LA-EU BIOFUELS RESEARCH WORKSHOP

Overview of Energy crops in European Union

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CAMPINAS, SAO PAULO STATE, BRAZIL

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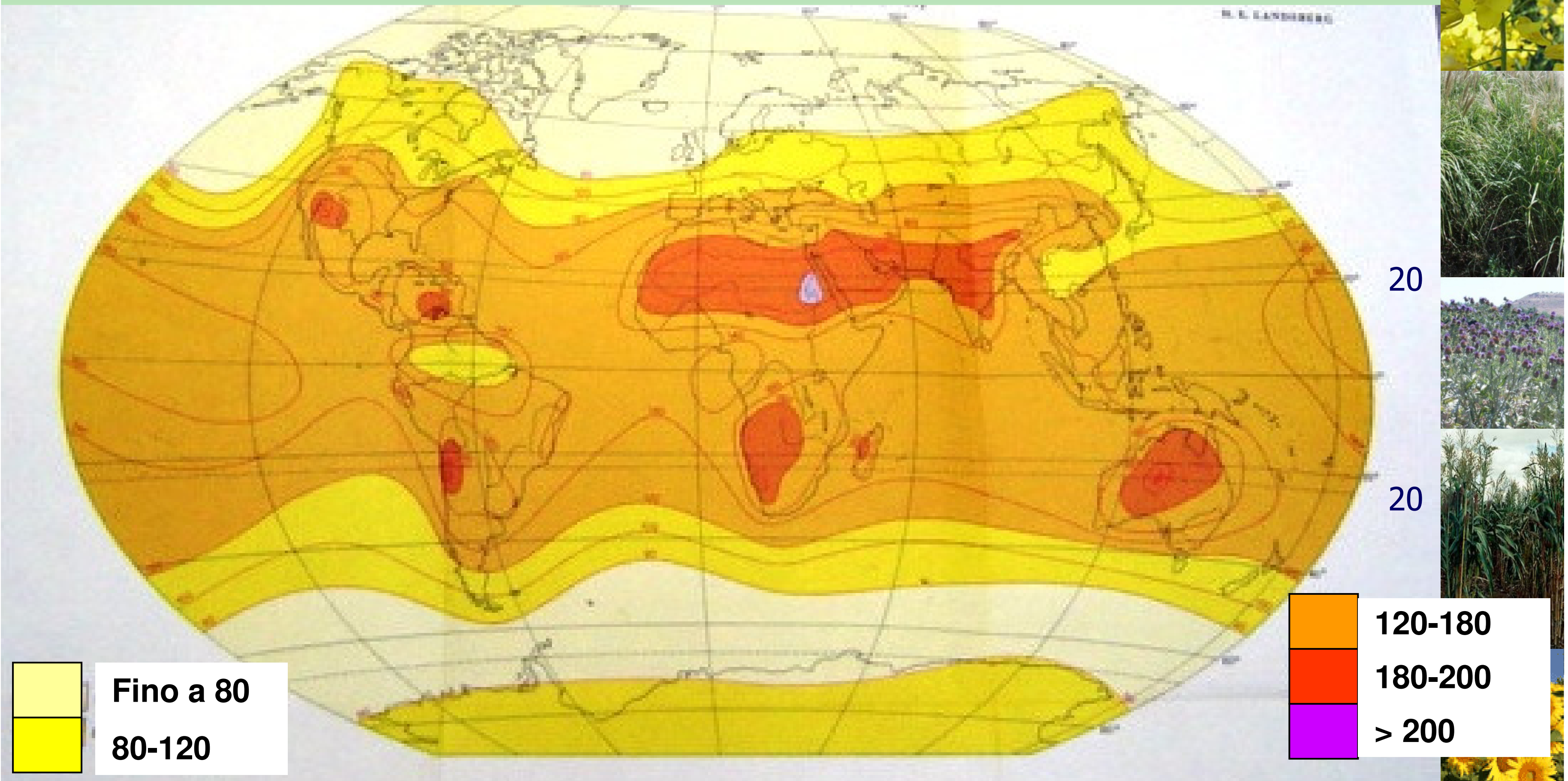
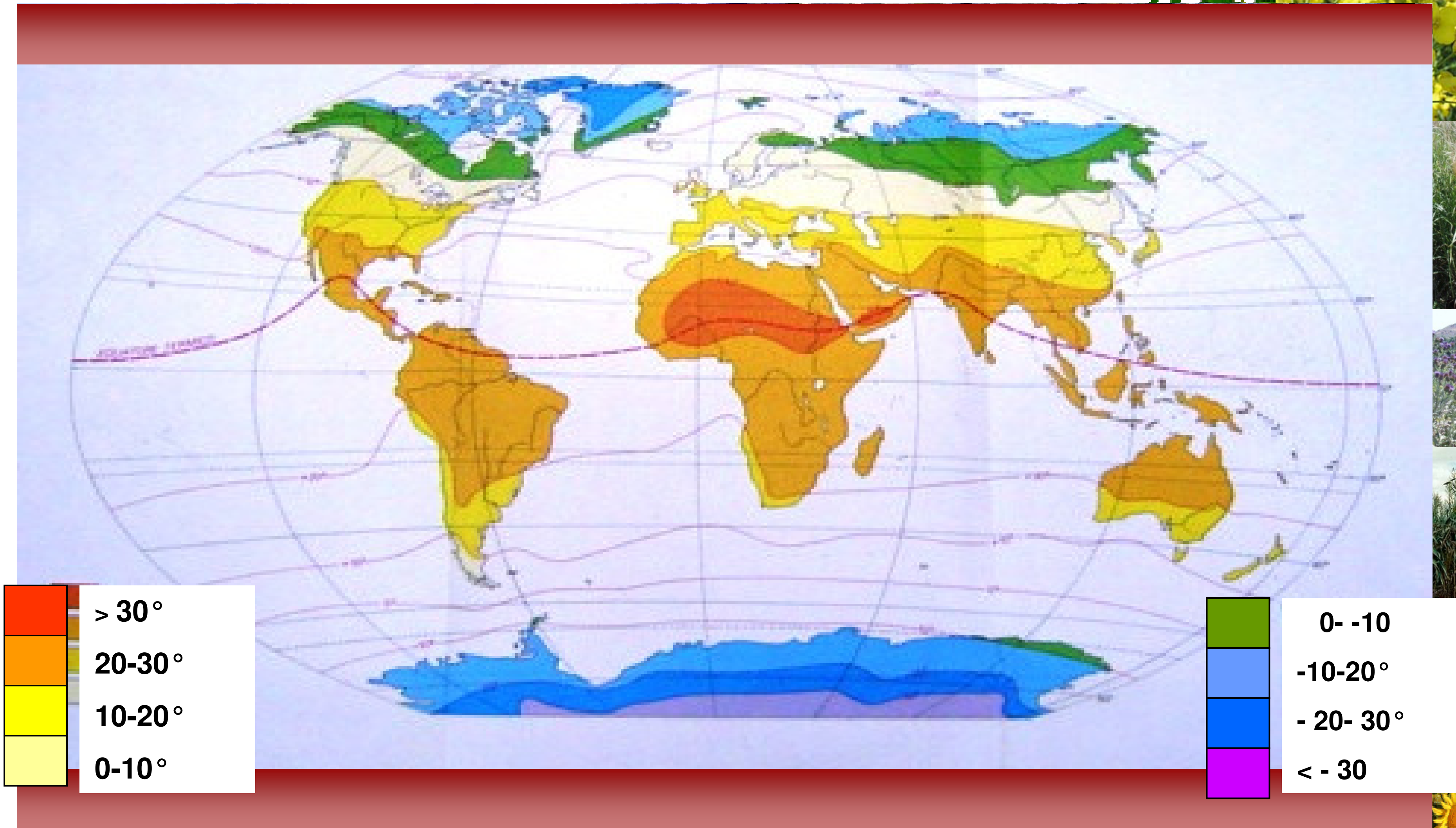
Global solar radiation
(kcal/cm^2/anno)

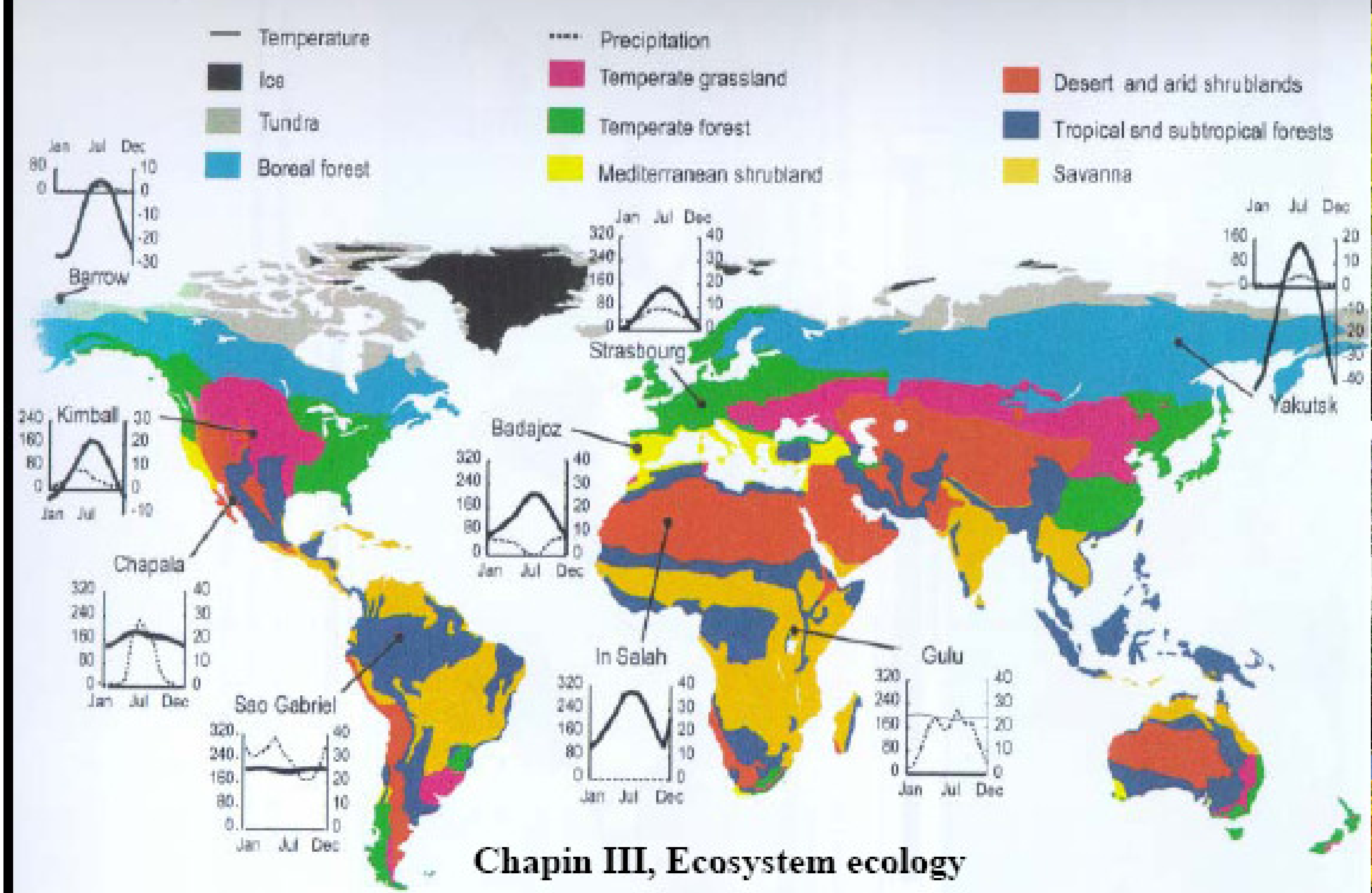


Average temperature at sea level (°C)



Annual average precipitations (mm)

Distribuzione dei maggiori biomi nel mondo



Chapin III, Ecosystem ecology

Energy crops currently used

- **Biogas**
  - Maize
- **Biodiesel**
  - Perennial species
    - Palm oil
    - *Jatropha curcas*

    } Tropical areas
  - Annual species
    - Rapeseed and Brassica spp-
    - Soyabean and sunflower

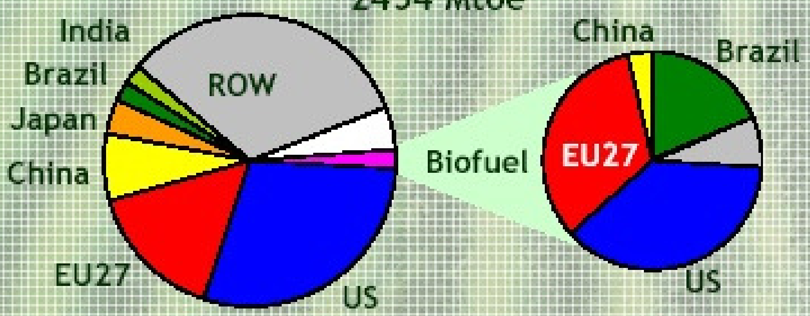
    } Temperate areas
- **Bioethanol**
  - Perennial species
    - Sugar cane (Brasil)

    } Tropical areas
  - Annual species
    - maize (negli Stati Uniti)
    - Sugar beet and wheat (in Europa)

    } Temperate areas
- **Heat and electricity**
  - Crop residues (straw, part of fruit trees, etc.)
  - Forest residues

Biofuels Are Starting to Contribute to World Fuels

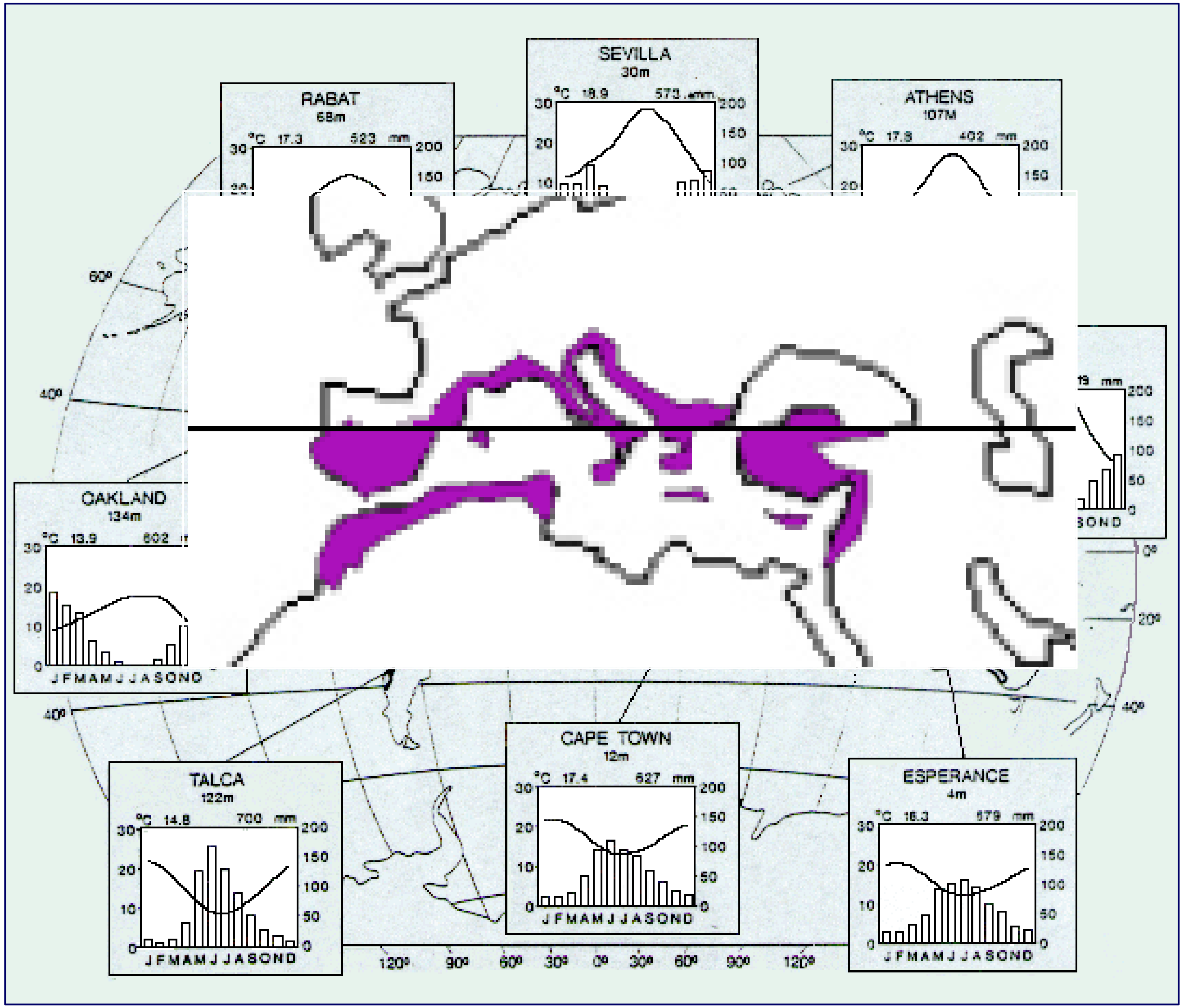
Biofuel Feedstocks, Mandates and Year of Implementation



- World biofuel production to grow 350% by 2015
- World transportation energy demand will grow by 25% during same period

Mtoe = million tonnes of oil
Source: World Energy Outlook 2006, IEA

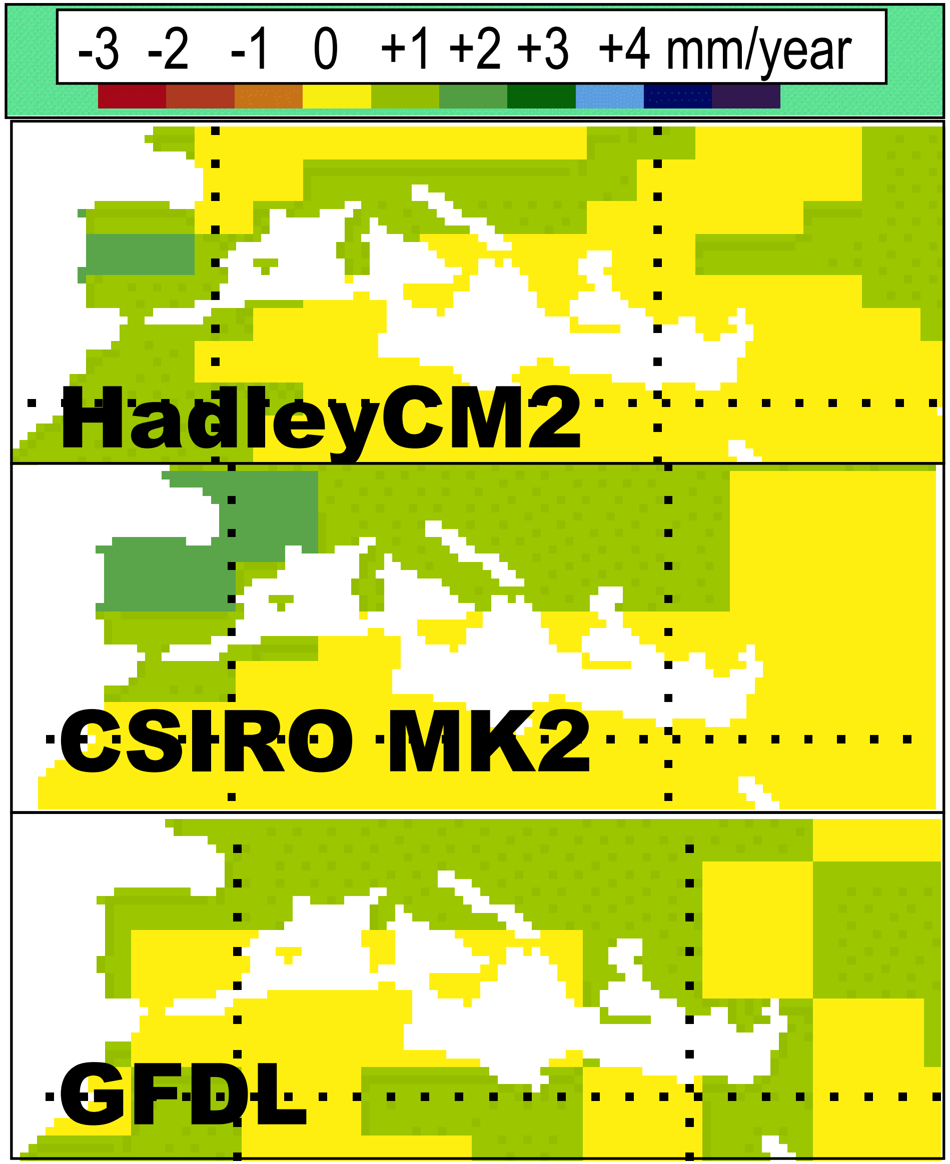
The environments with Mediterranean climate



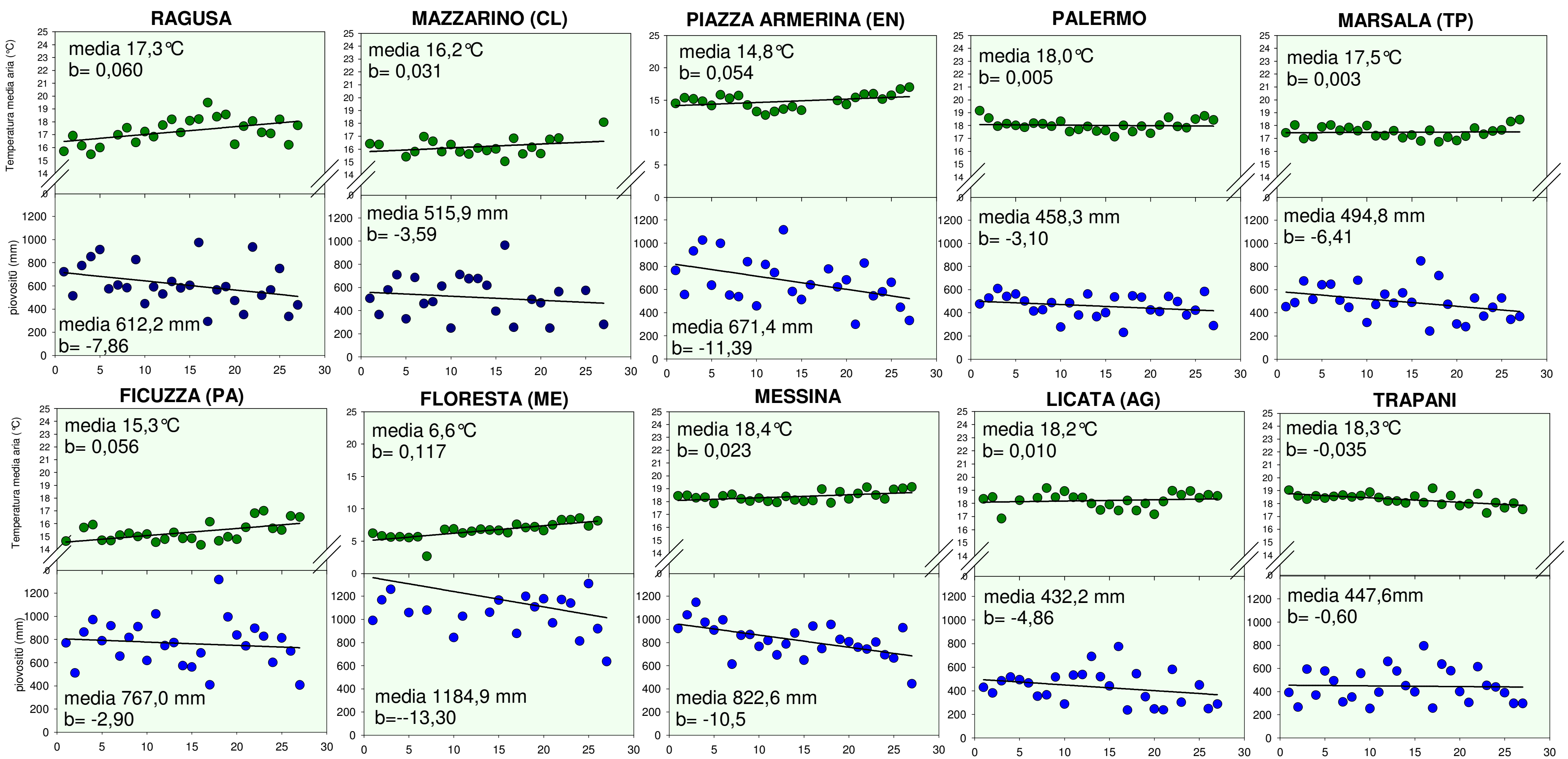
- The 65% of the annual precipitation between November and April
- The annual precipitations range between 275 and 900 mm
- The duration of the temperatures lower than 0°C not higher than 262 hours in a year (< 3% of total annual)

  (***Aschmann, 1973***)

Variation of average annual rainfall at 2050



Variation of average air temperature and rainfall in some localities of Sicily (1960-'90)

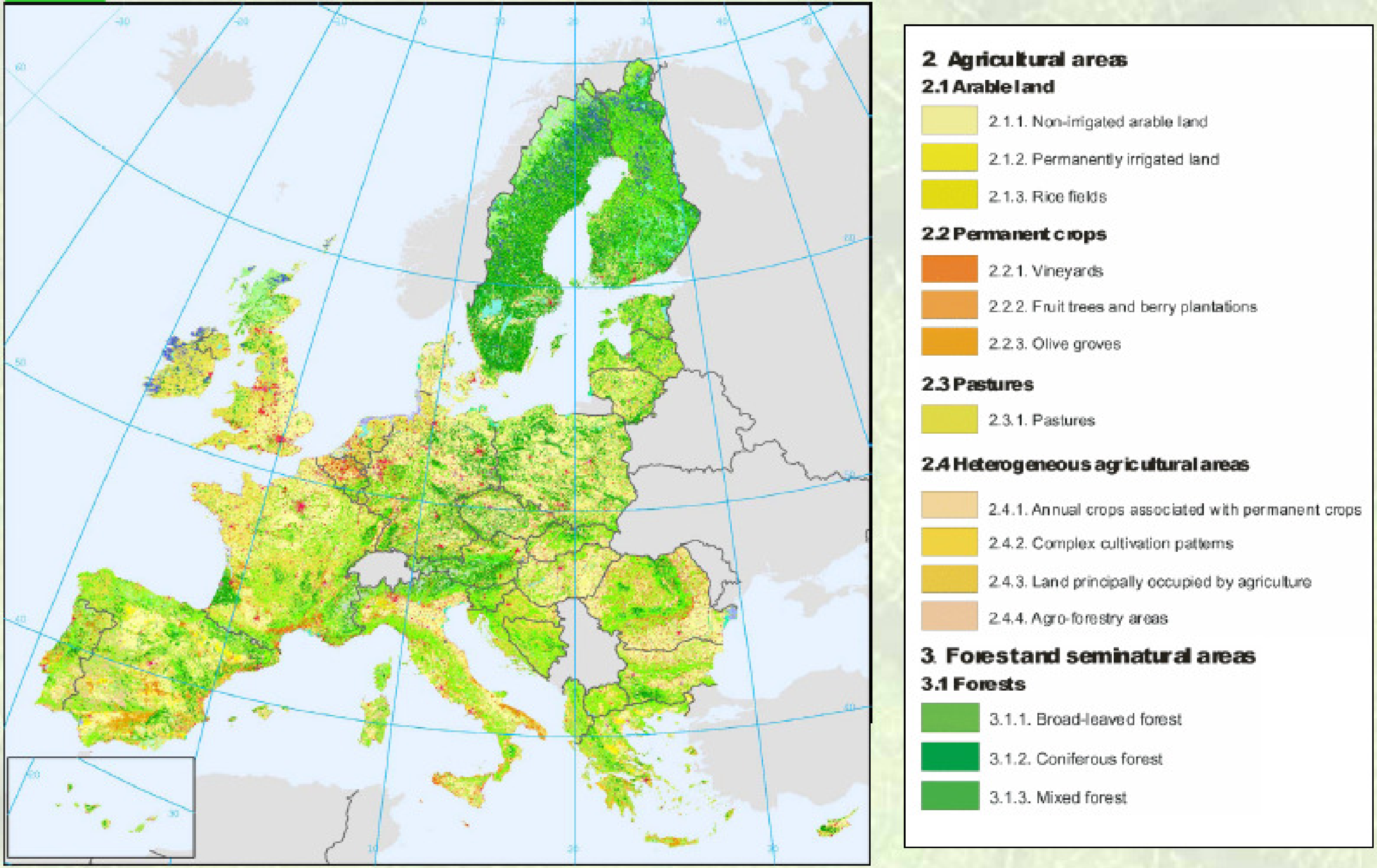


Average b temperature= 0,017℃ a^{-1} average b rainfall= -4,5 mm a^{-1}

Effects on crops (Kimball, Kobayashi, Bindi, 2002)

- Increase of CO_2 in the atmosphere
  - Photosynthesis→ *increase*
  - Plant-water relations→ *decrese stomatal conductance and transpiration*
  - Biomass accumulation→ *increase*
- Temperature raising
  - Duration of phases of the biological cycle → *reduction*
  - Biomass accumulation → *reduction*
- Rainfall decrease
  - Biomass accumulation → *reduction*

Land use in Europe



Energy Crops in relation to final product

Bioethanol

Carbohydrates crops

Sugar Cane, Sugar beet, Sweet sorghum

Biodiesel

Oil Crops

Rapeseed, Sunflower, Soyabean

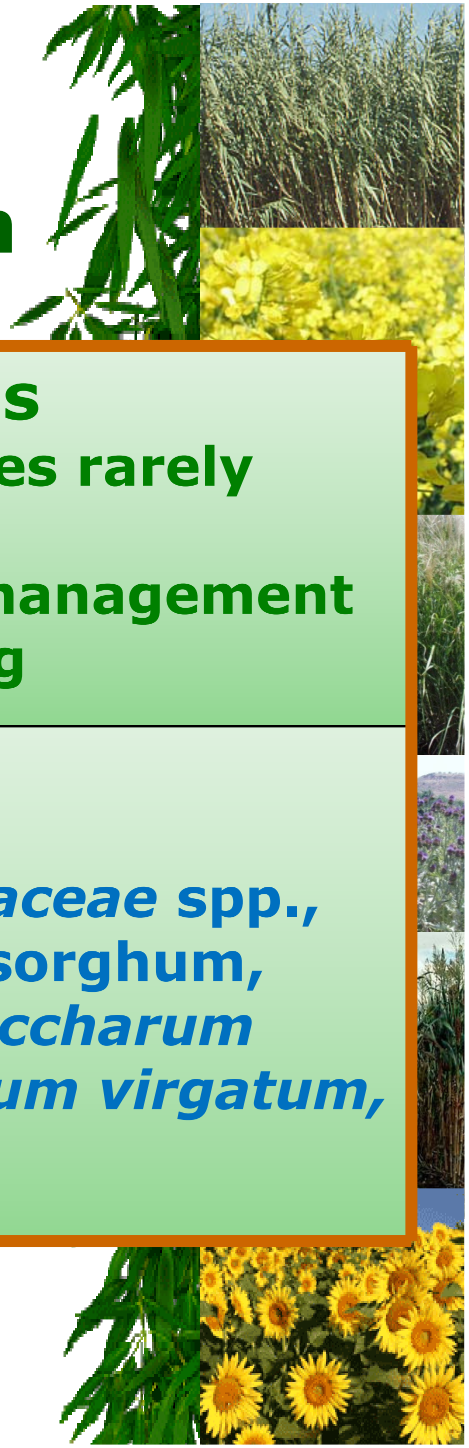
Heat and Power

Ligno-cellulosic crops

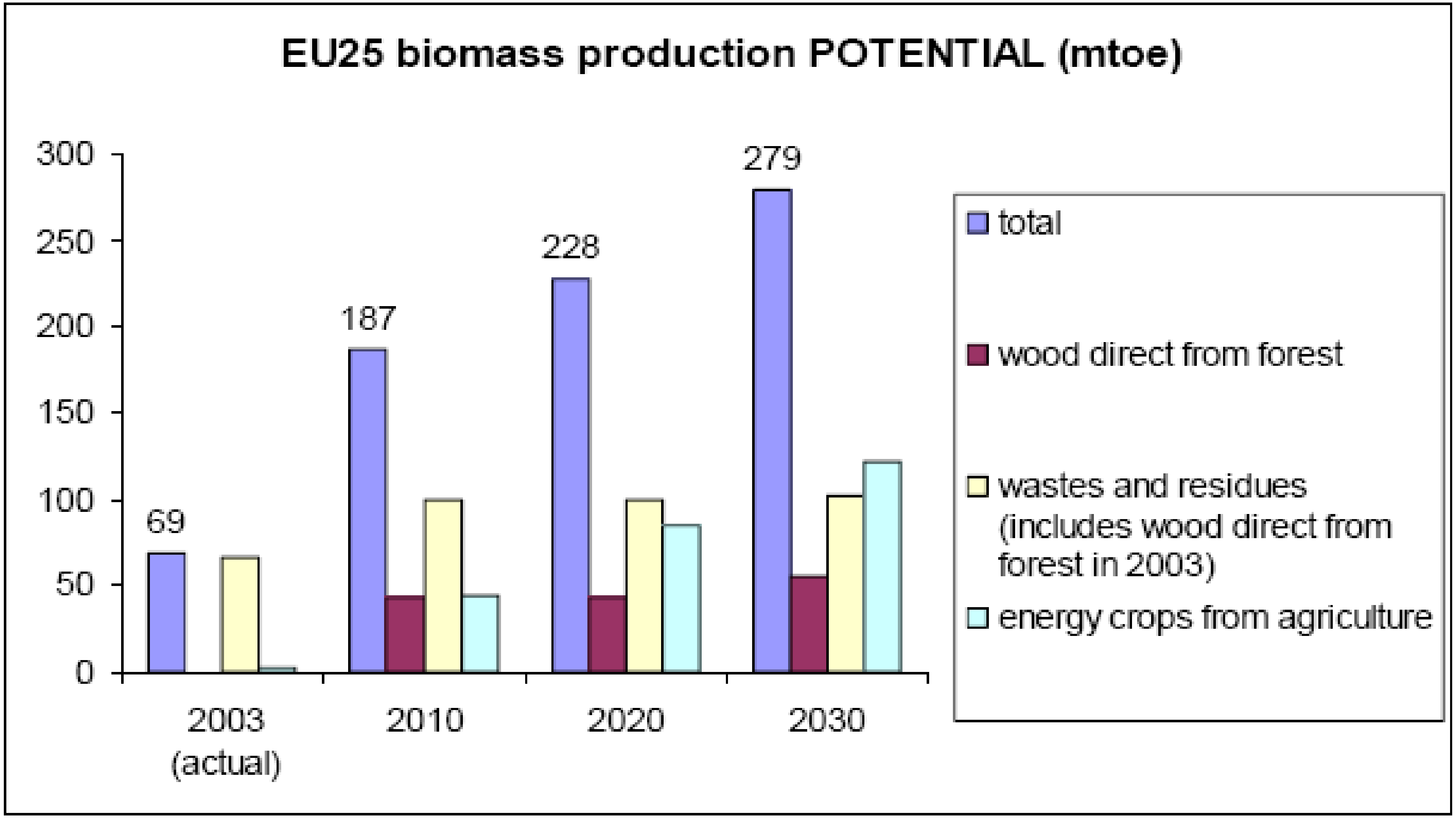
Fiber sorghum, Miscanthus, Arundo, Switchgrass, Cynara, S.R.F.

Energy crops
Agronomic classification

Food crops **Consolidated crop management and breeding**	**Novel crops** **(wild species, species rarely cultivated)** **Absence or poor crop management and breeding**
Wheat, maize, barley, rapeseed, soyaben, sunflower, sugar beet	**Aundo donax, *Brassicaceae* spp., Cynara spp., sweet sorghum, *Miscanthus* spp., *Saccharum spontaneum spp., Panicum virgatum,***



EU-25 biomass production potential



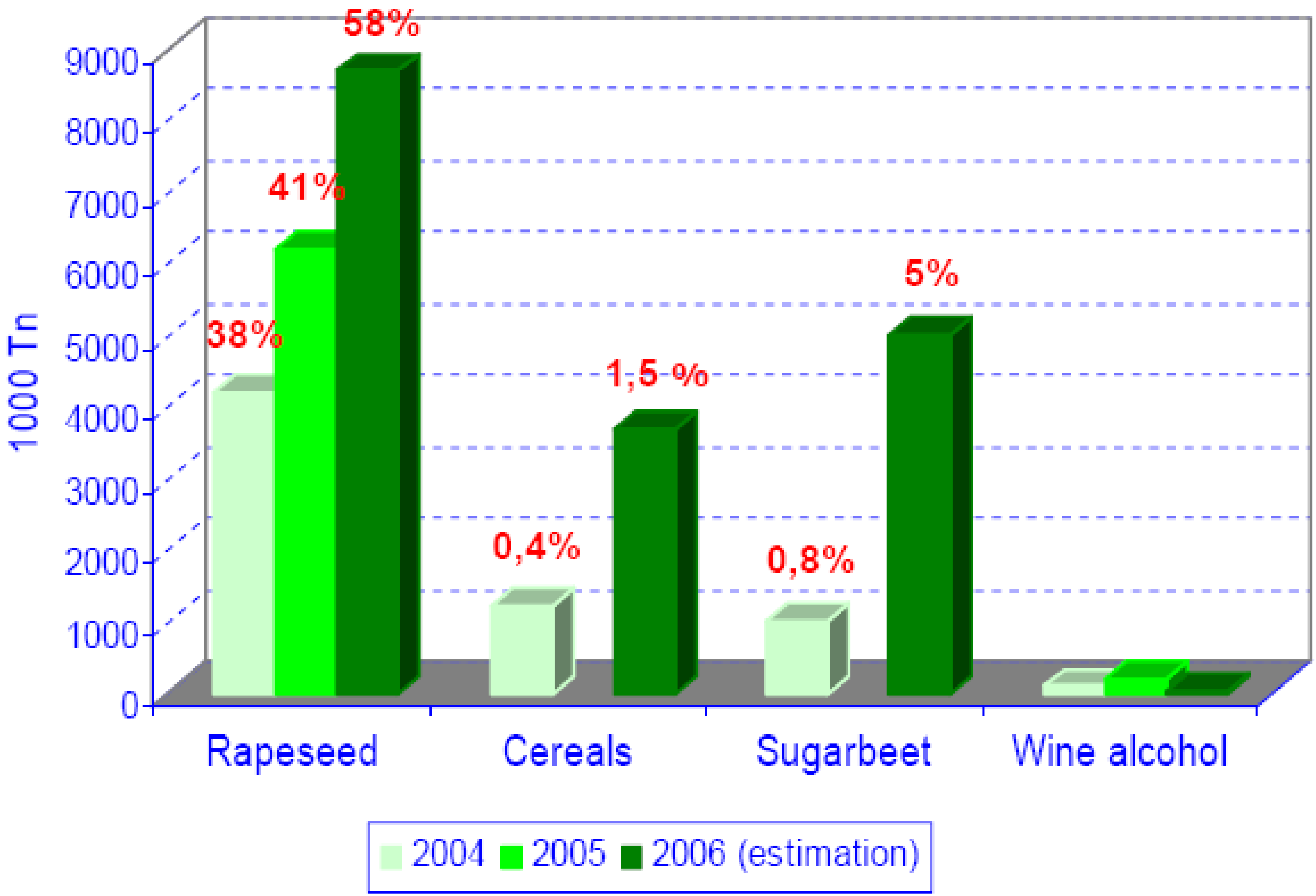
Sources: Eurostat (2003) / European Environmental Agency (projections)

Feedstocks for energy: current land use

(Million hectares)	2003 (EU-15)	2004 (EU-25)	2005 (EU-25)
On **set-aside area**, of which	0,9	0,6	0,9
• Rapeseed		*0,5*	*0,8*
With **energy crop premium**, of which		0,3	0,6
• Rapeseed		*0,2*	-
Without specific support (estimated)	0,3	0,5	1,1-1,3
Total area	**1,2**	**1,4**	**2,6-2,8**

► **Energy crops : about 3% of the EU-25 arable area**

Feedstocks for biofuels: crops used and share of total production



Energy crop species currently used or perspective to be used in energy or fuel production in Europe. Source: (Venendaal, et al., 1997).

Latin name	Common English name	Hectares
	Woody crops	
Salix sp	Willow	18,000
Eucaliptus sp.	Eucalyptus	500,000
Populus sp	Poplar	4050
	Herbaceous crops	
Triticum aestivum	Winter wheat (GWC)	
Secale cereale	Winter rye (GWC)	
Triticale	Triticale (GWC)	
Hordeum vulgare	Spring barley (GWC)	
	Total for GWC (Grain Whole Crop)	9,400
Phalaris arundinacea	Reed Canary Grass	6250
Sorghum bicolor	Sweet Sorghum	50
Cannabis sativa	Hemp	550
Miscanthus sp.	Miscanthus	350
	Oil crops and crops for fermentation	
Cynara cardunculus	Cardoon	65
Brassica sp.	Rape seed	800,000
Helianthus annuus	Sunflower	91,000
Beta vulgaris	Sugar beet	9400

Brassicacee

- *Brassica carinata A.*Br.
- *Sinapis alba L.*
- *Crambe abyssinica Hochst*
- *Brassica campestris L.(A.R.Clapham)*
- *Brassica juncea Coss*
- *Brassica nigra Koch*

BIODIESEL

Species	Growing season	Yield (t ha^{-1})	Oil content (%)
B. napus	winter	1,2-4,1	40-45
B. carinata	spring	0,4-3,1	32-38
B. juncea	spring	0,8-2,9	30-42
C. abyssinica	spring	1,0-3,0	26-37

Species	Growing season	Yield (t ha^{-1})	Oil content (%)
B. napus	winter	0,7-4,9	38-47
B. carinata	winter	3,2-3,3	33-39
B. juncea	winter	1,7-2,2	31-39
C. abyssinica	spring	1,4-3,5	27-38
Sunflower	summer	2,9-3,3	45-52

Species	Growing season	Yield (t ha^{-1})	Oil content (%)
B. napus	winter	0,8-3,8	32-43
B. carinata	winter	1,9-3,5	30-38
B. juncea	winter	0,7-2,1	29-42
C. abyssinica	spring	1,0-2,4	21-34
Cardoon	winter	0,4-2,0	24-26

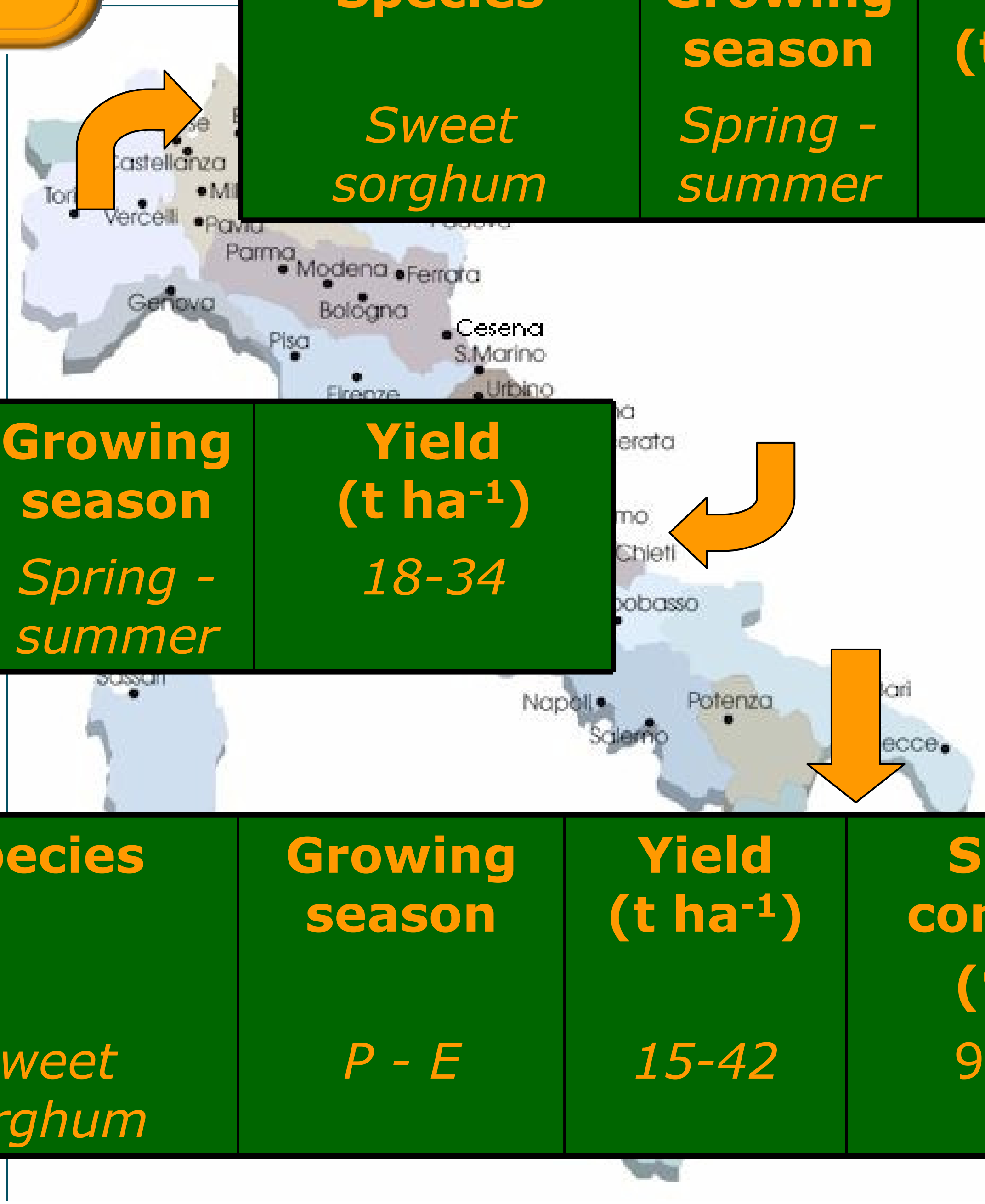
Sorghum bicolor (L.) **Moench**

Botanical Family: Poaceae (Tribù: Andropogoneae)

- Origin: East Africa, Etiopia, Sudan,
- C4 photosynthetic pathway
- Annual cycle
- Thermal requirements: 12 - 40 ° C (macrothermal)
- Drought resistant
- Water use: 2000- 6000 m3/ha

- Yield between 25 e le 40 t ha^{-1} d.m.
- Sugar content: between 10 e 18%
- Ethanol Yield between 4.000 and 7.000 liters per hectare

Bioethanol



Species	Growing season	Yield (t ha^{-1})
Sweet sorghum	*Spring - summer*	16-38

Species	Growing season	Yield (t ha^{-1})
Sweet sorghum	*Spring - summer*	*18-34*

Species	Growing season	Yield (t ha^{-1})	Sugr content (%)
Sweet sorghum	*P - E*	*15-42*	9-18

Miscanthus spp.

Botanical Family : *Poaceae*

- Origin: South-Est Asia – Tropics and Subtropics
- Perennial grasses
- Hybrid *M.* x *Giganteus* (*M. sinensis* x *M. sacchariflorus)* introduced in Europe in 1935
- Thermal requirements: 10-35° C (mesothermal)
- Photoperiodic control of flowering
- Water use: 5000-8000 m3/ha
- Photosynthetic pathway: C4
- Propagation: vegetative part of plant (absence of seeds)
- Yield between 15 and 30 t ha^{-1} after the second year

Arundo donax L.
Giant Reed

Botanical Family : *Poaceae* Tribe *Arundineae*

- Origin: Far East
- Diffusion: wild in all Mediterranean basin
- Photosynthetic pathway: C3
- Crop cycle: perennial
- Propagation: vegetative part of plant (absence of seeds)
- Thermal requirements: 10-30° C (mesothermal)
- Water use: 4000-7000 m3/ha

Biomass Yield

- Higher than 100 t ha^{-1} of fresh matter in optimal conditions
- In southern Europe around 30-40 t ha^{-1} of d.m.

Cynara cardunculus L. (cardoon)

Botanical Family : *Asteraceae (Compositae)*

- Origin: Mediterranean basin
- C3 photosynthetic pathway
- Perennial habitus
- Thermal requirements: 5 - 25°C (microthermal)
- Winter growing season
- Drought resistant
- Seed propagated
- Biomass Yield between 6 and 30 t
- Seed Yield 1-2 t ha^{-1}
- High ash content

Heat and Power

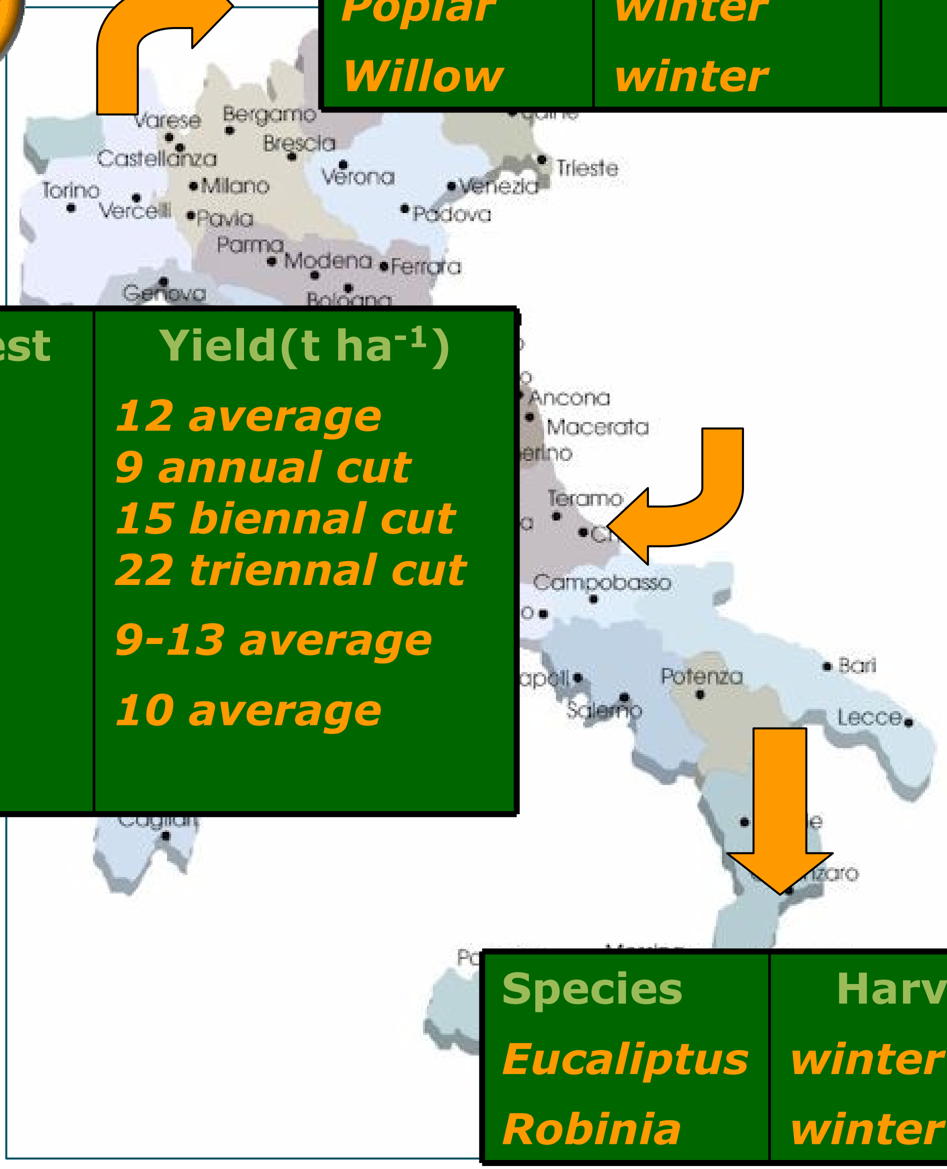
Species	Growing season	Yield (t ha^{-1})	Humidity (%)
Miscanthus spp.	summer	13-24	27-48
A. donax L.	summer	28-51	32-47
Fiber sorghum	summer	16-29	35-38

Species	Growing season	Yield(t ha^{-1})	Humidity(%)
Miscanthus spp.	summer	17-48	52-57
A. donax L.	summer	21-41	55-58
C. cardunculus L.	Winter spring	7-21	16-40
P. virgatum	summer	8-17	15-35
Fiber Sorghum	Spring summer	22-36	65-73

Species	Growing season	Yield(t ha^{-1})	Humidity(%)
Miscanthus spp.	summer	11–32 (25% - 100% ETM)	30-39
A. donax L.	summer	25–45 (25% - 100% ETM)	50-53
C. cardunculus L.	winter	9-24	15-55
Fiber sorghum	summer	20-36	70-73

Heat and Power

Species	Harvest	Yield (t ha^{-1})
Poplar	*winter*	*17*
Willow	*winter*	*19*



Species	Harvest	Yield(t ha^{-1})
Pioppo	*winter*	*12 average* *9 annual cut* *15 biennal cut* *22 triennal cut*
Salice	*winter*	*9-13 average*
Robinia	*winter*	*10 average*
Eucalipto	*winter*	

Species	Harvest
Eucaliptus	*winter*
Robinia	*winter*

Comparison between annual and perennials

Annual crops	*Perennial crops*

Strengths

Annual crops

- Annual growing season
- Easy access to seed
- Easy introduction in crop rotation
- Existing farm machinery

Perennial crops

- High annual productivity than S.R.F.
- Longevity
- Seed propagation (cynara, switchgrass)
- Easy adaptation
- Reduced environmental impact
  - ✓Less use of agrochemicals (herbicides)
  - ✓ absence of soil tillage
  - ✓ control of soil erosion

Weaknesses

Annual crops

High environmental impact

Annual soil tillage

High use of agrochemicals

Perennial crops

- Low yield in the establisment year(s)
- Propagation material (miscanthus, arundo)
- New farm machinery needed
- High ash content

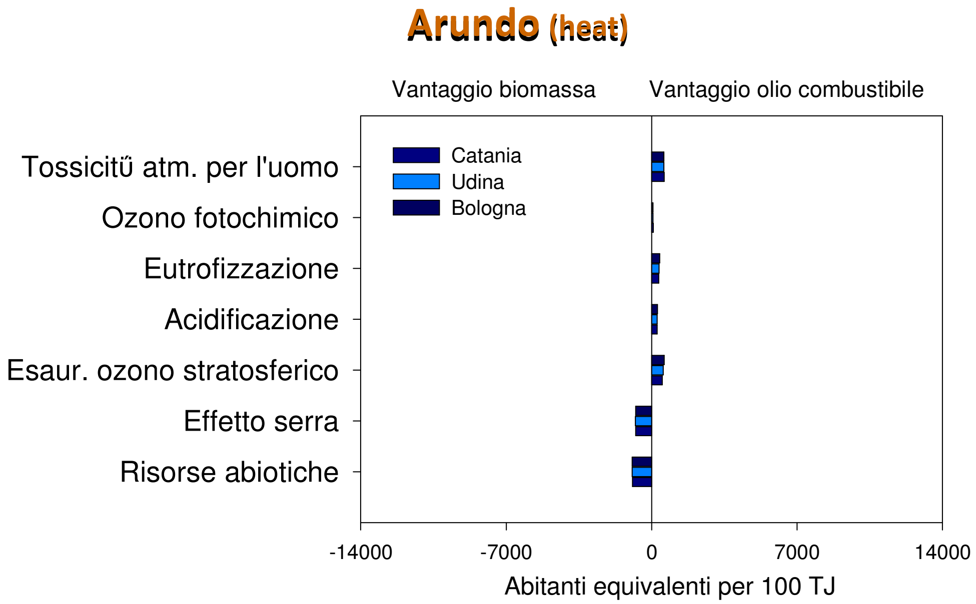
Energetic Yield and Efficiency

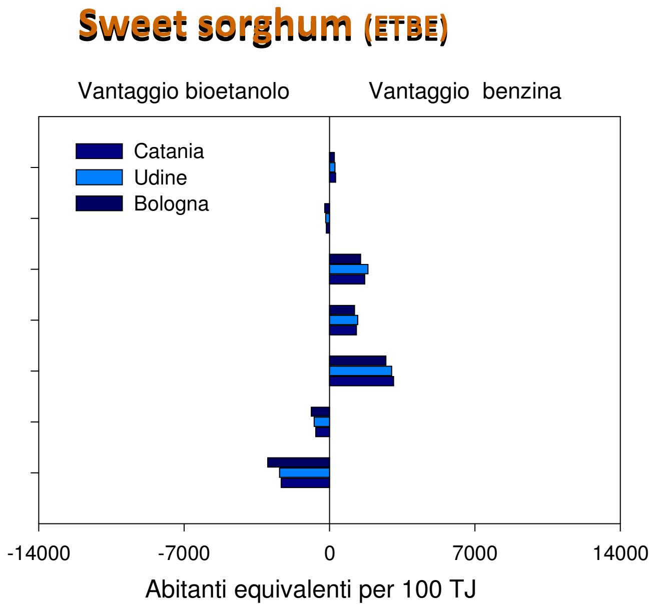
Species	Yield (O –I) (GJ ha^{-1})	Efficiency (O/I)
Arundo donax	118-592	11-77
Miscanthus	199-543	4,5-47
Cardoon	133-344	7-31
Fiber Sorghum	260-494	7-39
Sweet Sorghum	119-409	6-32
Panicum virgatum	152-427	8-54
Rapeseed	4-56	1,4-13,4
Sunflower	-6,4-57	0,7-5
Soyabean	-0,6-39	1-2
Sugar beet	45-130	2,8-3,2
Maize	10-110	1,4-3,8

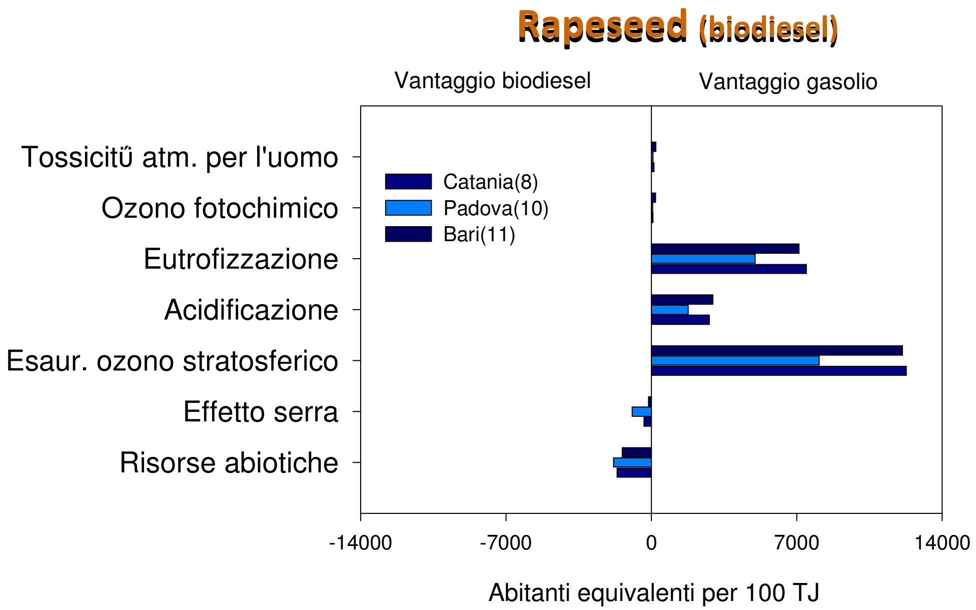
CO_2 equivalents "saved"

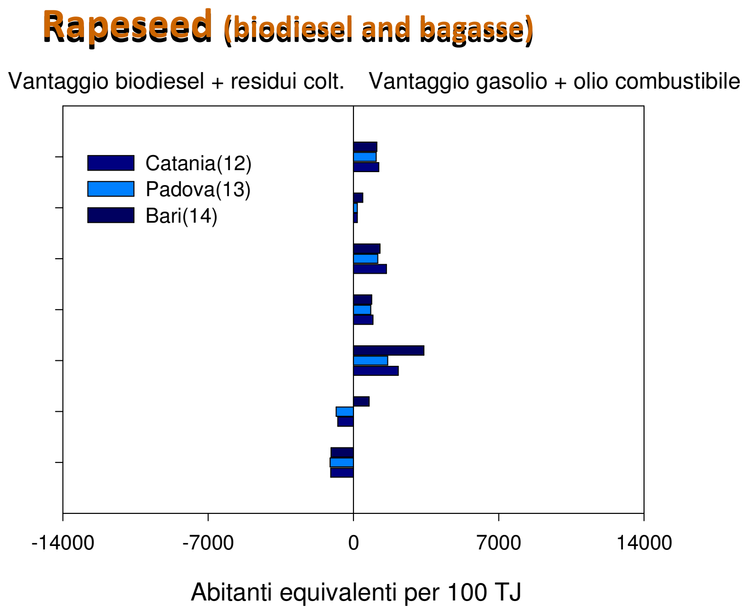
	Biomass	Bioenergy	Fossil	Balance
	Yield (t ha^{-1})	Emissions t CO_2 equ. ha^{-1} (a)	Emiss. t CO_2 equ. ha^{-1} (b)	Emiss. t CO_2 equ. ha^{-1} saved (b-a)
Biomass for heat				
Arundo	35,7	6,8	44,4	37,7
Miscanthus	17,3	4,2	21,6	17,5
Cardoon	18,2	4,0	22,7	19,1
Fiber sorghum	24,6	5,7	30,7	25,1
ETBE				
Sweet sorghum	21,4	15,8	19,9	3,9
Biodiesel				
Rapeseed	2,6	1,9	3,1	1,2

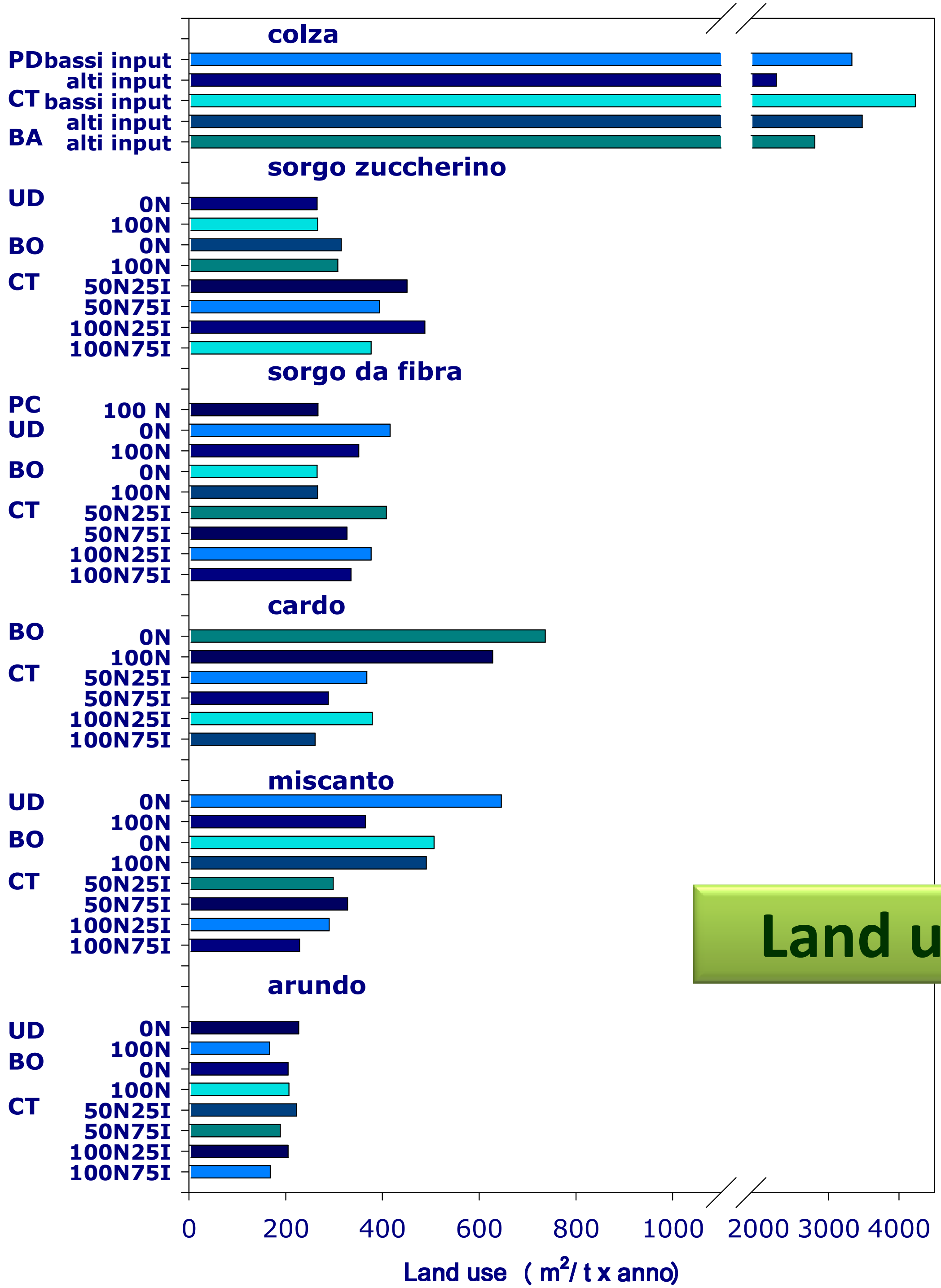
Comparison between bio-combustibles and fossil











colza
PD bassi input
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CT bassi input
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BA alti input
sorgo zuccherino
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Land use (m²/ t x anno)

Land use

Soil erosion loss of different energy crops (hilly area of Sicily)

Crops	Soil erosion (t ha^{-1})		Difference (t ha^{-1})	Loss compared to control (%)
	Crop	Fallow - Wheat		
Sweet sorghum	4,14	16,5	-12,36	25,1
Rapeseed	5,92	8,76	-2,84	67,6
Miscanthus	0,16	7,64	-7,48	2,1

Definition

"*Energy crops*" may be defined as crops specifically cultivated to produce biomass which, for specific traits, serve as an energy vector to release energy either by direct combustion or by conversion to other vectors such as biogas or liquid biofuels.

Plant/crop ideotype for energy production

An energy crop should gather the following characteristics:

- High yielding close to potential yield of each region
- High radiation use efficiency in relation to the environment (temperature, photoperiod, water availability)
- Specifically developed for an environment
- Able to utilize available natural resources
- Resistant to biotic stress
- Resistant to abiotic stress (water, low and high temperature, salt)
- Quality traits specific for each different use (biogas, biodiesel, ethanol first generation, ethanol 2^{nd} generation from cellulose, Biomass to liquid (BTL), Biohydrogen)
- Highly positive energy balance
- Environmentally friendly

Lines of research

- Agro-ecological characterization of the lands available for energy crops
- Individuation and assessment of new species
- Crop management techniques
- Assessment of environmental and social impacts
- Development of simulation models

Agro-ecological characterization of the lands available for energy crops in a region

- Energy and food are two different markets and energy crops should not compete with food crops for lands
- Land area within a same agro-ecological category should be quantified in order to build a territory planning for energy crops, related industries and logistics.
- The focus of this work should be on more marginally productive lands with poor agricultural incomes.

Individuation and assessment of new species

- Screening of biodiversity and genetic variability within species with respect to the ideotype
- Assessment of new species adapted at the soil and climatic condition of each environment
- Domestication of new species
- Assessment of plant productivity
- Quality characterization of the biomass or crop yield
- Energy balance

Studies on crop physiology

The new species must be classified according to their response to the environment (soil and climate).

- Growth analysis (LAI, CGR, NAR, etc.)
- phenology and fillochron
- relation with temperature and photoperiod (photo-thermal units, vernalisation),
- response to light intensity (radiation use efficiency),
- response to temperature and photoperiod
- water balance and water use efficiency and mechanism of adaptation to drought
- nutrients balance
- nitrogen balance and nitrogen use efficiency
- adaptation to soil salinity

Miscanthus floridulus

Miscanthus x giganteus

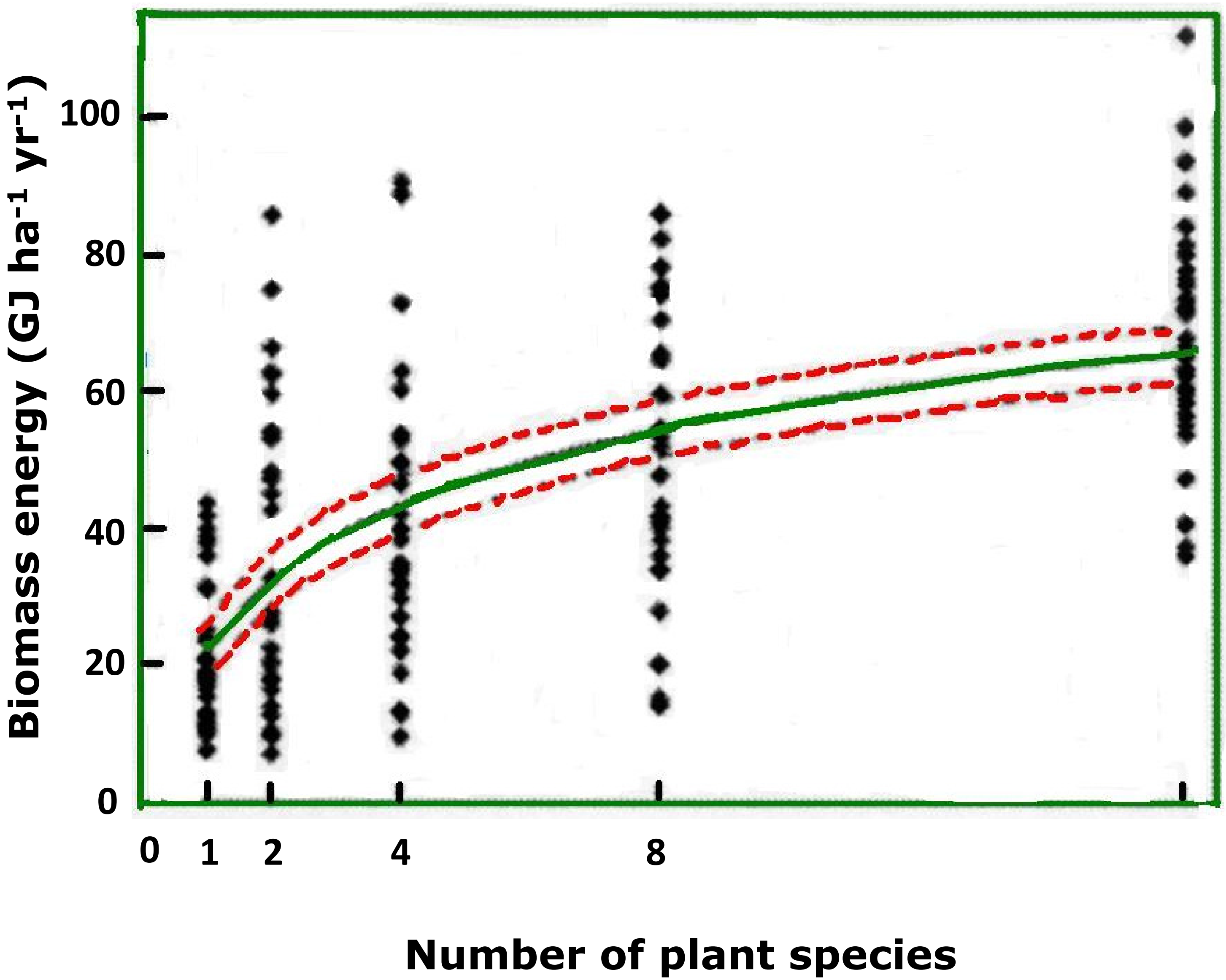
Saccharum aegyptiacum

Miscanthus sinensis

***Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass (*Tilman D., Hill J., Lehman C., Science, 2006)**

Species used in the research (18)

Specie	Tipo funzionale
Lupinis perennis	Legume
Andropogon gerardi	Gramineae C_4
Schizachyrium scoparium	Gramineae C_4
Sorghastrum nutans	Gramineae C_4
Solidago rigida	Herbaceous species
Amorpha canascens	Woody legume
Lespedeza capitata	Legume
Poa pratensis	Graminacea C_3
Petalostemum purpureum	Legume
Monarda fistulosa	Herbaceous species
Achillea millefolium	Herbaceous species
Panicum virgatum	Gramineae C_4
Liatris aspera	Herbaceous species
Quercus macrocarpa	Woody
Koeleria cristata	Gramineae C_3
Quercus elipsoidalis	Woody
Elymus canadensis	Gramineae C_3
Agropyron smithii	Gramineae C_3



(Tilman *et al.*, 2006, Science)

Crop management techniques

- Methods of propagation (perennials)
- Plant density
- Response to low or no inputs (soil tillage, fertilisation, irrigation, crop protection, weed control)
- Possibilities for utilization of waste water, sludge and/or ashes in energy crops;
- Role and behavior in cropping systems (annual crops)
- Planting/Harvesting/ Collection/ Storage

Genetics and breeding activity

For well established crops, optimize for biomass production

There is a lot of potential for dedicated biomass crops (biomass raw material quantity and quality)

- Definition of breeding goals for energy plants (ideotype)
- Development of analytical tools to precisely measure the defined breeding goals (HTP-assays)
- Screening of biodiversity and genetic variability within species with respect to the new breeding goals
- Deduction of physiological bottlenecks (e.g. WUE,…) for reaching the new breeding goals, definition of selection criteria
- Development of innovative breeding strategies to improve breeding progress (Transgenic ?)

Assessment the environmental impact: Sustainability

- Biodiversity and agroecosystem sustainability
- Soil erosion control and soil conservation
- Carbon sequestration
- Agrochemicals release to the agroecosystem and environment
- Carbon emission balances
- Life cycle assessment, analysis of the emissions and energy consumption of a product from “cradle to grave”

Development of simulation models and decision support systems

- To define the "potential yield" for a definite environment
- To evaluate the performance of the crops in different environments and timeframes and in the changing climatic conditions.
- The crop growth models together with economic models may be applied to develop territorial plans in order to find out the most suitable areas for energy crops cultivation considering good agricultural areas and marginal land.

LA-EU BIOFUELS RESEARCH WORKSHOP

Energy crops

Thank you for your kind attention

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Resource Assessment

Resource assessment forecasts in relation to spatial distribution, availability factors and climate

Develop biomass cost- supply curves in relation to availability factors, costs and life cycle analysis

Feedstock production

Activity for conventional crops (wheat, rapeseed, maize, etc.): breeding of new varietiesmanagement practices (propagation, cropping systems, etc.) also using transgenic methods and optimise associated

Activity on new species (Miscanthus, Arundo, cynara, panicum, etc.): genomics and breeding activity and management practices (propagation, plant density, cropping systems, etc.)

Individuation of novel species (adaptation and crop physiology)

Development of simulation models and associated predictive tools to evaluate the performance of the crops in different environments and timeframes and in the changing climatic conditions.

Planting/Harvesting/ Collection/ Storage

1. Activity for conventional crops (wheat, rapeseed, maize, etc.): Develop harvesting and collection systems (new equipment, new chains) to maximise supply by minimizing costs per unit.
2. Activity on new species (Miscanthus, Arundo, cynara, panicum, etc.): develop planting, harvesting and collection systems (new equipment, new chains) to maximise supply by minimizing costs per unit.
3. Individuation of novel species (adaptation and crop physiology): Develop harvesting and collection systems (new equipment, new chains) to maximise supply by minimizing costs per unit.
4. Develop feedstock quality and monitoring systems both for wet and for dry storage.

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Biomass feedstock properties

- Develop feedstock quality data (physical and chemical) both for dry and wet biomass in relation to diverse end use options and post harvest operations such as size reduction, densification, blending, etc.
- Develop physical and chemical pre-processing methods (including blending and fractionation), systems and strategies to provide homogeneous feedstock for large scale applications thus meeting the quality requirements of the conversion technologies.
- Safety and standardisation issues covering the full supply chain

System analysis

Optimise supply system tools taking into account various land use and market interdependencies, transport, international trade, etc.

Demonstration of a portfolio of systems (subject to regional ecology and climate) with high potential for feedstock supply in relation to availability, infrastructure and supportive policy framework. System analysis on the supply and demand of biomass feedstocks and the impacts of policy and legislative mechanisms (national, EU27, global level).