup *et al.* (1998), TU Wien (2010), Venendaal *et al.* (1997).

Table A.2. - Pesticides application and pesticide score found for each crop, in the Mediterranean Europe.

Type of crop	Crop	Application options[1]	Pesticide score[2]
Oil crops	Rapeseed	Metazachlor (1 $kg.ha^{-1}$) + Esfenvalerate (0.015 $kg.ha^{-1}$); Alachlor (0.7 $kg.ha^{-1}$) + Trifuralin (0.05 $kg.ha^{-1}$) + Chlorpyrifos (0.3 $kg.ha^{-1}$)	5
	Sunflower	Linuron (0,2 $cm^3.m^{-2}$); Alachlor (4-5 $L.ha^{-1}$)	12 - 24
	Ethiopian mustard	Metazachlor (1 $kg.ha^{-1}$)	5
Sugar crops	Sugar beet	Trifuralin (0.004 $kg.ha^{-1}$) + Chlorpyrifos (0.08 $kg.ha^{-1}$) + Copper oxichloride (0.7 $kg.ha^{-1}$) + Zineb (1.4 $kg.ha^{-1}$); Carbendazim (0.08 kg.ha-1) + Aldicarb (10 kg.ha-1) + Flusilazole (0.2 $kg.ha^{-1}$) + Phenmedipham (1.7 $L.ha^{-1}$)	11 – 72
	Sweet Sorghum	Pirimicarb (0.5 $kg.ha^{-1}$); Atrazine (2-3 $kg.ha^{-1}$)	3 – 10
Fiber crops	Hemp	No weeding or disease control necessary.	0
	Flax	Linuron (1.4 $kg.ha^{-1}$) + Haloskyfop-R (1 $L.ha^{-1}$); Chlorsulfuron (1.4 $kg.ha^{-1}$) + Haloskyfop-R (1 $L. ha^{-1}$); Deltamethrin (0.03 $kg.ha^{-1}$) + Triazophos (0.42 $kg.ha^{-1}$) + Lindane (0.56 $kg.ha^{-1}$); Dimethoate (0.34 $kg.ha^{-1}$)	2 – 10
Lignocellulosic crops	Miscanthus	Bromoxynil (2 $L.ha^{-1}$) + MCPA (0.3 $kg.ha^{-1}$) + MCPB (1.7 $kg.ha^{-1}$), 1st year + Glyphosate (4 $L.ha^{-1}$), 2nd year onwards; No weeding or disease control necessary	0 – 15
	Giant reed	No weeding or disease control necessary	0
	Cardoon	Captan (9 $kg.ha^{-1}$) + Dimetoate (0.2 $kg.ha^{-1}$) + Linuron (0.4 $kg.ha^{-1}$) + Alachlor (1.5 $kg.ha^{-1}$), 1st year; No weeding or disease control necessary	0-4
Woody crops	Poplar	Glyphosate (4 $L.ha^{-1}$), 1st year + Methylpirimidos (0.5 $L.ha^{-1}$), 2nd-6th years + Propineb 70% (0.5 $L.ha^{-1}$), 7th-16th years + Methylpirimidos (0.5 $L.ha^{-1}$), 7th-16th years; No weeding or disease control necessary	0-5
	Willow	Captan (1.5 $kg.ha^{-1}$), 1st year; No weeding or disease control necessary	0-3
	Eucalyptus	No weeding or disease control necessary	0

Table A.2. - Pesticides application and pesticide score found for each crop, in the Mediterranean Europe (cont.).

Type of crop	Crop	Application options[1]	Pesticide score[2]
Food crops	Wheat	Mesosulfuron-methyl (0.012 $kg.ha^{-1}$) + Iodosulfuron-methyl-sodium (0.0024 $kg.ha^{-1}$) + Chlorotoluron (1.1 $kg.ha^{-1}$) + Diflufenican (0.069 $kg.ha^{-1}$); Glyphosate (1 $L.ha^{-1}$) + Tebuconazol (0.25 $kg.ha^{-1}$) + Chlorotoluron (6.03 $kg.ha^{-1}$); Glyphosate (1 $L.ha^{-1}$) + Chlorotoluron (6.03 $kg.ha^{-1}$)	5 – 28
	Potato	Mancozeb (0.87 $kg.ha^{-1}$) + Propamocarb (0.45 $kg.ha^{-1}$) + Metalaxyl-M (0.32 $kg.ha^{-1}$); Mancozeb (0.25 $kg.ha^{-1}$) + Cymoxanil (0.01 $kg.ha^{-1}$) + Metalaxyl-M (0.01 $kg.ha^{-1}$); Mancozeb (0.39 $kg.ha^{-1}$) + Cymoxanil (0.05 $kg.ha^{-1}$); Mancozeb (0.29 $kg.ha^{-1}$); Mancozeb (14.78 $kg.ha^{-1}$) + Prosulfocarb (2.25 $kg.ha^{-1}$) + Metiram (0.50 $kg.ha^{-1}$); Mancozeb (3.06 $kg.ha^{-1}$) + Propamocarb (0.36 $kg.ha^{-1}$) + Chlorothalonil (0.36 $kg.ha^{-1}$) + Metribuzin (0.28 $kg.ha^{-1}$) + Chlorpyrifos (0.25 $kg.ha^{-1}$); Mancozeb (8.61 $kg.ha^{-1}$) + Fluazinam (0.42 $kg.ha^{-1}$) + Prosulfocarb (0.39 $kg.ha^{-1}$) + Aclonifen (0.33 $kg.ha^{-1}$) + Diquat (0.22 $kg.ha^{-1}$); Mancozeb (2.45 $kg.ha^{-1}$) + Prosulfocarb (1.07 $kg.ha^{-1}$) + Metiram (0.52 $kg.ha^{-1}$) + Propamocarb (0.31 $kg.ha^{-1}$); Mancozeb (0.46 $kg.ha^{-1}$) + Chlorothalonil (0.16 $kg.ha^{-1}$) + Linuron (0.08 $kg.ha^{-1}$) + Propamocarb (0.07 $kg.ha^{-1}$); Mancozeb (2.81 $kg.ha^{-1}$) + Chlorpyrifos (0.76 $kg.ha^{-1}$) + Cypermethrin (0.19 $kg.ha^{-1}$) + Cymoxanil (0.10 $kg.ha^{-1}$) + Bentazone (0.10 $kg.ha^{-1}$); Mancozeb (1.58 $kg.ha^{-1}$) + Chlorothalonil (0.42 $kg.ha^{-1}$) + Propamocarb (0.38 $kg.ha^{-1}$) + Metribuzin (0.31 $kg.ha^{-1}$) + Terbutryn (0.19 $kg.ha^{-1}$); Mancozeb (18.71 $kg.ha^{-1}$); Mancozeb (9.42 $kg.ha^{-1}$) + 1,3 Dicholopropene (3.05 $kg.ha^{-1}$) + Cymoxanil (0.46 $kg.ha^{-1}$); Mancozeb (11.33 $kg.ha^{-1}$) + Prosulfocarb (1.87 $kg.ha^{-1}$) + Folpet (1.59 $kg.ha^{-1}$); Mancozeb (4.30 $kg.ha^{-1}$) + Metiram (2.73 $kg.ha^{-1}$) + Prosulfocarb (0.69 $kg.ha^{-1}$) + Chlorothalonil (0.65 $kg.ha^{-1}$); Mancozeb (2.16 $kg.ha^{-1}$) + 1,3 Dicholopropene (1.68 $kg.ha^{-1}$) + Cymoxanil (0.14 $kg.ha^{-1}$); Mancozeb (3.44 $kg.ha^{-1}$) + 1,3 Dicholopropene (19 $kg.ha^{-1}$) + Cymoxanil (10 $kg.ha^{-1}$); Mancozeb (1.07 $kg.ha^{-1}$) + Copper (0.35 $kg.ha^{-1}$) + Pendimethalin (0.18 $kg.ha^{-1}$) + Sulphur (0.15 $kg.ha^{-1}$); 1,3 Dichloropropene (2.75 $kg.ha^{-1}$) + Mancozeb (1.89 $kg.ha^{-1}$) + Paraquat (0.61 $kg.ha^{-1}$)	2– 146

1) Bernesson *et al.* (2004), Bullard and Metcalfe (2001), Cardone *et al*. (2003), El Bassam (1998), Eurostat (2007), Ferguson *et al.* (1997), Gasol *et al*., (2009), Göksoy *et al.* (2004), Lima *et al*. (1998), Luger (2003a) Raccuia and Melilli (2007), Tzilivakis *et al. (*2005), UNDP and GEF (2004), van der Werf and Turunen (2008), WDA (2009) and own field experience.

2) EAWAG (2009), EPA (2009), EXTOXNET (2009), FAO (2007a, 2009), HC-SC (2009), INCHEM (2009), IUPAC (2009), MAL (2009), PAN (2009), PMEP (2009), SpecLab (2009)