Agronomic aspects of future energy crops in Europe

Biomass crops energy supply

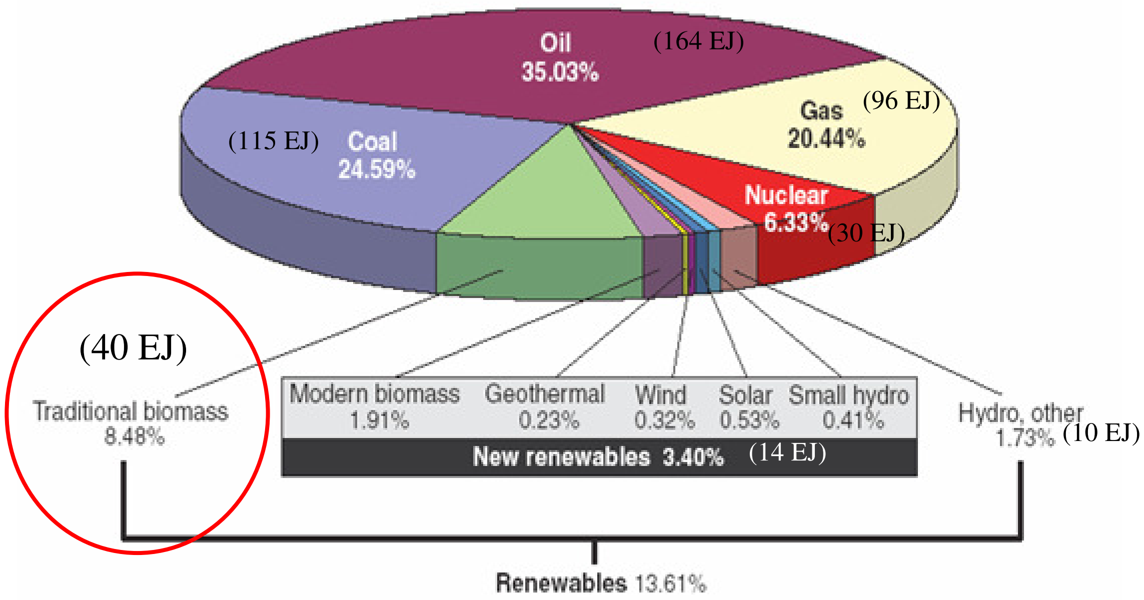


Fig. 1. World total primary energy supply 2004, shares of 11.2 billion tons of oil equivalent, or 470 EJ (*15, 16*).

Goldemberg, 2007

European Union Directives

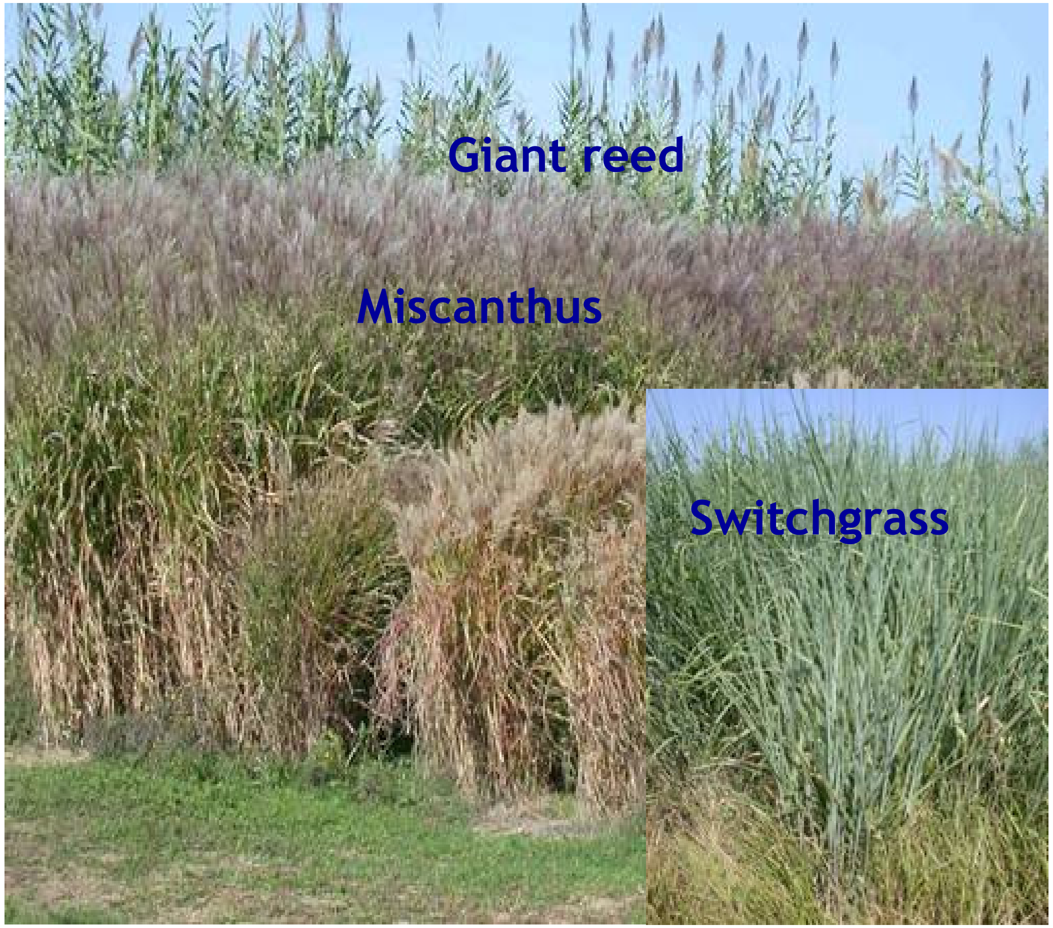
European Union Directives

- 10% biofuels by 2020 (Res. PE-CONS 3736/08; Res. 8040/09 ADD1)
- 17.5 and 21.1 millions hectares of arable land dedicated to energy crops

Maximize productivity

- No information on production potential/agronomic practices
- Appropriate crop management practices assed

Perennial herbaceous crops



- Low production costs
- Suitability to marginal lands
- Low water needs (switchgrass, Miscanthus)
- Low nutrient and agrochemical requirements
- Environmental benefits

Perennial herbaceous crops

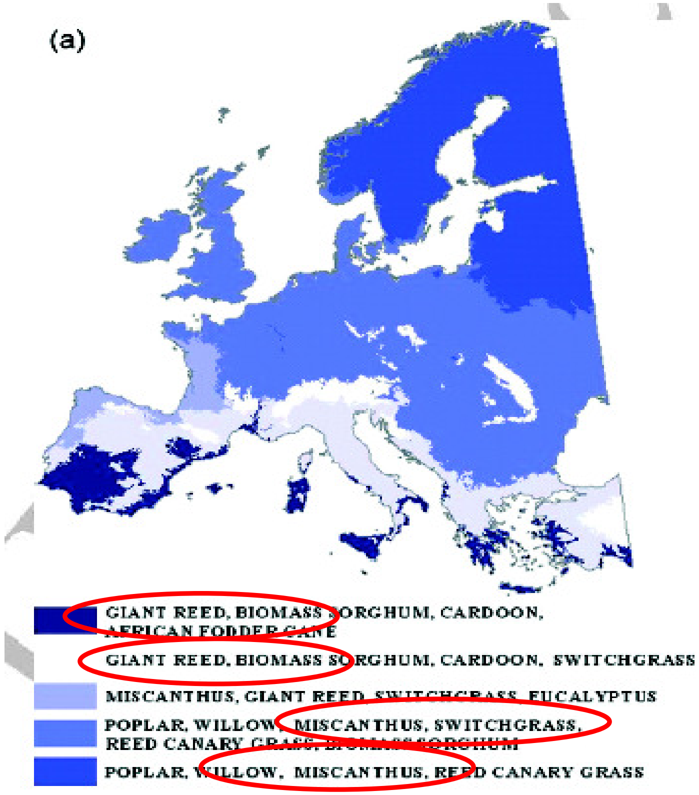


Figure 1. Distribution map of possible biomass (a) and oilseed (b) energy crops in Europe. The potential cropping areas were determined according to the crop climatic requirements taking in consideration the bioclimatic zones determined by Metzger *et al.*[121] The data source for the elaboration of the present map was taken from Mücher *et al.*[122] The crops are listed in order of importance from left to right.

Zegada-Lizarazu et al., 2010

Switchgrass and Miscanthus:

- Central and northern Europe

Giant reed:

- Mediterranean climates of southern Europe

Perennial herbaceous crops

Switchgrass seeds

Miscanthus and giant reed rhizomes

Seed reproduction gives switchgrass an economical and environmental advantage

Perennial herbaceous crops

- Weed control

Non weeded
(early growth stage)

Weeded
(early growth stage)

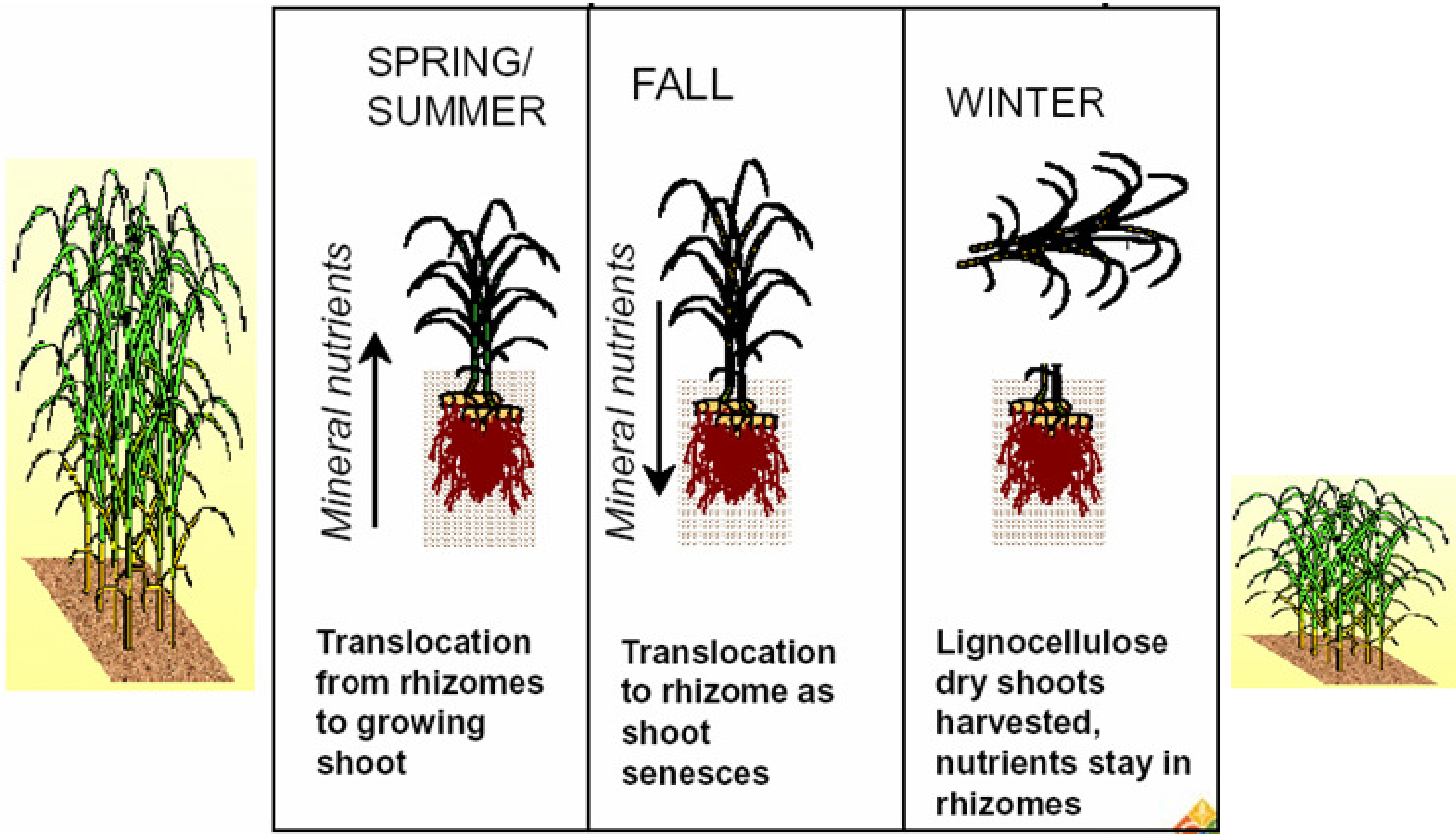
Table 5-1. Response to switchgrass to pre-emergence herbicides at Yoakum TX, seeded 7 Oct. 1999.

Herbicide treatment	Rate kg/ha	--Switchgrass stands-- 11-23-99	4-26-00	DM yield[a] (kg/ha)
		--------- % ---------		
Check	-	40	2	289
Dual Magnum	0.56	28	7	1033
	1.12	8	4	389
Strongarm	0.02	5	1	113
	0.03	0	4	75
Prowl	0.84	15	2	224
Zorial	0.44	45	2	170
Caparol	1.12	28	4	306
	1.68	10	4	347
Cotoran	1.12	13	8	444
	1.68	3	6	426
Atrazine	1.12	50	3	103
	2.24	8	10	2226
Frontier	0.84	43	8	1382
	1.40	20	7	213
Sencor	0.56	13	11	908
	1.12	5	4	137
First Rate[b]	21.0	73	11	1307
	42.0	75	16	3504
Python[b]	35.0	40	12	1691
	70.0	45	16	1556
LSD (0.05)		23	14	1634

[a]Switchgrass harvested 26 July, 2000
[b]grams/ha Ocumpaugh et al., 2002

- Fertilization
- Supplemental irrigation

Perennial herbaceous crops



Perennial herbaceous crops

Table 4. Agronomic characteristics of the most common energy crops.

	Sowing, crop duration (days), and harvesting for maximum energy yields	Plant density (plants m^{-2})	Nitrogen Requirement (Kg ha^{-1})	Water needs (mm)	Pests management	Biomass yield (Mg ha^{-1} d.w.)	Energy yield (GJ ha^{-1})
Miscanthus	Sowing: spring Economic life: >20 years[31] Harvesting: annually (spring), when the crop has senesced[19], yields stabilize from the 2nd year onwards.	1–3[19]	0 –100[19]	700–800[32]	Mechanical or chemical weed management required during the establishment year only. No serious problems from pest and diseases have been reported.	10–30[19]	170–528[118]
Switchgrass	Sowing: spring. Economic life: >20 years[33]. Harvesting: annually (fall), between R3 an R5[34,a], yields stabilize from 3 to 5 years after sowing.	100 to 200[33]	0 –70	450–750[35]	Mechanical or chemical weed management required during the establishment year only. No serious problems from pest and diseases have been reported.	10–25[30]	174–435[30]
Giant reed	Sowing: spring Economic life: 10[36–38] Harvesting: annually (spring)[31], yields stabilize from the 2nd year onwards	1–2[36–38]	50–100	??	Mechanical or chemical weed management required during the establishment year only. No serious problems from pest and diseases have been reported.	7–61	496–637[36–38]

Perennial herbaceous crops

Table 5. Effects of delayed harvest on mineral and carbohydrate contents (% dry matter) in giant reed, switchgrass and miscanthus biomass.

	Giant reed		Switchgrass[87,a]		Miscanthus[75]	
	Fall	Winter	Fall	Spring	Fall	Winter
Ash	–	7.1[88,b]	–	4.9e	–	4.1e
N	–	2.4[88,b]	0.46	0.41	0.47	0.36
P	–	0.06[88,b]	0.09	0.05	0.06	0.00
K	–	0.53[88,b]	0.34	0.06	1.22	0.96
Cl	–	0.63[88,b]	0.08	0.03	0.56	0.09
Sugars	–	–	3.55	0.37	0.30	2.07
Starch	–	–	0.92	0.29	0.70	0.14
Yield (Mg ha^{-1})	24[36,c]	26[36,c]	7	4	17[31,d]	11[31,d]

[a] Mineral contents averaged over three years and locations, carbohydrates averaged over two years and yields averaged over three locations and years.
[b] Average values of different plant parts.
[c] Average biomass of six years.
[d] Average yields of different genotypes grown at several locations in Europe during the third growing season.

Zegada-Lizarazu et al., 2010

Late harvest

- Maintain soil nutrients
- Biomass quality
- Reduced yield

Perennial herbaceous crops

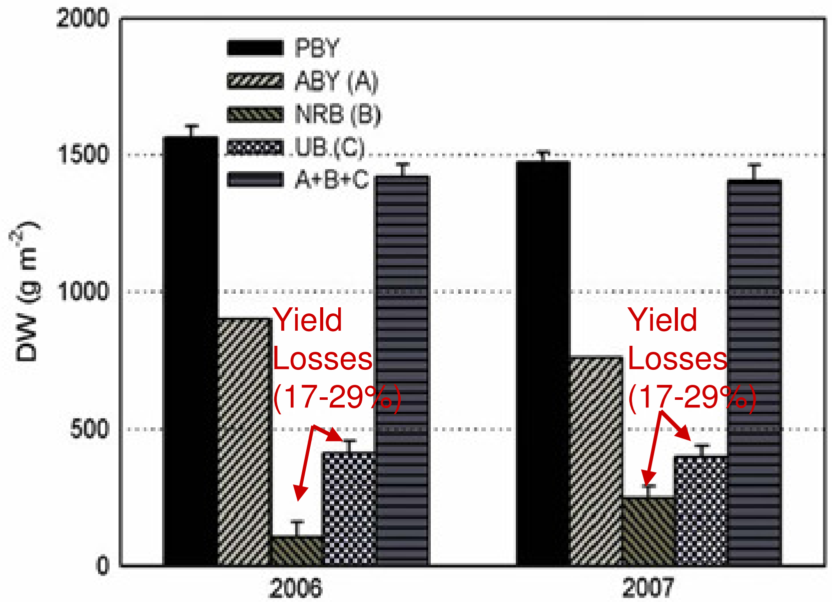


Fig. 4 – Harvest losses in 2006 and 2007, and discrepancy between plot (PBY) and field (A + B + C) potential biomass yields. ABY is the actual harvested biomass, NRB and UB represent the biomass losses during field harvest (cut and not recovered biomass and uncut biomass, respectively).

Monti. et al., 2009

Short rotation woody crops

Poplar

Willow

Eucalyptus

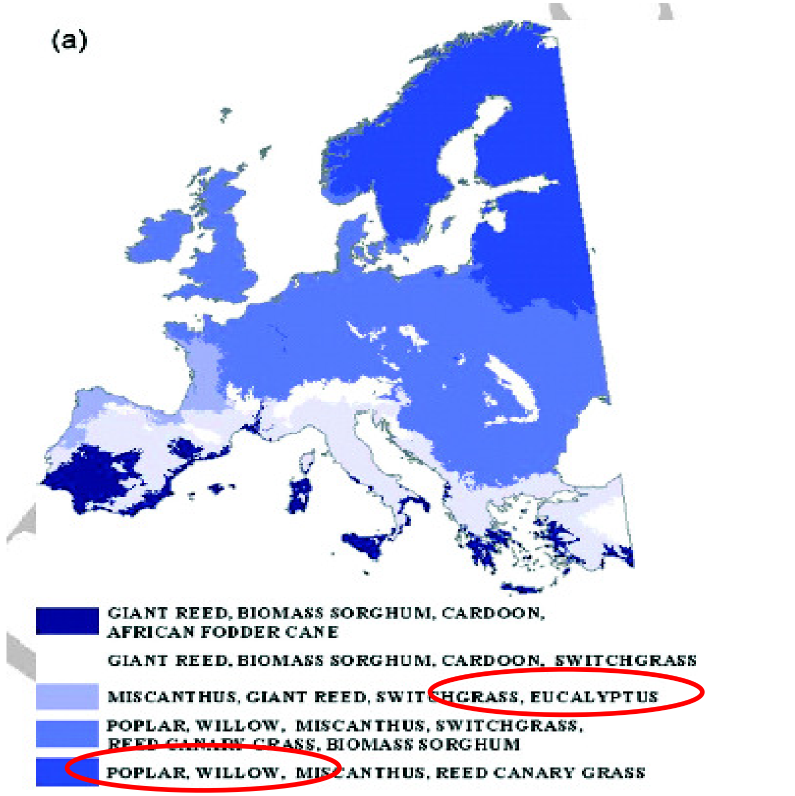


Figure 1. Distribution map of possible biomass (a) and oilseed (b) energy crops in Europe. The potential cropping areas were determined according to the crop climatic requirements taking in consideration the bioclimatic zones determined by Metzger *et al.*[121] The data source for the elaboration of the present map was taken from Mücher *et al.*[122] The crops are listed in order of importance from left to right.

Short rotation woody crops

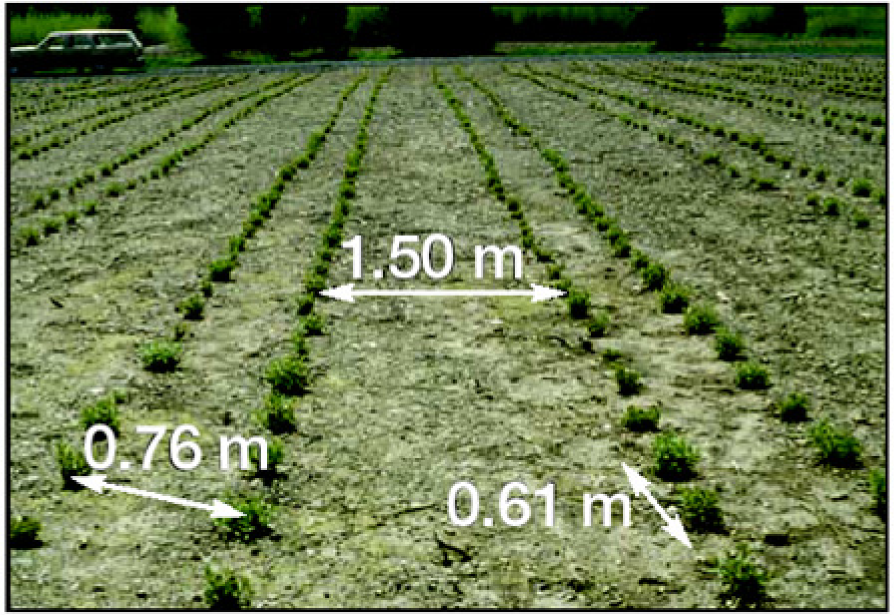


Figure 1. *Willow biomass crops planted in the typical double-row configuration. Plants have just sprouted in the spring, after being cut back to ground level (coppiced) during the winter. Each willow plant will develop multiple (6–15) stems. Arrows indicate the recommended spacing for willow biomass crops, resulting in a plant density of just over 14 000 per hectare.*

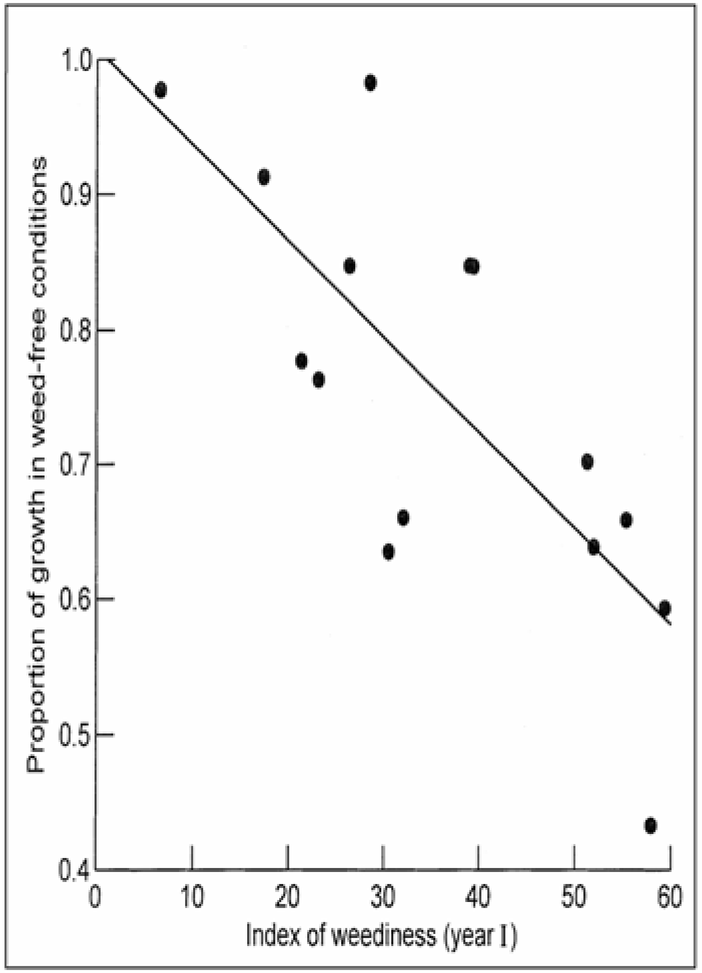
Volk et al., 2004

Eucalyptus seedling

Eucalyptus Rooted cutting

Short rotation woody crops

Fig. 4 Mean coppice growth increment over the 2-year study period (year II–year 0) with weediness expressed as a proportion of the growth increment in weed-free conditions (per trial row, $n = 20$ weeded and 20 unweeded stools for each point). This relationship is significant ($P < 0.01$, $r^2 = 0.57$, $n = 15$ rows) and, for indices between about 5 and 60, is defined by the expression (with standard error of slope): $G_{0\text{-II}} = 1.0078 - (0.0071 \pm 0.0017) \times I_{0\text{-II}}$. $G_{0\text{-II}}$ is coppice growth increment as a proportion of stool growth with no weeds; $I_{0\text{-I}}$ is weediness index for year I (% area × mean height).



Unweeded

Mechanically weeded

Chemically weeded

Sage, 1999

Short rotation woody crops

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Poplar	Planting: spring Economic life: 25–30 years[39] Harvested on 3–7 years rotation (winter)[39]	0.8–1[39]	112–450[39]	> 350[39]	Requires good and moderate management during the establishment and harvesting periods, respectively.	7–28[39]	173–259[18]
Willow	Planting: spring Economic life: 25–30 Harvested on 3–4 years rotation (winter)[40]	0.5–2[41]	80–150[42,b]	1000[43]	Requires good and moderate management during the establishment and harvesting periods, respectively.	10–30[44]	187–280[18]
Eucalyptus	Planting: spring Economic life: Harvested on 6–15 years rotation (in very short rotations harvested every 2–3 years) (winter)[45]	0.1–2[45,c]	60–125	870–1085[46,47]	Requires good and moderate management during the establishment and harvesting periods, respectively.	10.4–25.5[45]	1000[48]

Short rotation woody crops

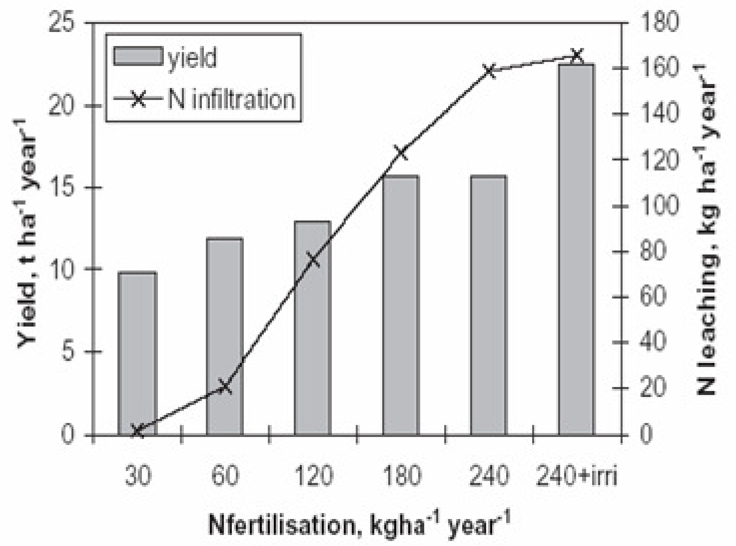


Fig. 2. Effect of N-fertilization (from 30–240 kg ha^{-1} year^{-1}) on the simulated yield of poplar coppice, and on the N leaching. Averages of 150 years simulation are given.

Deckmyn et al., 2004

Cropping strategies to minimize fertilization:

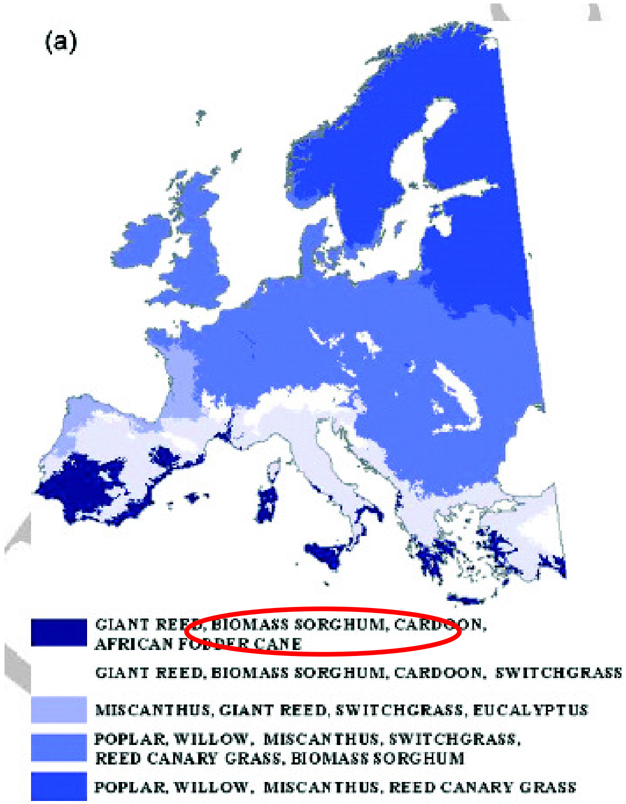
- Longer rotations
- Mixture of nitrogen fixing trees (alder, *Albizia*)
- Intercropping with nitrogen fixing annual crops
- Reincorporation crop residues (leaves, twigs)
- Harvest during dormancy/ growth cessation

Short rotation woody crops

Chipping

Trunk stacking on-site

Annual crops (sorghum, hemp)



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Zegada-Lizarazu et al., 2010

Sorghum:

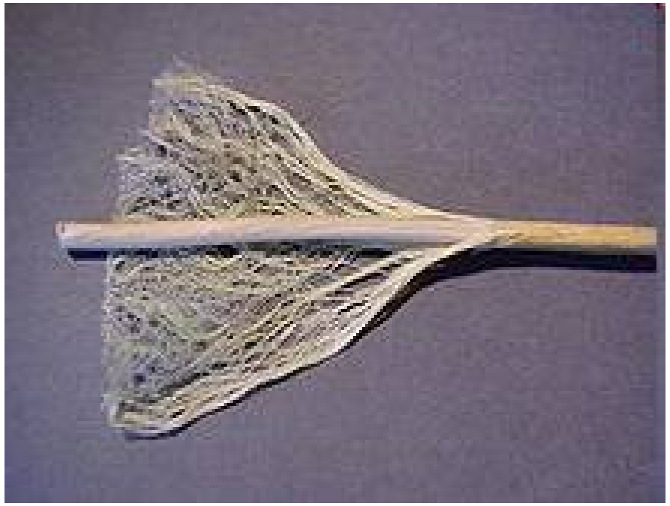
- Mediterranean climates of southern Europe

Hemp:

- Wide variety of agro-ecological conditions (manly central Europe)

Annual crops (sorghum, hemp)

Sorghum genotypes: fiber, grain, sugar



Hemp: long history as a fiber crop

Annual crops (sorghum, hemp)

Advantages:

- Propagated by seeds
- Deep rooted
- High cellulose content (hemp) and

fermentable carbohydrates (sweet sorghum)

- Relatively low nutrient requirements

Annual crops (sorghum, hemp)

Advantages:

- Row crops
- High planting density:

  14 to 20 plants m^{-2} (sweet sorghum)

  Up to 270 plants m^{-2} (hemp)

Annual crops (sorghum, hemp)

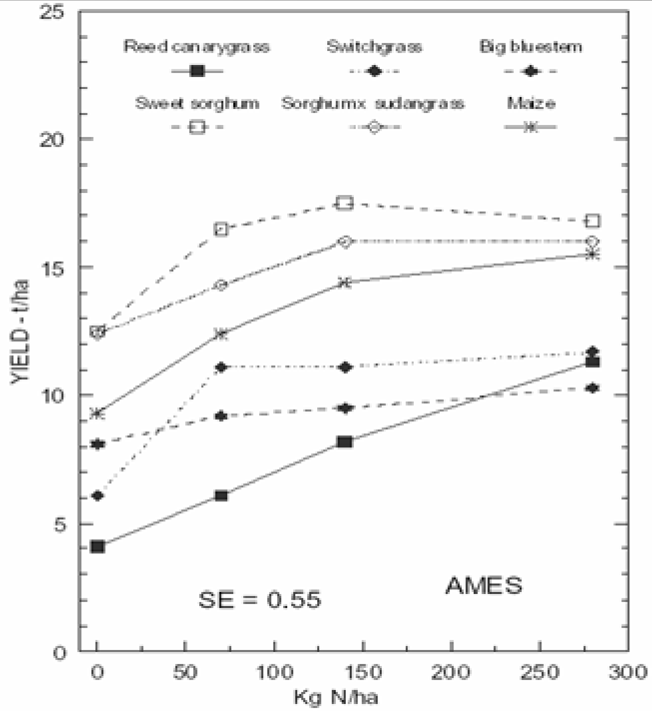


Figure 1. Yields of annual and perennial crops grown 1989 through 1992 near Ames, IA. Anderson et al., 1995

Crop rotations:

- Control of pest
- Efficient use of soil resources

Nutrient requirements:

- Low compared to maize (sweet sorghum)
- High leaf turnover rate (hemp)

Annual crops (sorghum, hemp)

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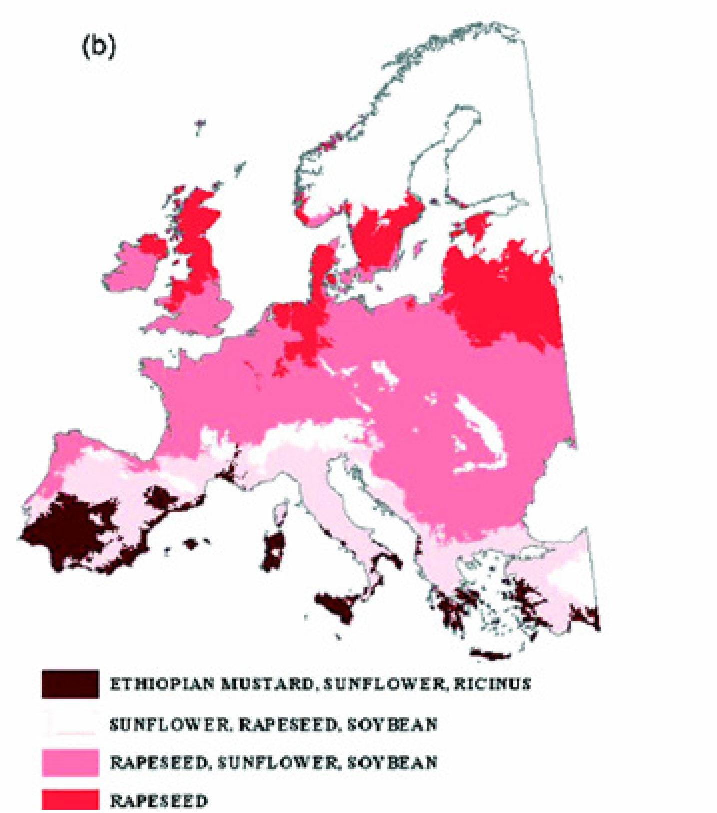
Sweet sorghum	Sowing: spring Duration: 105–119[26,27] Harvesting: fall	14.3–20[20,28]	56–224[29]	300–700[30]	Requires moderate management of weeds, diseases and other pests.	5–30[20,28]	250–422[30]
Hemp	Sowing: spring Duration: 112–154[22] Harvesting: summer	90–270[22]	100–220[22]	400–600[116,117]	Less pest and disease complex, easy management.	12–22.5[22]	128–207[30]

Zegada-Lizarazu et al., 2010

Harvest:

- Silage harvesters, straw balers, or sugarcane harvesters (sweet sorghum)
- Available harvesting equipment need some modifications (hemp)

Oilseed crops (Ethiopian mustard)



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Ethiopian mustard	Sowing: fall Duration: 155–175[49] Harvesting: spring/summer	100[50]	80–170	??	Requires moderate/ low management of weeds, diseases and other pests	2.6–3.98[51]	17–171[52,53]




- Harvesting with existing technology

Conclusions

- The most suitable energy crops (in terms of agronomic management, climatic adaptability and potential biomass production) for northern Europe are some fast growing trees and perennial grasses such as poplar, willow, and miscanthus.

- Under Mediterranean climates of southern Europe eucalyptus, sweet sorghum, and giant reed are promising energy crops.

Conclusions

• In general, most of the perennial grasses and woody crops are largely undomesticated and are at their early stages of development and management. These crops, however, show some advantages over annual crops in terms of agricultural inputs, yields, production costs, food security, reduced greenhouse gas emissions, and environmental sustainability.

Conclusions

• Important cultivation and management practices that need further development and evaluation 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.

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