Future Crops for Food, Feed, Fiber and Fuel
4F Crops

WP2 - Task 2.1 Choice of the crops

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1. Introduction

Within the next ten-year period the use of biomasses for different purposes should triplicate due to the extensiveness of dedicated crops which should increase from the present 2.8% to the 50% of total biomasses by the year 2030 (Biomass Action Plan, 2005). In Europe, a recent Directive mandated the use of 10% biofuels by 2020, which means that between 17.5 and 21.1 million hectares of arable land will have to be dedicated to the production of energy crops. (Özdemir et al., 2009; AGRI G-2/WM, 2007). The theoretical area that could be available for the cultivation of non-food crops in Europe by the year 2020 was estimated at about 20.3 million hectares, coming mainly from fallowed land (Krasuska et al., 2010).

A great advantage of the agro-energetic sector is the possibility to point out towards different energy markets (electricity, biofuels, bio-products, etc.) simply varying the crops or changing the single crop destination in relation to specific situations or market requirements (Zegada Lizarazu et al., 2010). Biodiesel and bioethanol chains, in fact, in same cases already existing in large scale (i.e. Brazil and USA for bioethanol production, Germany for biodiesel), are based on traditional crops (i.e. sugarcane or maize and rapeseed) and well-known processes (i.e. fermentation or transesterification).

The Strategic Research Agenda (SRA) of the EU aims to provide solutions and highlight the Research, Technology Development and demonstration effort required to achieve the Vision for Biofuel in Europe as set out in the Report of the Biofuel Research Advisory Council. The document reports that “A wide range of biomass feedstocks of different origin and composition could be used for production of transport biofuels as new technology is produced”, and many food crops may contribute to biofuel production, but it is also possible to increase the production of dedicated crops, the ‘energy crops’, “that are bred and cultivated to produce biomass with specific traits that favour their use as an energy vector”.

The ‘Energy crops’, annual or perennial species which have been studied in the last 15 years to assess their adaptation, yield potentials and quality characteristics under different soil-climatic conditions, today include oilseed crops, sugar and starch crops, lignocellulosic and woody crops. To this purpose, the progress required in developing energy crops indicated:

- maximisation of yield and crop resistance to biotic and abiotic factors (pests, diseases, water scarcity, rising temperature, etc.);

- innovative cropping systems to allow efficient, bulk material production for food, feed, fiber and fuel (4F agricultural systems);

- exploitation of marginal lands.

In the field of production of energy crops in all EU countries, table 1 shows the wide range of crops has been tested as energy crops in Europe (Vanandal et al., 1997). Crops were grouped regarding their end use product, as discussed above; some crops, such as cardoon or hemp could be used either as oil or lignocellulosic production.

In the short period research should be addressed toward a production and management practises optimisation; in the long period should point out the plant breeding in order to increase yield and crop production efficiency, yield stability in different environments and energy plant rotation systems, but also innovative cropping systems which include soil no tillage, double cropping and multifunctional land use, potential of marginal land cultivation and low input systems.

In each region or environmental zone, the choice of the crops depends, primarily, upon its suitability to the:

- climatic constraints (rainfall, maximum and minimum temperature) and presence of water for irrigation if needed;
- soil conditions (arable good soil, marginal soil).

If potential yields of the region are sufficient for industrial development (medium and large scale) other constraints to be considered are:

- existing varieties suitable to the region (breeding activity);
- propagation material;
- knowledge of agronomic practices (soil tillage, sowing methods, fertilisation, crop protection, harvest time);
- mechanisation (establishment, sowing, harvest);
- logistics (transport, storage);
- Farmer’s acceptance.

Taking in mind the above mentioned factors, the present task (2.1) focuses on the choice of the crop for the entire European area, analyzing the effects of the climatic condition over the selected crop and crop constrains for possible suggestions of new energy crops in EU.

Table 1 - Annual and perennial species which have been studied as energy crops (Vanandaal et al., 1997)

Scientific name	Common name
Oil crops	Oil crops
Brassica spp.	Oilseed rape seed
Helianthus annus	Sunflower
Cannabis sativa	Hemp
Linum usitatissimum	Flax
Camelina sativa	False flax
Cynara cardunculus	Cardoon
Sinapis alba	White mustard
Sugar and starch crops	Sugar and starch crops
Beta vulgaris	Sugar beet
Triticum aestivum	Winter wheat
Secale cereale	Winter rye
Triticosecale	Triticale
Hordeum vulgare	Spring barley
Sorghum bicolor	Sweet sorghum
Zea mays	Maize
Solanum tuberosum	Potato
Helianthus tuberosus	Jerusalem artichoke
Opuntia ficus-indica	Prickly pear
Lignocellulosic crops	Lignocellulosic crops
Phalaris arundinacea	Reed canary grass
Miscanthus spp.	Miscanthus
Hibiscus cannabinus	Kenaf
Arundo donax	Giant reed
Cynara cardunculus	Cardoon
Cannabis sativa	Hemp
Linum usitatissimum	Flax
Panicum virgatum	Switchgrass
Phragmites australis	Reed
Reynoutria japonica sachalimensis	Knotweed
Spartina spp.	Spartina (Cordgrass)
Onopordum nervosum	Birch
Woody crops	Woody crops
Salix spp.	Willow
Populus spp.	Poplar
Eucalyptus spp.	Eucalyptus
Alnus spp.	Alder
Robinia pseudoacacia	Black locust
Acacia spp.	
Betula spp.	
Spartium junceum	Broom

2. European climatic zoning

Europe has a quite different climatic condition, ranging form typical warm-semi-arid environment of southern to cold temperate ones of northern. In order to analyse the climatic constraints we decided to use the following environmental stratification of Europe suggested by Metzger et al. (2005), assuming similar environmental parameters where agriculture land could be suitable for non-food crops cultivation (see Annex I). Among the bioclimatic areas indicated, we selected the following environmental zones characterized by the subsequent meteorological parameters: maximum and minimum temperature (ºC), rainfalls (mm), number of months < 0 ºC, active temperature > 10°C and length of the growing season (days). Nemoral, Continental (combined with Pannonian), Atlantic North, Atlantic Central, Lusitanian, Mediterranean North and Mediterranean South were considered, while Alpine North and South, Boreal, Anatolian and Mediterranean mountains were not analysed due to the extreme severe temperatures, or the impossibility of growing species different meadow or feed crops.

From an agronomic point of view precipitations and temperatures are main limiting factors for which impose the use of different energy crops for each selected environment (see Annex II).

Abundant precipitations during spring-summer period and sufficiently extended growing season makes Atlantic Central and North quite good zones for agriculture in spring-summer time while during winter time the temperature are too low, mainly in Atlantic North. Nemoral and Continental climate is somewhat less favourable, due to relatively low precipitation during summer time and the amplitude of the annual temperature cycle, which reduces the choice of crops. Lusitanian, Mediterranean North and South with their longer growing season, favourable temperatures, abundant and middle-favourable precipitations respectively for Lusitanian and Mediterranean makes those zones the best suitable for growing different energy crops. A limiting factor for Mediterranean area, particularly for South, is the summer drought that impose the use of irrigation or drought resistant species and varieties for this environment (Table 2).

Table 2 - Meteorological parameters of seven environmental zones. Description of geographic allocation of environmental zones from EBONE (European Biodiversity Observation Network). Active temperatures and length of growing season from (EEA, 2007)

Environmental zone	Temperature (°C)		Rainfall (mm)		Months	Active temperatures	Length growing season
	Min	Max	Oct-Apr	May-Sept	Temp < 0°C	> 10°C	Days
Nemoral[a]	2.4	9.3	309.8	310.8	4.6	2717	196
Continental+Pannonian[b]	4.2	13.1	380.9	393.4	4.1	3294	227
Atlantic North[c]	4.5	11.2	760.7	437.9	1.9	3198	255
Atlantic Central[d]	6.2	13.6	563.5	349.4	0.2	3849	296
Lusitanian[e]	8.4	17.4	851.5	321.7	0.0	4749	353
Mediterranean North[f]	8.2	18.1	477.8	218.1	0.4	5104	335
Mediterranean South[g]	11.2	21.1	470.1	114.4	0.0	6021	363

[a] Nemoral: Finland (South-West); Sweden (Götaland); Poland (North-East Podlaskie, North-East Warminsko-Mazurskie); Estonia; Latvia; Lithuania

[b] Continental: Austria (Medium elevation mountains and foothills, North-Eastern Alpine foothills, Middle Danube plain); Belgium (Ardennes); Bulgaria (foothills of Southern Carpathians, Northern Balkan, low mountains and undulating plains of South-Eastern Europe, valley of Struma, Middle and lower Danube plain); Czech Republic (medium elevation mountains and foothills of CZ, Central, Carpathian foothills, foothills of Tartra); Denmark (Northeast Jutland); Germany (Northern Bavaria, Thüringen, Brandenburg, Sachsen, Pfalz, Schwarzwald-Schwaben, Bavarian Plateau, North-Eastern Alpine foothills, North German plain); Hungary (middle and lower Danube Plain, low mountains and undulating plains of South-Eastern Europe); Lithuania (Baltic coast); Luxembourg; Poland (Northeastern, Carpathian foothills, foothills of Tartra, North German plain, Great Polish plain, Lubland plateau); Romania (Carpathian foothills, Transilvanian uplands, Romanian Moldavia, foothills of Southern Carpathians, Moldavian Plateau, Low mountains of South-Eastern Europe, Balkans, middle and lower Danube plain); Slovakia (Carpathian foothills, foothill of Tartra, Middle Danube Plain)

[c] Atlantic North: Denmark (Jutland, Faroes); Germany (Schleswig Holsten, Niedersachsen, Sachsen Anhalt, Sauerland); Ireland Eire (Northern Ireland); Netherlands (Groningen); United Kingdom (Shetlands, Orkneys, Western Isles, Scottish Highland, Grampian Mountians, Lake District, Snowdonia, South-East Scotland, Pennines, Lancashire, East Wales, Tyne region, Edinburgh)

[d] Atlantic Central: Belgium (Flanders); France (Western Brittany, Dordogne, Picardie, Champagne, Haute Marne, Bassin de Paris, Normandy); Germany (North Rhine-Westphalia); Ireland (Central Ireland Eire, West Ireland); Netherland (West-South Nederland); United Kingdom (South-East UK, South-West Wales, Cornwall)

[e] Lusitanian: France (Atlantic plains of France (Vendée, Saintonge, Médoc, Graves), Les Grandes Landes); Portugal (Beira Litoral, Minho-Beira Baixo); Spain (foothills of the Cantabrian Mountains and West Pyrenees, foothills and low mountains in Galicia and Cantabria, West Cantabrian Coast)

[f] Mediterranean North: France (Southern foothills of Massif Central, Herault, Coast of Corsica, Vaucluse, Aix en Provence); Greece (Paikon, East Rodopi, Northern Egean coast, Chalkidiki, Vermion, Olympus, Ossa, Ionian coast, Thessalin); Italy (Padua-Venetian plain, foothills of the Apennines, Po Valley, Coast of Livorno-Pescara-Brindisi, Central Sardinia, coast of Lazio); Portugal (Middle Duoro, Eastern Beira Baixa, Serra de Gata); Spain (Northern Sierra de la Demanda Southern foothills of Cordillera Cantabrica, Middle Duoro, Eastern Beira Baixa, plains of the Castilla Léon, low mountains of Sierra de Guadarrama, Sistema Ibérica, Southern Pyranees, Sierra de Moncaya, Sierra de Toledo, Coastal mountains Catalunya, mountains Murcua, Albacete)

[g] Mediterranean South: France (Camargue); Greece (Tessaloniki, Tessalia, South Peleponessos, Euboia-Attica-Nauplion, Males-Crete, Zakinthos Kefalinia, Aegean Islands); Italy (North Sicily, Sardinian lowlands, South Italian coast, South Sardinian coast, Southern Sicily); Portugal (Western Algarve, Eastern Alentejo); Spain (Southern Meseta, Zaragoza-Tarragona, Majorca, Sierra de Frenegal, da Ronda, coast Barcelona Perpigan, Sierra Morena and coastal mountains, Southern and Eastern Spain (Estremadura-Guadalquivir, Cartagena-Valencia, Las Marismas, Cabo de Gato).

3. Choice of the crops

The allocation of an energy crop rather than another one should be based on ecology (area of origin, temperature requirements, water requirements, photoperiodic response, nutrients requirements, soil requirements), biology (phenology, growing season, growing habit), crop physiology (radiation use efficiency, water use efficiency, nutrients use efficiency), along with agronomic aspects (years of cultivation, breeding activity, role in crop rotation, propagation material, abiotic and biotic resistance, mechanization).

Currently, agricultural and arable land in the different EU-countries is sharing out with food, feed and, with lesser extent, by energy crops, as shown in table 3.

Wheat is considered one of the most important food crops in the world and in Europe as main carbohydrate source. In Europe, it is widespread in Continental (38%), in the Atlantic Central (22%), Atlantic North (10%) and Mediterranean South (12%) zones respectively; it is less represented in the other bioclimatic zones.

Barley has a main distribution on the Continental (29%) and Atlantic Central area (15%), but also in Atlantic North and Mediterranean North zones (13 and 15%, respectively), whilst in other bioclimatic areas its presence is limited by climatic conditions.

Maize cultivation area is extended to 8 Mha of European arable land, with the most in Continental area (57%). It is also present in Atlantic Central (14%) and Mediterranean North areas (15%). It represents share below 10% in the other European areas, with exception of Nemoral and Atlantic North zones, where air temperature does not permit its cultivation.

Rapeseed is the most important oleaginous crop in Europe. It is more widespread in the Continental zone (43%), but it is well represented in Atlantic North (27%) and Lusitanian (8%) areas. This crop grows in Atlantic North (15%) and Nemoral (< 1%) zones due to its resistance to low temperatures.

In Europe triticale cultivation area is evaluated around to 2.5 Mha. It is more present in Continental zone (70%) and also spread in Atlantic North and Central areas (6 and 13%, respectively), while less represented in the other bioclimatic zones.

Sugar beet is one of the most important crop for the food sugar-based and no food production. It is largely distributed in Continental area (35%), Atlantic Central (30%) and North (12%), respectively. In other bioclimatic zones as Lusitanian, Mediterranean North and South were found lower values.

Other food and feed crops such as sunflower, oats, rye, soybean, alfalfa and fodder crops are much less represented in total agricultural European land.

Table 3 - EU countries and respective climatic zones with sharing of agricultural and arable land currently used with food, feed and energy crops (source: FAOSTAT database).

EU Countries	Climatic Zone	Agricultural Land	Arable land	Current Crops	Agricultural Land use
Hungary	Continental	5.9 million ha 3.1% of EU27 Total Agric. Land	4.6 million ha	Wheat	19%
				Maize	19%
				Sunflower	9%
				Barley	5%
				Triticale	2%
Ireland	Atlantic Central Atlantic North	4.2 million ha 2.2% of EU27 Total Agric. Land	1.2 million ha	Barley	4%
				Wheat	2%
Latvia	Continental Atlantic North	1.7 million ha 0.9% of EU27 Total Agric. Land	1.1 million ha	Wheat	9%
				Barley	8%
				Oats	3%
				Rye	3%
Lithuania	Contin. Atlantic North	2.8 million ha 1.5% of EU27 Total Agric. Land	1.9 million ha	Barley	13%
				Wheat	12%
				Rye	4%
				Oats	2%
				Rapeseed	2%
Luxembourg	Contin.	0.1 million ha 0.1% of EU27 Total Agric. Land	0.06 million ha	Wheat	13%
				Barley	10%
				Rapeseed	5%
				Triticale	3%
Malta	Med. South Lusitan.	0.01million ha 0.0% of EU27 Total Agric. Land	0.009 million ha	Wheat	23%
				Barley	5%
Germany	Continental Atlantic CentralAtlantic North	17 million ha 8.9% of EU27 Total Agric. Land	11.9 million ha	Wheat	19%
				Fodder crop	13%
				Barley	12%
				Rapeseed	8%
				Rye	4%
				Sugar beet	2%
				Triticale	2%
				Maize	2%
Netherlands	Atlantic Central Atlantic North	1.9 million ha 1.0% of EU27 Total Agric. Land	0.9 million ha	Wheat	7%
				Sugar beet	4%
				Barley	2%
				Maize	1%
Poland	Continental	15.9 million ha 8.3% of EU27 Total Agric. Land	12.1 million ha	Wheat	15%
				Rye	10
				Barley	7%
				Triticale	7%
				Maize	2%
				Sugar beet	2%
Romania	Continental Pannonian	14,5 million ha 7.6% of EU27 Total Agric. Land	9.3 million ha	Maize	15%
				Wheat	13%
				Sunflower	6%
				Barley	3%
				Alfalfa	2%
				Rapeseed	2%
				Soybean	1%

Italy	Med. North Med. South	14,7 million ha 7.7% of EU27 Total Agric. Land	7.7 million ha	Wheat Maize Alfalfa Barley Soybean Sugar beet Sunflower	14% 7% 5% 2% 1% 1% 1%
Spain	Lusitanian Med. North Med. South	29 million ha 15.1% of EU27 Total Agric. Land	13.7 million ha	Barley Wheat Sunflower Maize Alfalfa	11% 6% 2% 1% 1%
Portugal	Lusitanian Med. North Med. South	3,7 million ha 1.9% of EU27 Total Agric. Land	1.5 million ha	Maize Wheat Barley	3% 2% 1%
Greece	Med. North Med. South	8,4 million ha 4.4% of EU27 Total Agric. Land	2.6 million ha	Wheat Barley Maize	8% 2% 1%
France	Atlantic Central Atlantic North	29.6 million ha 15.5% of EU27 Total Agric. Land	18.5 million ha	Wheat Barley Maize Rapeseed Sunflower Sugar beet Alfalfa	18% 6% 5% 5% 2% 1% 1%
UK	Atlantic central Atlantic North	16,6 million ha 8.7% of EU27 Total Agric. Land	5.7 million ha	Wheat Barley Rapeseed Sugar beet	11% 5% 4% 1%
Austria	Contin.	3.2 million ha 1.7% of EU27 Total Agric. Land	1.4 million ha	Wheat Barley Maize Fodder grass	8% 6% 5% 4%
Belgium	Atlantic Central	1.4 million ha 0.7% of EU27 Total Agric. Land	0.8 million ha	Wheat Sugar beet Maize Barley	14% 7% 4% 3%
Bulgaria	Contin. Panonian	5.3 million ha 2.8% of EU27 Total Agric. Land	3.2 million ha	Wheat Sunflower Maize Barley	16% 10% 6% 4%
Estonia	Contin. Atlantic North	0.8 million ha 0.4% of EU27 Total Agric. Land	0.6 million ha	Forage crops Barley Oats Wheat	29% 24% 5% 4%
Slovakia	Contin..	1.9 million ha 1.0% of EU27 Total Agric. Land	1.4 million ha	Maize Wheat Barley Sunflower Sugar beet	18% 13% 8% 7% 2%
Slovenia	Contin.	0.5 million ha 0.3% of EU27 Total Agric. Land	0.2 million ha	Maize Wheat Barley	8% 6% 3%

Sweden	Atlantic Central Atlantic North	3.2 million ha 1.7% of EU27 Total Agricultural Land	2.7 million ha	Barley	13%
				Wheat	11%
				Oats	8%
				Rapeseed	2%
				Sugar Beet	2%
Cyprus	Lusitan. Med. South	0.1 million ha 0.1% of EU27 Total Agricultural Land	0.1 million ha	Barley	45%
				Wheat	6%

In general, all plant species could be used as feedstock for bioenergy generation, but only a limited number of them meet the standard requirements of a good energy feedstock to be used in transport (first and second generation biofuels), electricity, and heating(Zegada-Lizarazu and Monti, 2010). Due to their origin as a cultivated resource, biofuels are closely related to the production of annual crops, while electricity and heating are related to the production of perennial herbaceous and woody crops (Biomass action plan, 2005). However, the agronomic management of the vast majority of potential energy crops remains undeveloped. In the coming years the spectrum uses of annual, herbaceous perennials, and woody crops could be broadened to cover second generation liquid biofuels which can be based on a wide range of feedstock, but in terms of crop substrate, second-generation biofuels are based on lignocellulosic crops, both annual or perennial and part of crop rich in lignocelluloses, such as the stover of cereals. Even though such crops are considered to be the future of the bioenergy industry, the transition from first- to second-generation biofuels still faces technological constraints. The lack of cost-effective conversion technologies to break down lignocellulosic biomass into sugar, in the case of fermentation routes, inhibits the rapid development of specialized crop species and agronomic practices that would optimize their production (Yuan et al., 2008).

The so-called “bioenergy crops” could be divided into conventional or of new introduction; among conventional, annual crops such as rapeseed, sunflower, soybean, safflower, sugar beet, maize, flax, hemp and kenaf are commonly grown as rotational for food, feed and fiber; when used as bioenergy crops their requirements should be not very different from when they are used for their traditional purpose.

Among the crops of new introduction, sweet and fiber sorghum (*Sorghum bicolor* L. Moench), C4 annual crops native from tropical areas, are characterized by a high yield potential and a great resistance to long drought periods due to its evapotranspiration coefficient considerably lower than those of other ethanol crops, such as maize (Dercas and Liakatas, 1999; Geng et al., 1989; Smith and Buxton, 1993). However, the susceptibility of sorghum to low temperatures impedes its cultivation at high latitudes (Zegada Lizarazu et al., 2010). A major advantage of cultivating sweet sorghum as an energy crop is its easy and relatively cheap establishment by seeds, although finding seeds of appropriate cultivars is problematic. Several sorghum hybrids have been developed and improved through the years for the production of lignocellulosic, sugar, and starch feedstock but its development as an energy crop is still far behind ethanol crops such as maize, sugarbeet, and sugarcane.(Rooney et al., 2007; Dercas and Liakatas, 1999).

At present, due to its requirements, sorghum can be cultivated from Continental to Mediterranean environmental zones (Dalianis 1996; AIR CT 92 0041; FAIR CT 96 1913).

Ethiopian mustard (*Brassica carinata* A. Braun), native to the Ethiopian highlands, is one example of a large number of oil crops being considered for biodiesel production. Unlike well-known oilseed crops such as sunflower, soybean, and rapeseed, among others, the agronomic practices of Ethiopian mustard had received little attention. In general, crop management practices, such as sowing, fertilization, harvesting, and other cultural methods used for rapeseed can easily be adapted to Ethiopian mustard production. Moreover, the better adaptability of Ethiopian mustard than rapeseed to sub-optimal growing conditions, such as high temperatures and low rainfall, makes it a suitable new oil crop for the Mediterranean climates of southern Europe. Cardone et al., 2003; Copani et al., 2009; Cosentino et al., 2008).

Reed canarygrass (*Phalaris arundinacea* L.) is a perennial C3 grass native to the temperate regions of Europe, Asia and North America. Reed canarygrass is used as a forage crop mainly in North America, but also to some extent in Eastern Europe, Scandinavia and Japan. In Middle Europe it was used as fodder for horses until the 19th century (Lewandowski et al., 2003). It is adapted to and grows very well in a cool temperate climate. It has also good winter hardiness and survives very well in northern Scandinavia. Reed canarygrass is a persistent species, which grows well on most kinds of soils (Østrem, 1987). It is one of the best grass species for poorly drained soils and tolerates flooding better then other cool-season grasses (Lewandowski et al., 2003). Reed canarygrass is established by seeding and usually harvested in summer and autumn when the soil is dry enough for carrying the harvesting machinery and the crop is dry enough for storage without artificial drying.

Miscanthus (*Miscanthus* spp.), rhizomatous C4 perennial grass, has a broad genetic base which enables enough adapted varieties and hybrids for different site conditions in Europe. It could be cultivated in all environmental zones of Europe, except in Nemoral and Mediterranean South where no resistance to extreme cold at the transplanting year and necessity of supplementary irrigation is needed (Cosentino et al., 2008).

Its establishment is usually carried out by rhizomes or by in vitro culture. Methods for macro-propagation (i.e. mechanical cutting of rhizomes in the field), are under development. To avoid frost damage planting should be done when the frost period is finished. The optimal planting density is 1 to 2 plants m^{-2} (Lewandowski et al., 2003). In general, irrigation during the first growing season improves establishment rates.

Growth begins when soil temperatures reach 10 – 12 °C (Clifton-Brown, 1997). Leaf expansion occurs between 5 - 10 °C, depending on the genotypes (Clifton-Brown and Jones, 1997). The main problem of miscanthus production in northern Europe is the poor over-wintering of the rhizomes of the productive genotype *Miscanthus* × *giganteus* in the first winter after planting (Lewandowski et al., 2003).

Freezing tests showed that *M.* × *giganteus* rhizomes removed from the field in January are killed at temperatures below < - 3.5 °C while the rhizomes of *M. sinensis* survived until < − 6.5 °C (Clifton-Brown and Lewandowski, 2000). Miscanthus can be harvested only once a year since multiple cutting would over-exploit the rhizomes and kill the stands. The harvest depends on the local conditions and is between November and February/April. Late harvest at a water content lower than 30% is recommended because the costs for harvesting and drying of the biomass are increasing with the water content. (Lewandowski et al., 2003).

Switchgrass (*Panicum virgatum* L.), perennial C4 grass is native to North-America, with a wide range of climatic adaptability. It is one of the grasses that dominated the North American tall-grass prairie and become increasingly important as a pasture grass in the central and eastern US because of its ability to be productive during the hot months of summer, when cool-season grasses are less productive. It has high tolerance to severe water stress conditions (Monti et al., 2008), therefore it is expected to be more drought tolerant than Miscanthus (Van der Hilst et al., 2010), however extremely dry summer periods are a fundamental problem for these crops.

The establishment of switchgrass by seeds (about 4 – 10 kg ha^{-1} depending on seed size, dormancy, etc.) is relatively cheap and easy in comparison to Miscanthus one. Seeds germinates very slowly when the soil temperature is below 15.5 °C. Most seedlings will germinate after three days at 29.5 °C. Seed dormancy can be a problem and can be broken by cold stratification (Lewandowski et al., 2003).

Harvest trials have been performed to identify the optimal harvest frequencies and dates. In the South, a two-cut system with harvests in July and October has provided somewhat higher yields under the longer southern growing season and adequate summer soil water, whereas a single cut system may be more advantageous further North. Allowing switchgrass to mature fully and to dry down before harvest results in nutrient translocation. Therefore, late harvesting removes lower levels of nutrients (Wright, 1994).

Giant reed (*Arundo donax* L.) is a lignocellulosic, rhizomatous C3 perennial crop originated from Asia but it is also considered as a native species in the countries surrounding the Mediterranean Sea. Due to its multiple uses e.g. for musical instruments, rayon, paper and pulp, particle boards, hand-woven baskets, fencing, shading or as ornamental (Perdue, 1958) and its high productivity, giant reed has been rapidly widespread by man. It is currently found in India, China, USA, Australia, Southern Africa and in the Mediterranean regions (Rossa et al., 1998). As Miscanthus, giant reed is usually propagated by rhizomes or by in vitro culture. New method options to establish giant reed using stem cuttings have been already reported (Copani et al., 2010).

Even though it is a warm-temperate or subtropical species, it is able to survive short period frost; it prefers soils with abundant moisture but also presents high resistance to drought due to its vigorous root that penetrate deeply into soil (Lewandowski et al., 2003).

Giant reed biomass presents high content of structural polysaccharides (57% by weight) mainly composed by cellulose (36% of glucan), while xylan constitutes the largest fraction of hemicelluloses in giant reed biomass (about 19%). A recent study of Scordia and co-workers (2009) on pretreatment and subsequent simultaneous saccharification and fermentation of the residual solid has shown the great potentiality of giant reed as feedstock for second generation bioethanol bioconversion.

Giant reed can be harvested each year; two harvests per growing period are feasible, but without sustaining high growth rates and total production. In southern EU regions late winter harvest is recommended to attain a reduction in the moisture content of the stems.

Cardoon (*Cynara cardunculus* L.) is native to the Mediterranean regions where it is well adapted to the climates of southern Europe. It is a lignocellulosic and oleaginous perennial crop suitable to drought conditions of the Centre and South Mediterranean. Field experiments in southern Italy demonstrated that under optimum water supply conditions three-year-old giant reed and miscanthus plants used 1023 mm of water while cardoon used only 679 mm (Zegada Lizarazu et a., 2010).

Its propagation occurs by seedling which germinate as soil moisture and air temperature reach the optimal conditions (close to field capacity and 15-25°C, respectively). In Mediterranean environments cardoon establishment is carried out in autumn so that can reach a “rosette” phase and survive wintertime. In the case of early frost, spring sowing is recommended (Fernandez et al., 2006). The amount of seed ranges from 3 to 4 kg ha^{-1}.

Usually its growing season is in autumn-winter and harvested in late summer when moisture content reach its lower value (Foti and Cosentino, 2001; Cosentino et al., 2005b). Due to its multiple usage (e.g. vegetable, natural rennet, soild and liquid biofuels, paper pulp, green forage and pharmacological) and its low water requirements cardoon can be considered as a promising energy crop for oil and lignocellulose production for semi-arid Mediterranean environments (Fernandez et al., 2006).

Poplar (*Populus* spp.), willow (*Salix* spp.), and eucalyptus (*Eucalyptus* spp.) are fast-growing trees that could be established in short rotation coppice systems for the supply of lignocellulosic feedstock to the pulpwood and board industries and as a solid biomass for heat and power generation. In the future, they may also be used as feedstock for second generation liquid biofuels. Although poplar can be grown in warmer climates than willow, both species are more suitable for northern European climates than eucalyptus, which is better suited to warmer climates of southern Europe, especially the *E. globulus* which is the most widely spread species in Mediterranean countries (Rockwood et al., 2008). The dry matter yields of these trees vary widely depending on species/clones, plant density, climate, age, and management practices, so there is a great possibility to optimize productivity when appropriate site-specific choices are made. In general, optimum yields are obtained when they are grown on well-drained, deep, and fertile soils. Willow seems to have a higher nitrogen-demand than poplar, and accumulates biomass more rapidly. (Ceulemans et al., 1996; Jug et al., 1999). Eucalyptus produces best in sandy clay soils, but has the ability to grow in and improve marginal or poor soils (Campinhos, 1999). Vegetative propagation of selected clones is key for enhanced productivity of these trees. Poplar and willow cuttings are usually planted in double rows (two rows of trees planted per bed) during winter and spring. (Kauter et al., 2003; Volk et al., 2004; Mitchell et al., 1999; Rowe et al., 2009). Fall planting is not recommended. Eucalyptus can be reproduced either by seedlings or rooted cutting, with vegetative propagation preferred because of the potential to maintain the improved characteristic of a genotype (Gaspar et al., 2005). During the establishment period fertilization is not recommended, as weeds have higher capacity for nutrient uptake and can make better use of the applied nutrients. (Kauter et al., 2003; Volk et al., 2004; Mitchell et al., 1999; Ledin, 1996). This also depends on site conditions (availability of water and nutrients) and thus plant growth rate. In any case, proper chemical and/or mechanical weed control is essential at this period and after each harvest. Full establishment of poplar and willow takes up to 3–5 years, after which plantations can be harvested in rotation cycles of 3 to 7 years for 25 to 30 years. (Kauter et al., 2003; Keoleian and Volk, 2005; Rowe et al., 2009). Commercial biomass plantations of eucalyptus are usually harvested 6 or 7 years after establishment, with two additional rotations (Bernardo et al., 1998). Short to very short rotations (between 2 and 3 years) are also possible and usually practiced at high planting densities but the resulting increased yields may not compensate the higher establishment costs and increased risks of disease infection. (Kauter et al., 2003; Mitchell et al., 1999; Keoleian and Volk, 2005). Plantations containing mixtures of different species and hybrids may decrease the impact of diseases and pests (Keoleian and Volk, 2005). Although nutrient recycling (from canopy to roots) takes place during the dormant season of poplar and willow, continuous above-ground biomass harvesting cycles may deplete soil nutrients. So under most conditions, fertilization amendments are necessary to maintain productivity (Kauter et al., 2003, Heilman and Norby, 1998). Fertility management also becomes a major issue for eucalyptus grown over successive rotations, especially in poor soils such as those of the Mediterranean regions of Europe where eucalyptus is being intensively cultured (Jones et al., 1999). Several fertilization studies have demonstrated that eucalyptus growth beyond the establishment phase is markedly enhanced by supplemental nitrogen applications, but this should be accompanied with appropriate weed control practices (Adams et al., 2003; Corbeels et al., 2005).

Returning nutrient-rich organic material to the soil after harvest and plant-based fertilizer prescriptions can also help in the fertility management of short rotation plantations (Jones et al., 1999). In the case of eucalyptus, for example, the incorporation of harvest residues into the soil was a more effective way of returning nutrients than simply spreading the residues over the soil surface (Jones et al., 1999). Harvest of poplar and willow takes place while the plants are dormant (winter) so that the maximum amount of nutrients and carbohydrates are translocated to the roots. The availability of these nutrients is essential for maintenance of the plant's vitality and a vigorous sprouting the following spring. Unlike poplar and willow, eucalyptus is evergreen without a clear dormant phase, but results from Portugal suggest that during the harvest season a high ratio of growth inhibitors is produced coinciding with a cessation of stem and leaf growth (Ceulemans et al., 1996). Furthermore, it is reported that eucalyptus has efficient nutrient cycling mechanisms during this phase (Florence, 1986). Therefore winter harvest improves the combustion quality of short rotation trees because of low nutrient and moisture content in that period (Mitchell et al., 1999; Guo and Sims, 1999). However, the remaining moisture in the wood (45 to 60%) is still high, resulting in low calorific values if used immediately after harvest.

Harvesting can be performed with a range of commercially available machinery that cuts and chips the biomass in a single operation. Chipping is the most common pre-treatment used, usually carried out with mobile chippers. Cutting only the tree trunks and stacking them on site for drying, avoids the moisture-related problems of chips. The decision on the harvest and storage method will depend on the location site and characteristics of the processing plant.

With the development of second generation technologies the introduction of lignocellulosic herbaceous and woody perennials could contribute to the sustainable production of biomass for those promising technologies (EU, 2009/28/CE), as demonstrated by many researches (McKendry, 2002; Cosentino et al., 2004; McLaughlin and Walsh, 1998; Frank et al., 2004; Roth et al., 2005). However, their introduction needs careful considerations beyond agronomic and economic factors both at the national and European level. Establishment of these crops requires long rotation period (at least 15-20 years) that would lead to changes in the traditional agricultural/cultural landscape (Fischer et al., 2010).

The information on the crop for non-food purpose and their viability of been included in farming systems, based on their biological and ecological adaptability to climatic and geographical areas are summarized in table 4.

Table 4 – Main constrains of the selected energy crops

Crop	Temperature (°C)			Water requirement	Frost resistance	Drought resistance
	Seed germination	Growing (Mimimum)	Growing (Maximum)			
Rapeseed	>5	5	30	Medium	High	Medium
E. mustard	>5	5	30	Low	Low	High
Sunflower	10	5	35	Medium	Low	Medium
Hemp	8-10	10	35	High	Medium	Medium
Flax	7-9	8	30	Medium	Medium	Medium
Sorghum spp.	12	10	40	Medium	Low	High
Willow	-	0	30	High	High	Low
Poplar	-	0	30	Medium	Medium	Medium
Eucalyptus	-	5	35	High	Low	High
Reed canarygrass	>7	7	30	High	High	Low
Switchgrass	>15	10	35	Medium	High	Medium/High
Miscanthus	>8	10	40	High	Medium	Low
Giant reed	>5	5	35	Medium	Low	Medium/High
Cardoon	>5	5	35	Low	Low	High

4. Conclusion and recommendations

A wide range of crop species could be used as energy crops, but not all of them meet industry requirements and growers' demands to produce good quality feedstock for bioenergy purposes. Thus, appropriate plant species and production practices need to be identified and improved over time in order to maximize plant characteristics that make their pre-treatment or conversion process easier and less costly. A better understanding of currently available feedstocks, their cropping practices, their potential and actual yields, their geographical distribution, and their costs is required.

In general, the most suitable energy crops in terms of agronomic management, climatic adaptability, and potential biomass production in northern Europe are some fast-growing trees and perennial grasses such as poplar, willow, reed canarygrass, switchgrass and miscanthus. On the other hand, in the Mediterranean climate of southern Europe eucalyptus, sweet sorghum, giant reed and cardoon are promising energy crops (Table 6). In general, most of the crops that could provide feedstock for second-generation biofuels (such as perennial grasses and woody crops) are largely undomesticated and are in the early stages of development and management. Thus, investment in research and development of these crops will result in larger improvements than with traditional crops. Moreover, these crops show some advantages over annual crops in terms of agricultural inputs, yields, production costs, food security, reduced GHG emissions, and environmental sustainability. Important cultivation and management practices that will impact quantitatively and qualitatively on energy crop yields are appropriate selection of species and genotypes; crop establishment; water needs; fertilization timing and rates; control of weeds and pests; and harvest time and method. The decision when to harvest perennial grasses or short rotation tress, for example, faces the tradeoff between maximum biomass yield and quality of the product for energy production purposes. In the same context, increased fertilization could result in undesirable levels of N, P, K, and also ash, in the harvested biomass. Therefore, an in-depth localized evaluation of such factors, as well as their interactions, is necessary to refine cultural practices such as harvesting or fertilization to maximize yields and optimize feedstock quality. Moreover, substantial environmental benefits such as the reduction of soil erosion, nutrient leaching, and the emission of GHGs, at different scale levels, could be achieved by the implementation of appropriate and sound cropping management practices. Storage management of the harvested biomass also needs to be improved to ensure homogeneity of feedstock before and after transportation to the processing facilities. Apart from the required improvements on agronomic management practices, effective dissemination programs should accompany such developments since this is a key issue for the successful introduction of new energy crops in agriculture (Zegada-Lizarazu et al., 2010).

Table 5 – Non food crops in relation to the environmental zone and main product for European Union

MAIN PRODUCT	CLIMATIC AREA						
	Nemoral	Continental	Atlantic Central	Atlantic North	Lusitanian	Mediterranean North	Mediterranean South
Oil	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Rapeseed (*Brassica napus L.* var. *oleifera D.C.*)	Sunflower (*Helianthus annuus* L.)	Ethiopian mustard (*Brassica carinata* A. Braun)
Fiber	Hemp (*Cannabis sativa* L.)	Flax (*Linum usitatissimum* L.)	Flax (*Linum usitatissimum* L.)	Hemp (*Cannabis sativa* L.)	Hemp (*Cannabis sativa* L.)	Hemp (*Cannabis sativa* L.)	Flax (*Linum usitatissimum* L.)
SRC	Willow (*Salix humilis* Marsh.)	Poplar (*Populus* spp.)	Poplar (*Populus* spp.)	Willow (*Salix humilis* Marsh.)	Eucalyptus (*Eucalyptus spp.*)	Poplar (*Populus* spp.)	Eucalyptus (*Eucalyptus spp.*)
Lignocellulosic	Reed canary grass (*Phalaris arundinacea* L.)	Miscanthus (*Miscanthus x giganteus* Greef. et Deu.	Miscanthus (*Miscanthus x giganteus* Greef. et Deu.) Switchgrass (*Panicum virgatum* L.)		Miscanthus (*Miscanthus x giganteus* Greef. et Deu.	Giant reed (*Arundo donax* L.)	Cardoon (*Cynara cardunculus* L. var. *altilis*)
Sugar	-	Sugar beet (*Beta vulgaris* L.)	Sugar beet (*Beta vulgaris* L.)	-	Sweet Sorghum (*Sorghum bicolor* L. Moench)	Sweet Sorghum (*Sorghum bicolor* L. Moench)	Sweet Sorghum (*Sorghum bicolor* L. Moench)

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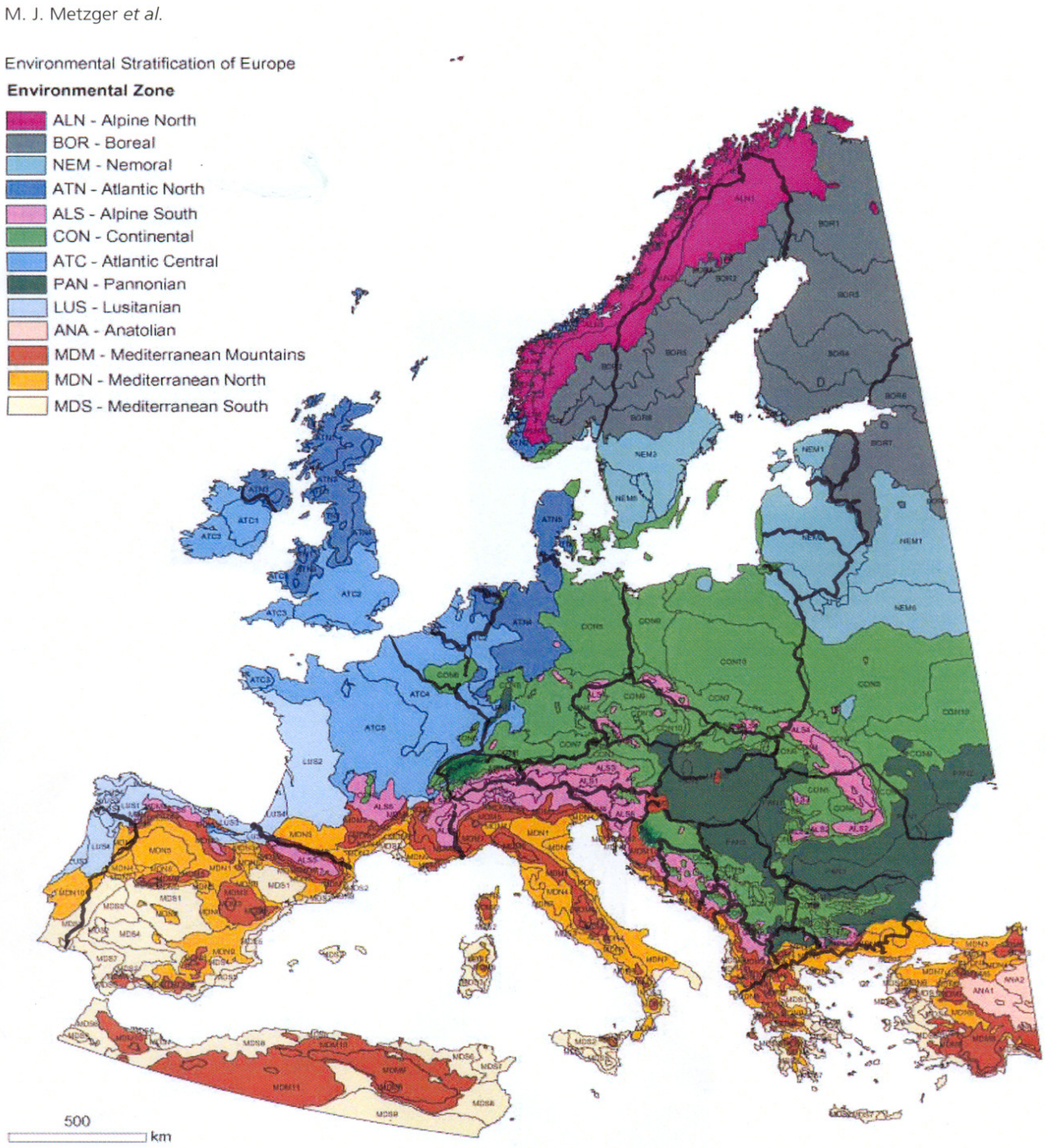
ANNEX I

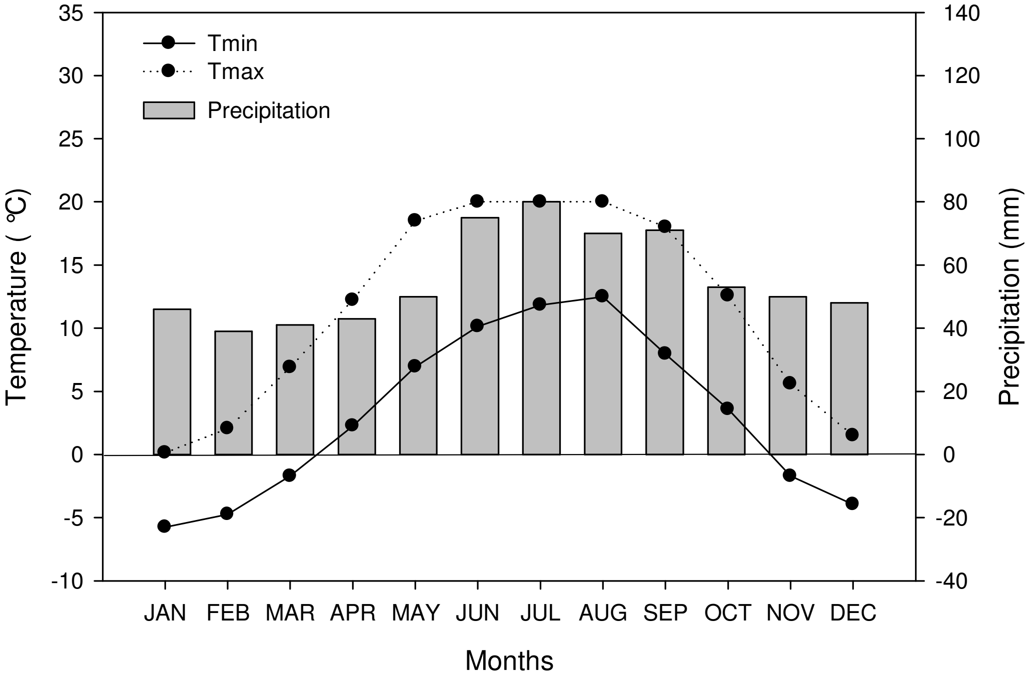
Environmental stratification of Europe (Metger et al., 2005)



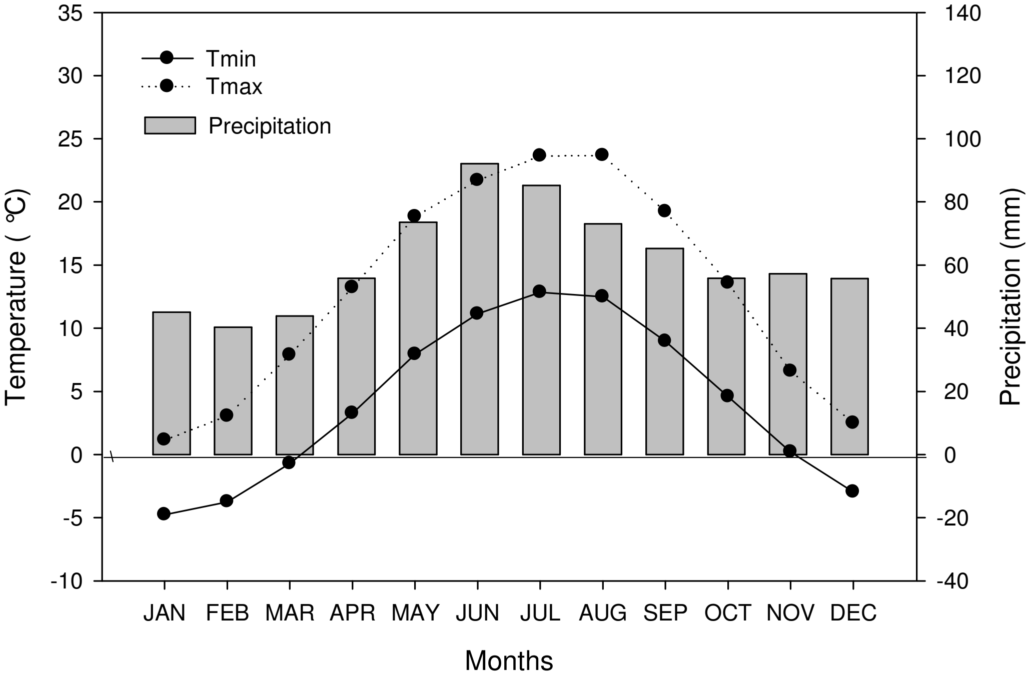
ANNEX II

Trend of minimum temperature, maximum temperature and rainfalls of the different European climatic zones.

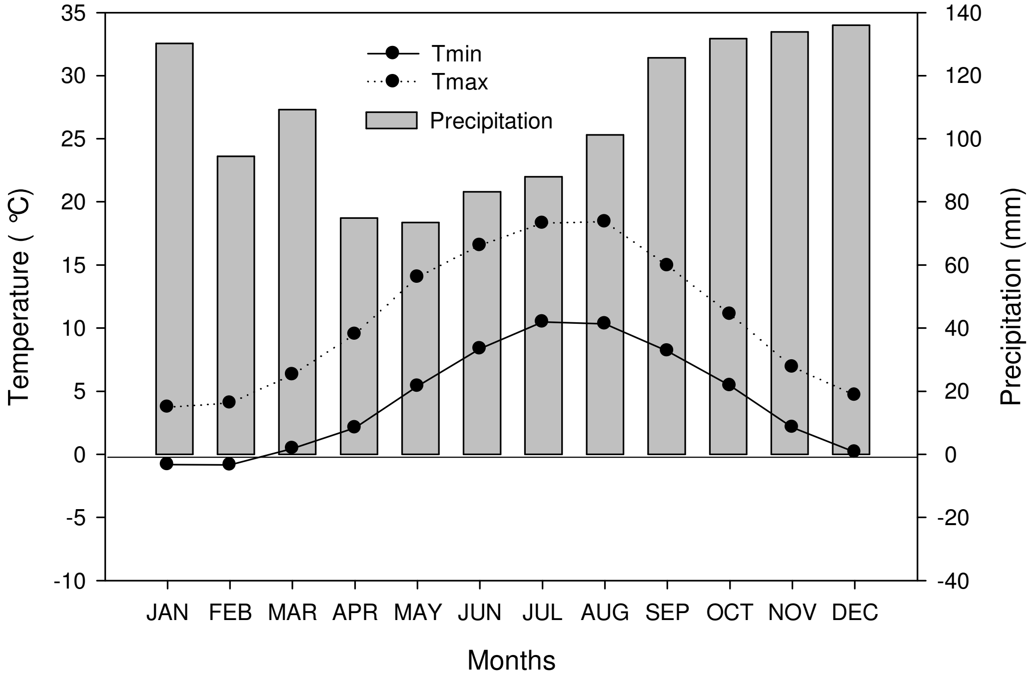
NEMORAL



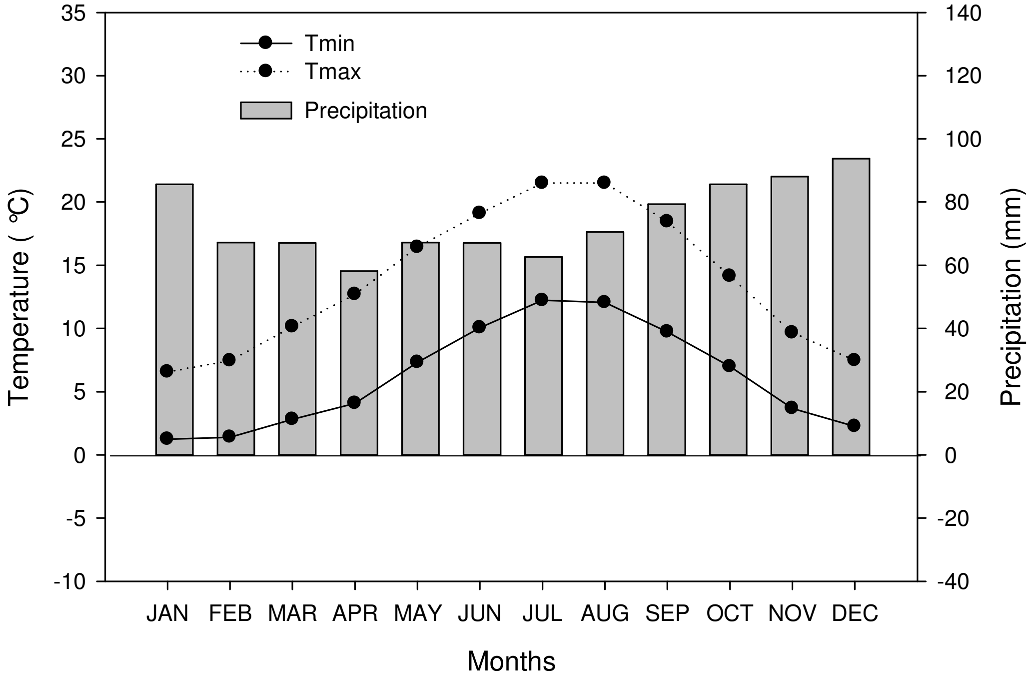
CONTINENTAL

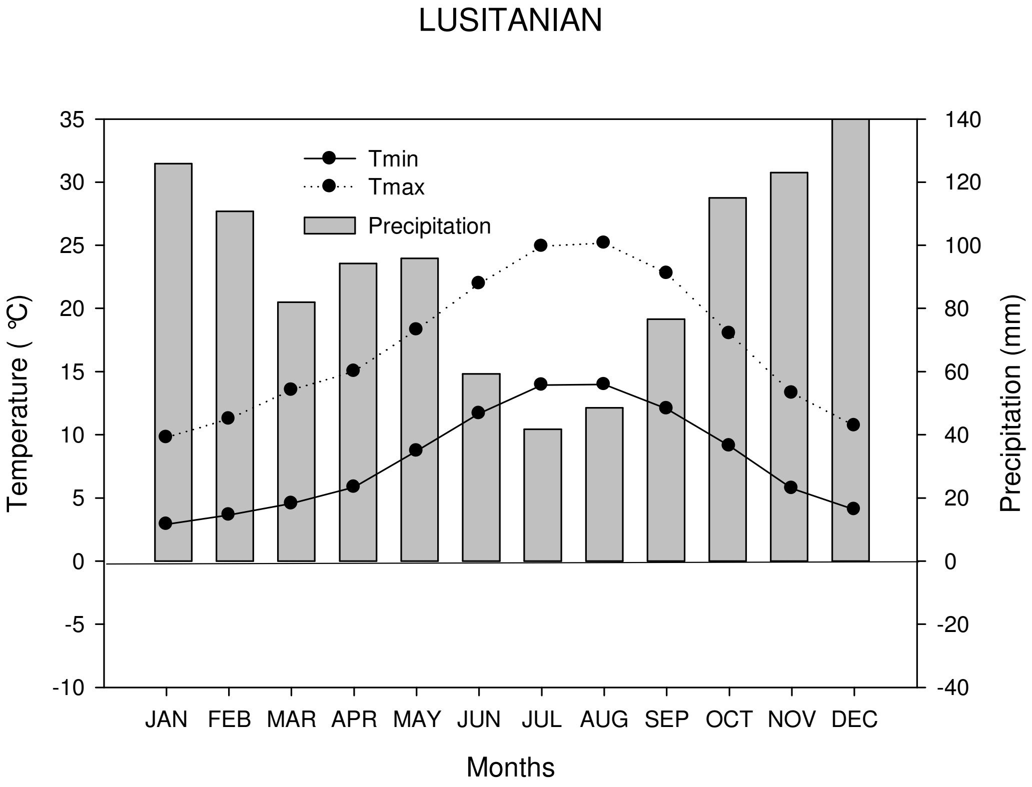


ATLANTIC NORTH

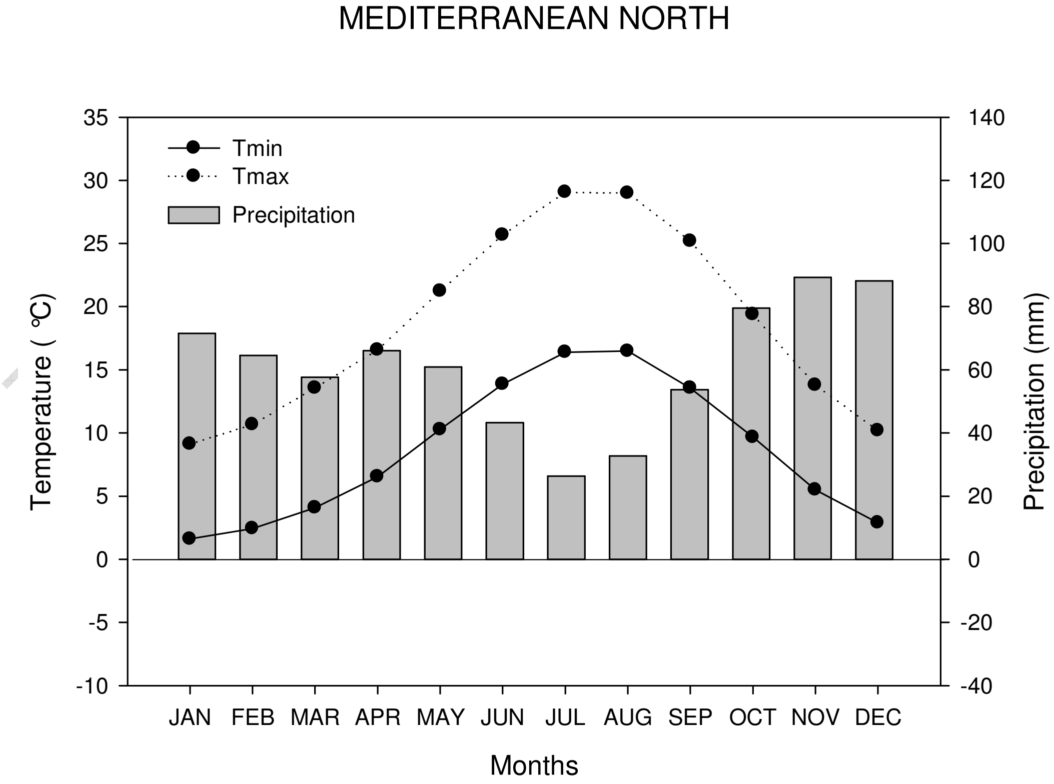


ATLANTIC CENTRAL

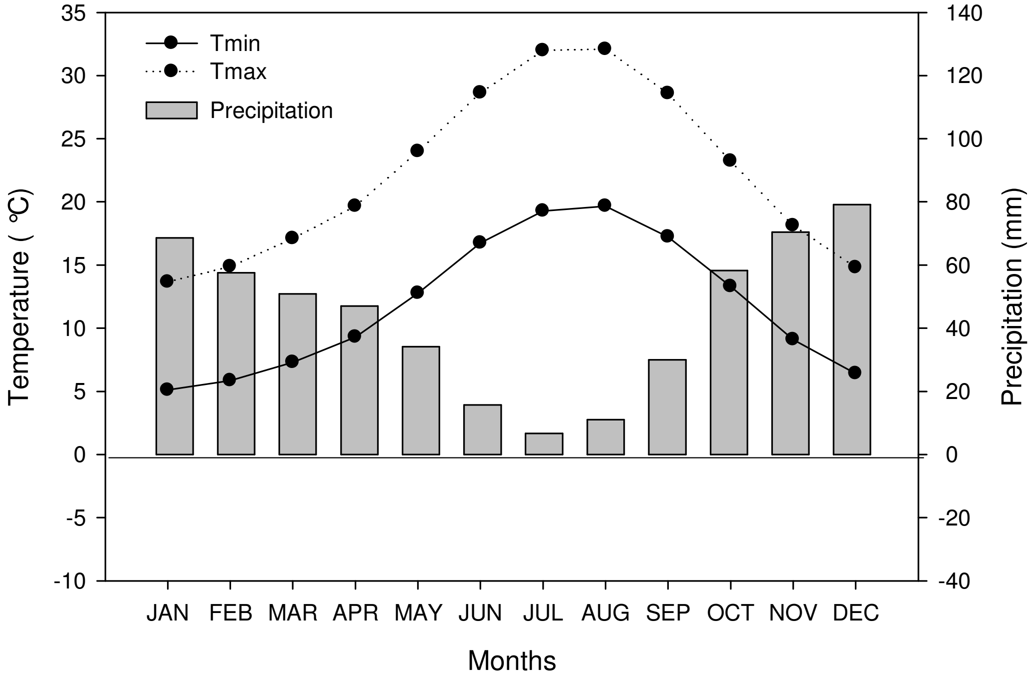




LUSITANIAN



MEDITERRANEAN NORTH



MEDITERRANEAN SOUTH