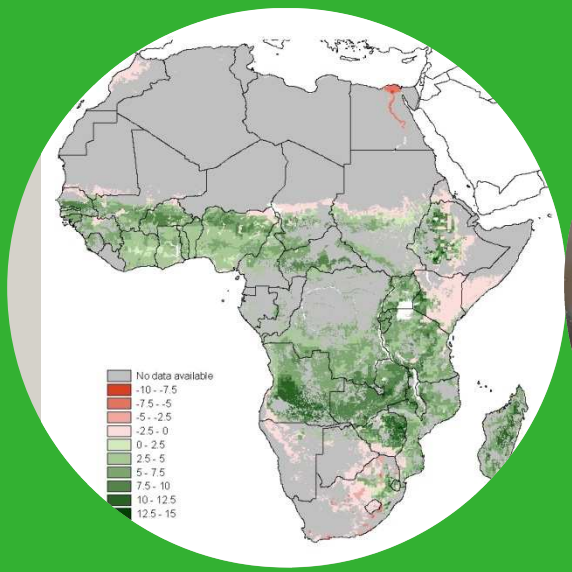
Bio-fuels, potential and drawbacks

Which crops for what feedstock and where do we grow them

Energy Day 7 - TU Eindhoven

21 February 2013

Dr R.E.E. (Raymond) Jongschaap



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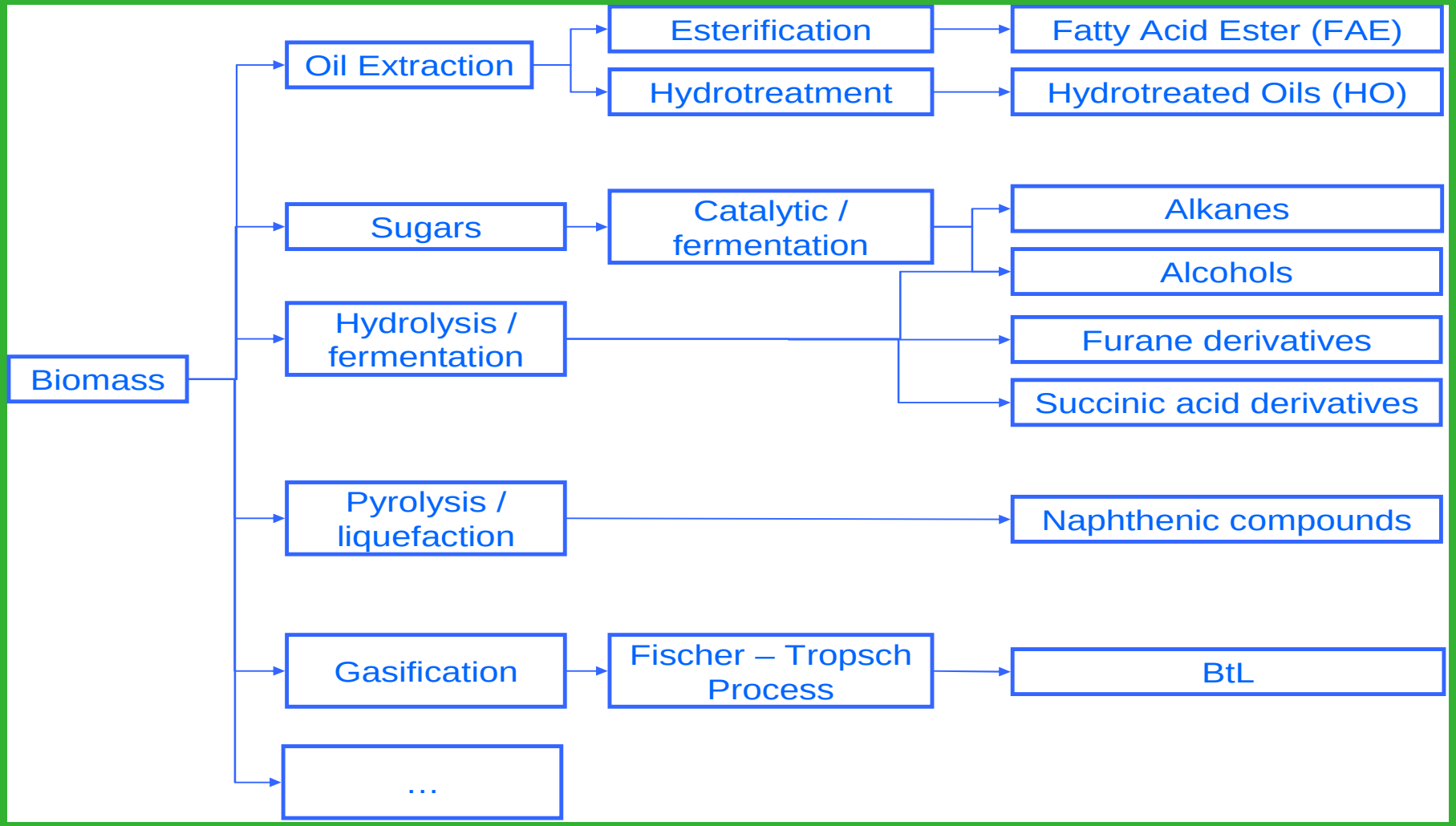
Outline

- Biomass to energy: not only biofuels
- Photosynthesis: solar energy conversion into biomass
- Production-ecology: yield gaps and crop management
- Competing claims (12 F's)
- Realistic potentials?
- Conclusions

Thermal, biological and chemical routes



Photosynthetic mechanisms

- Theoretical energy conversion
  - 4.5 - 5% for C3 crops (temperate regions)
  - 5.5 - 6% for C4 crops (tropical regions)
- Max rate of CO_2 fixation at 2000 µmol/m2/s (30° C)
  - 85 µmol/m2/s for C3 (4%)
  - 110 µmol/m2/s for C4 (5.5%)
- Not reached:
  - Respiratory costs
  - Canopies not closed

Energy efficiency

15 (45)%

2.3%

$C_6H_{12}O_6$

Annual actual efficiency

0.5% temperate regions
2.5% year round tropical **Gross !!**

0.2 – 0.8 % net energy

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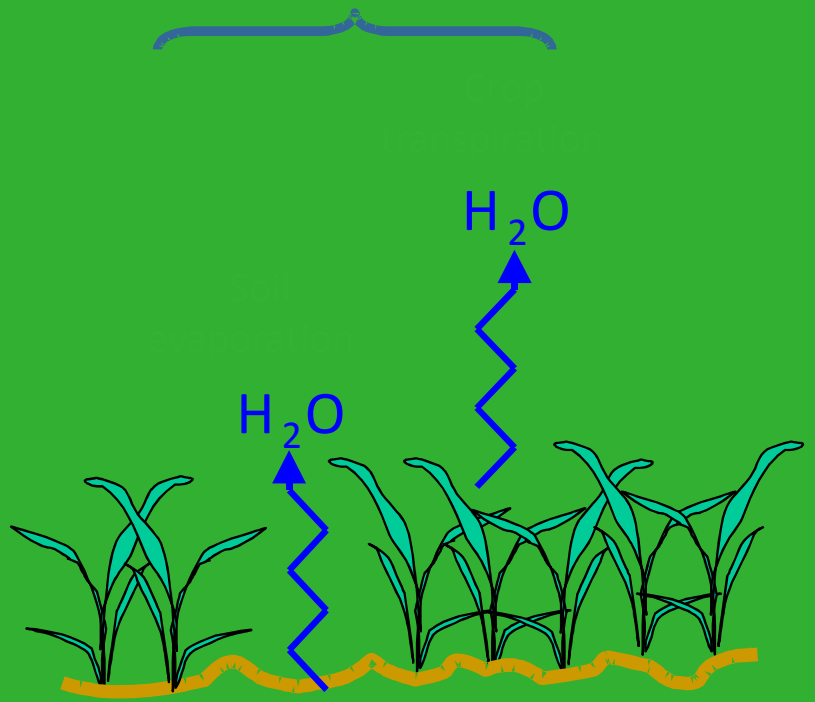
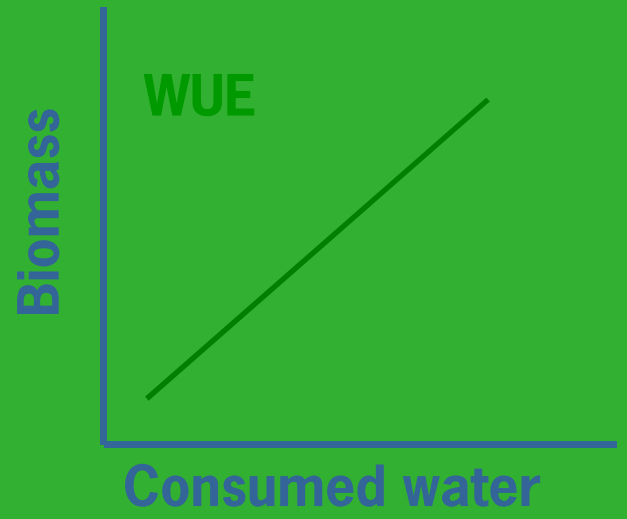
Water Use Efficiency

Water consumption





250 kg water / kg dry matter

Basic production ecological principles

Radiation use efficiency GROSS

0.5% temperate
2.5% year round

Radiation use efficiency GROSS

<< 0.5% temperate
2.5% year round

First & second generation!

- water - nutrients
+ water - nutrients
- water + nutrients
+ water + nutrients

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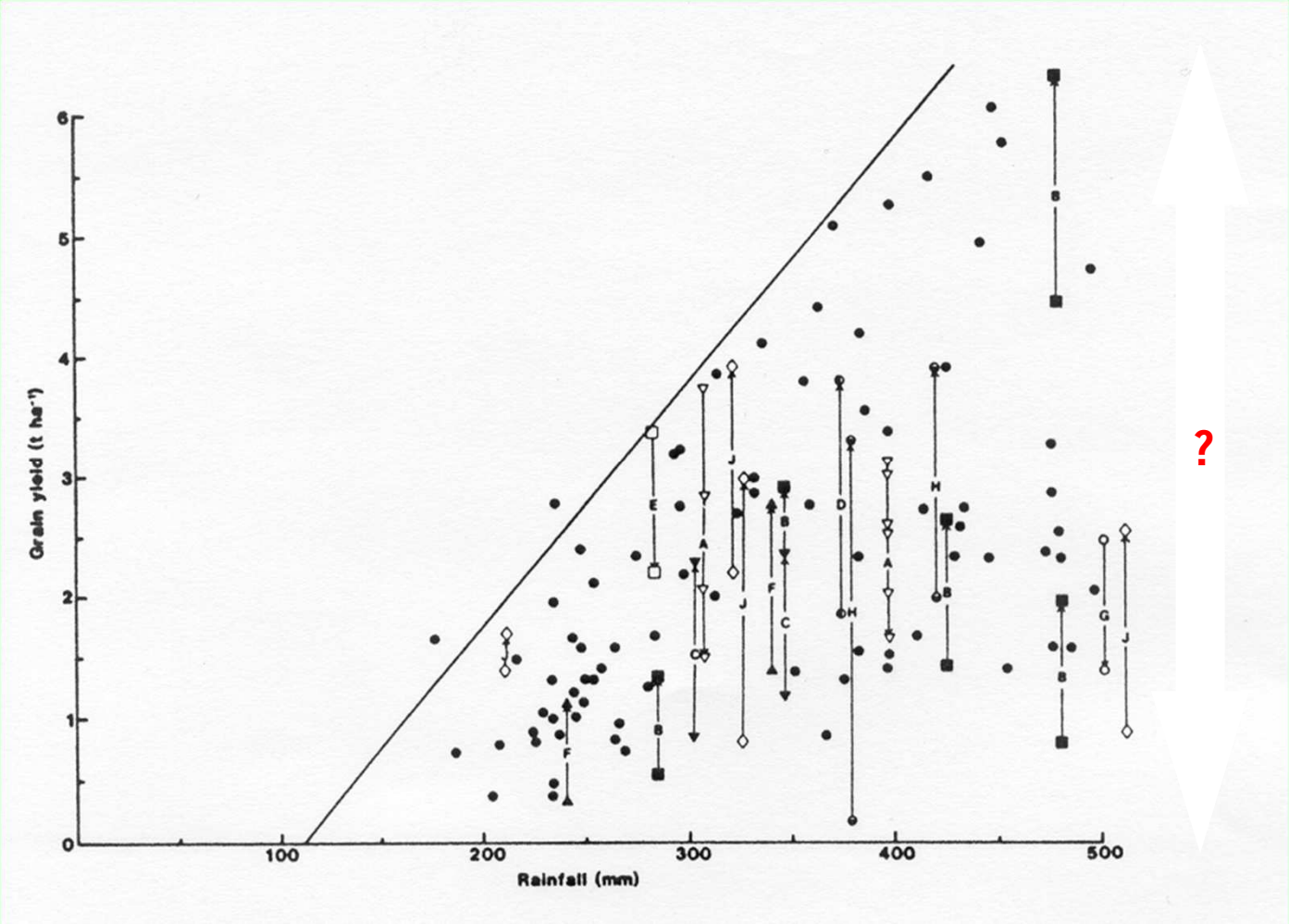
Experiments
Plant Research International - Prem Bindraban

Potential in current agriculture to increase WUE



Source: French and Schulz (1984)

Location specific soil management

BUT NOT WITHOUT RISK!

Rainfed
+ fertilizers

Rainfed
- fertilizers

Optimize rape seed production (NL)

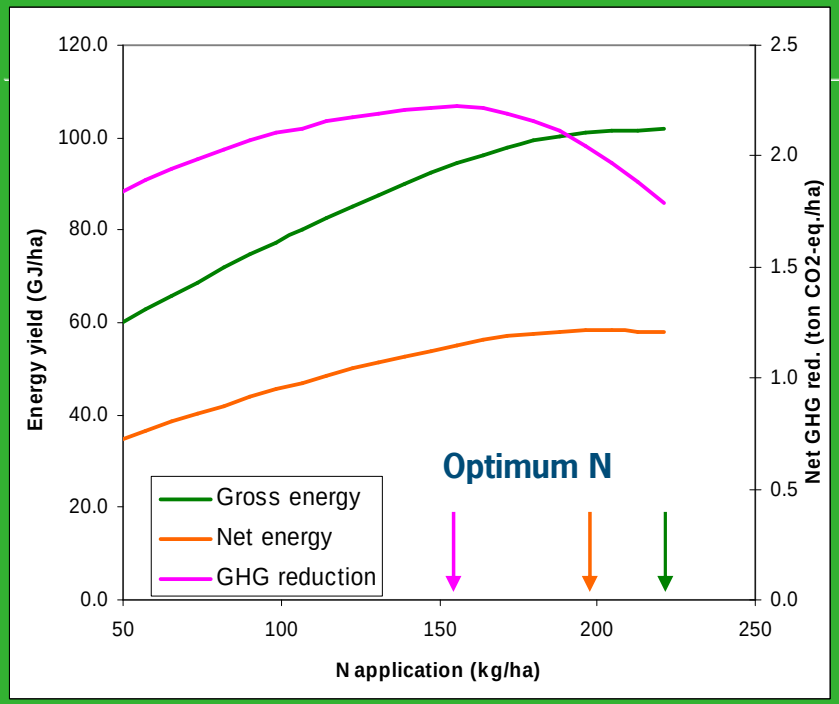


Figure 1. Effects of oilseed rape N application rates on net energy and GHG balance.

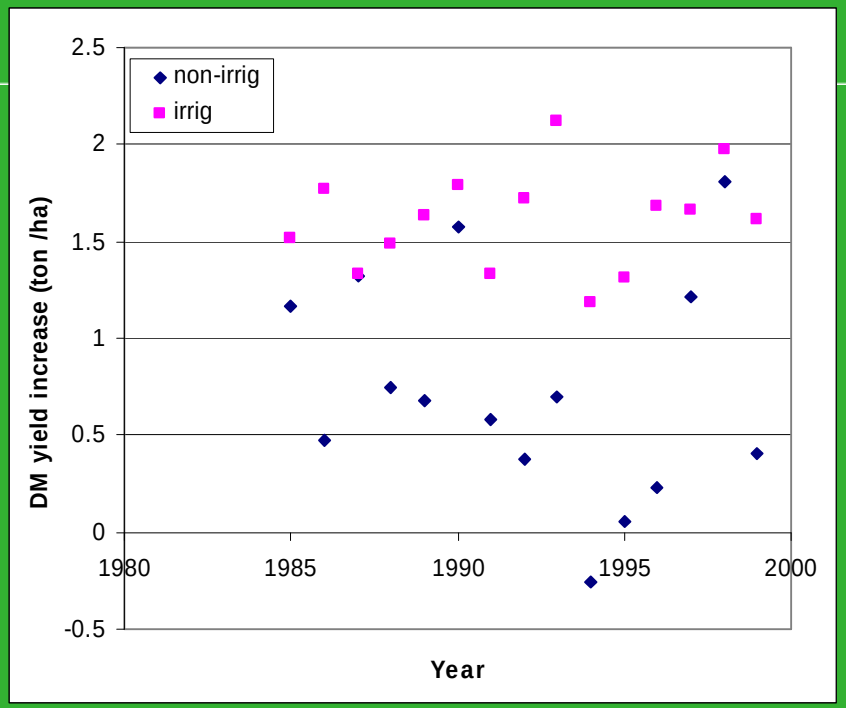


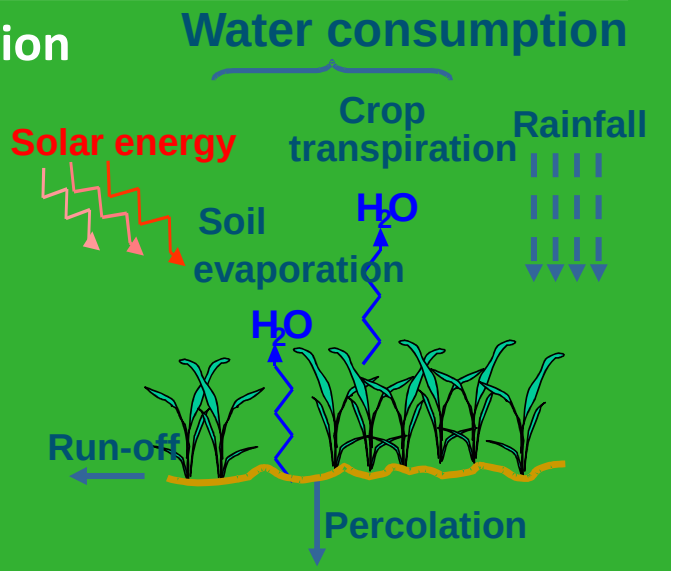
Figure 2. Yield increase with 30 days longer growth period of oilseed rape on sandy soils relative to current crop varieties

Source: Outlook on Agriculture 38, No 3, 2009

Realistic perspective on productivity

Production ecological principles drive plant production

- Crop characteristics (LGS, RUE, DM allocation)
- Radiation
- Temperature
- Precipitation
- Soil characteristics (texture, organic matter, slope)

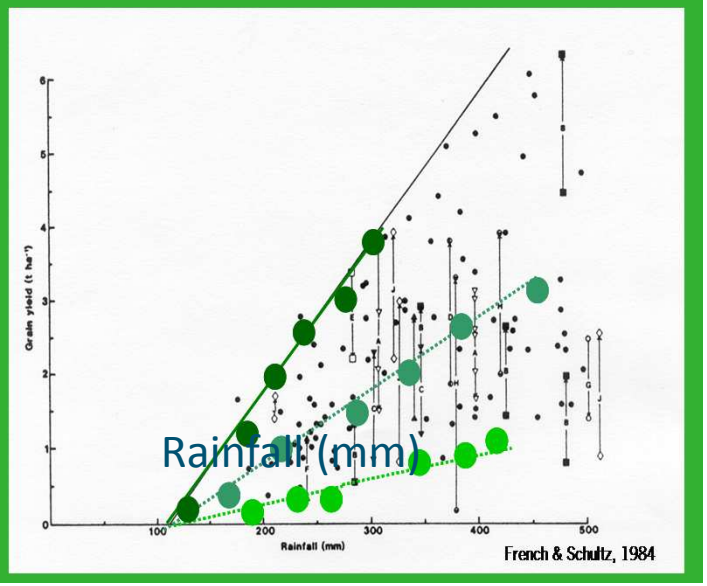


Socio-economic settings may limit plant production

- Crop management (soil, fertilization, etc.)

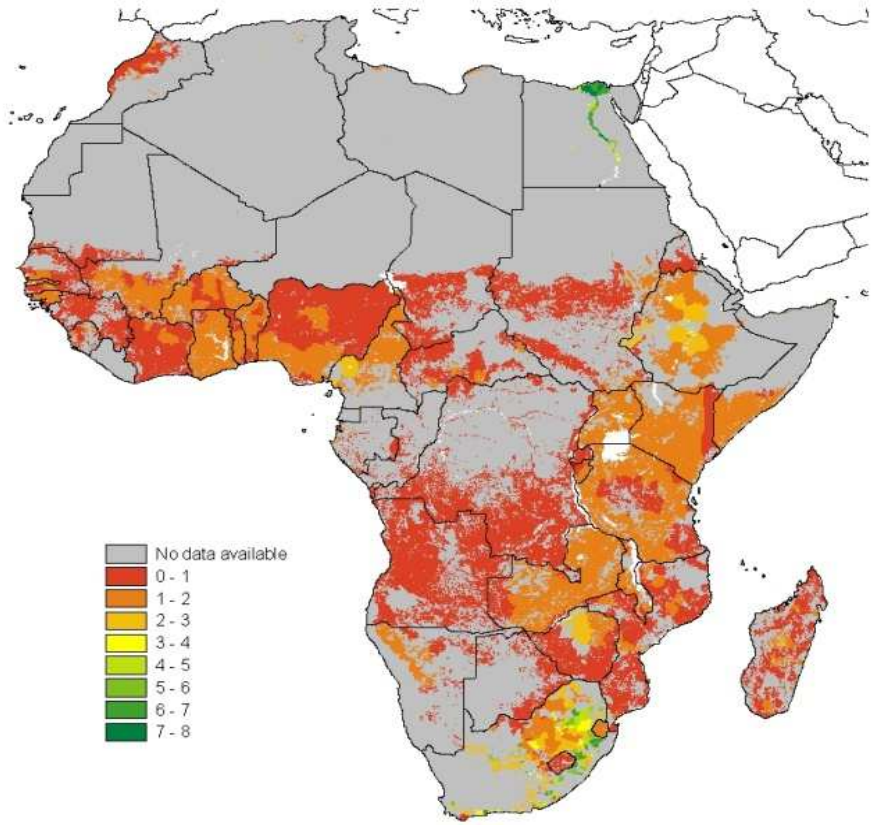
Abiotic and biotic stresses may reduce plant production

- Pests and diseases

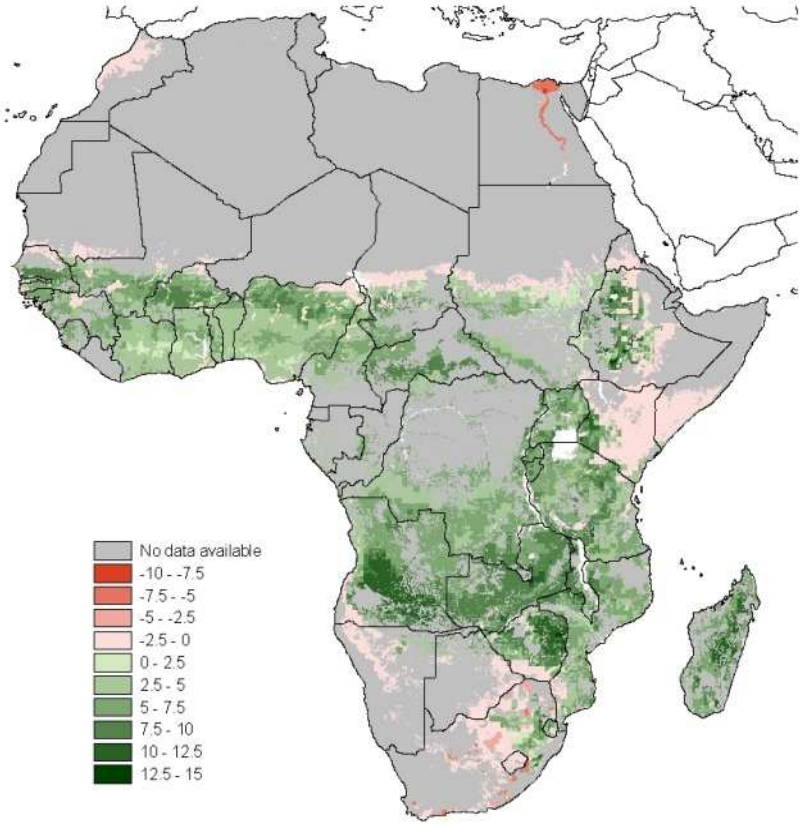


Rain-fed yield gaps at African continent

Current yield (t ha^{-1})

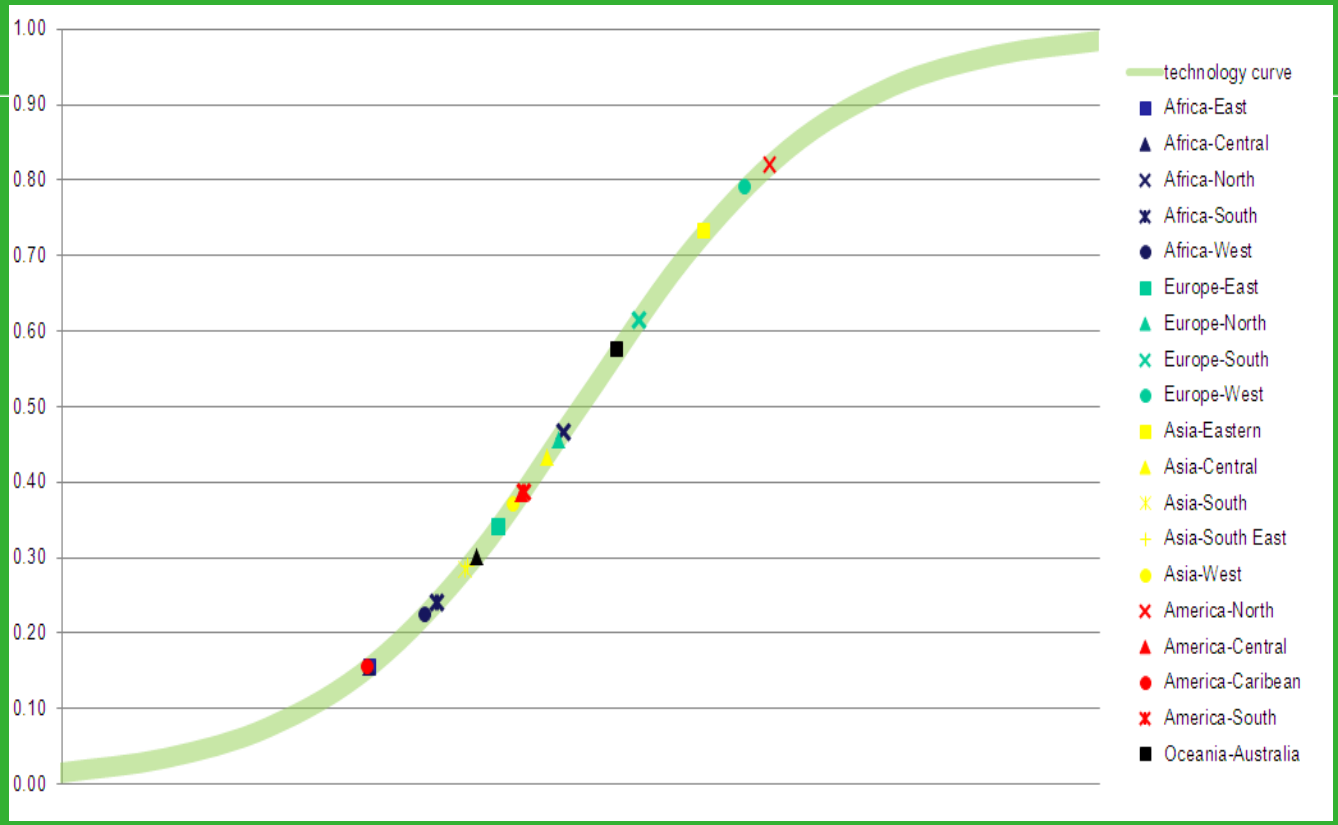


Yield gap (t ha^{-1})



Source: Conijn et al. (2011)

Upscale from spatial databases to regional data



Development Index (yield gap), expressed as ratio between actual productivity and biophysical maximum productivity levels for cereal and oilseed crops in the 22 UN sub-regions.

Source: Jongschaap et al. (2011)

Primary causes of food crisis

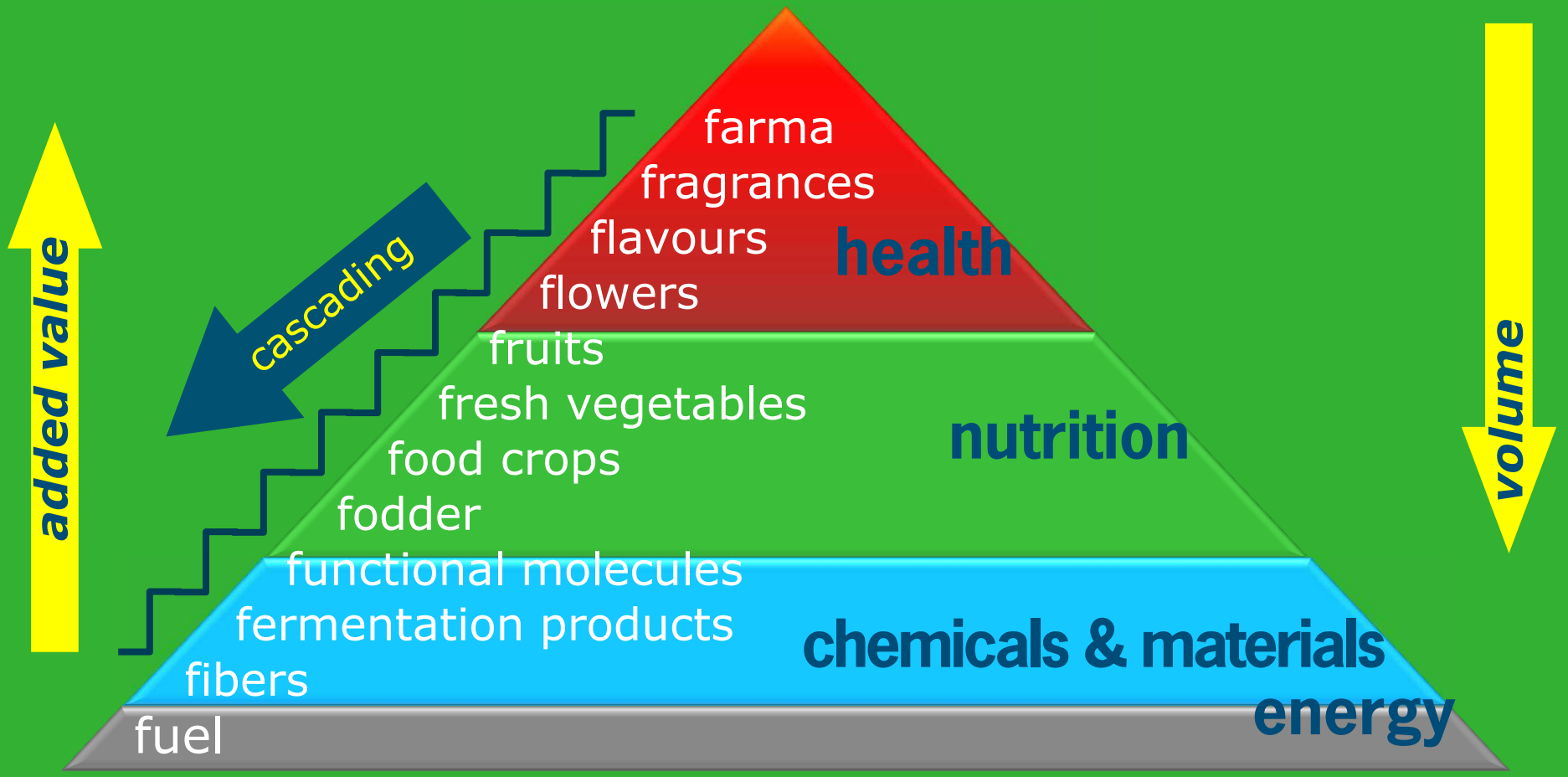
- The combination of extreme weather and subsequent decline in yields and cereal stocks; risks!
- A rapidly increasing share of non-food crops, primarily bio-fuels;
- High oil prices, affecting fertilizer use, food production, distribution and transport, and subsequently food prices;
- Speculation in the food markets.

Global challenge for the coming decades

- How can current and future generations be sustainably provided with sufficient food, energy, fibres and other ecosystem services, given the limited area of available land and natural resources, and increasing world population?

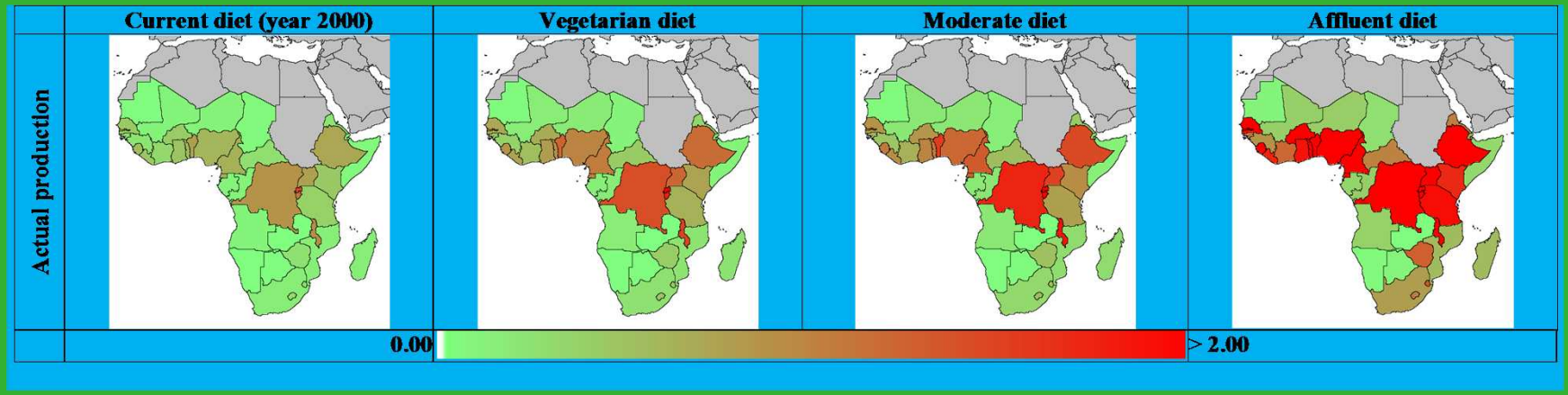
- Competing claims!

From Food to Fashion (12 F's of Rudy Rabbinge)



Requirement/availability of agricultural land

The ratio land requirements/availability for agricultural land per country in SSA for the actual production scenario and different diet compositions (current, vegetarian, moderate and affluent).



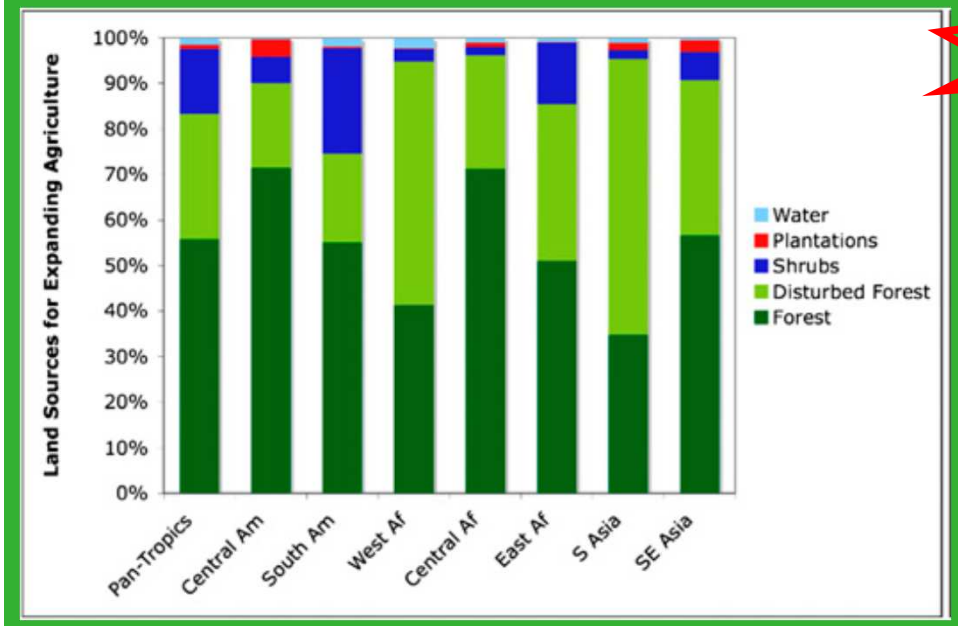
(Jongschaap & Bindraban, unpublished data)

Ultimate expansion into forests and savanna

1980s
and
1990s

biofuels

will exacerbate expansion



expansion of agricultural land appears to come from expansion into intact forest (55%), disturbed forest (28%) and savannah (8%)

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H. K. Gibbs, et al., 2010. Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s. PNAS, 107 (38) 16732–16737.

Realistic potentials

- Find candidate crops
- Assess realistic production

- Consider different crop types/products
  - Lignocellulose, sugar, starch and oil crops
  - Annual and perennial crops
  - Temperate and tropical crops
  - C3 or C4 photosynthetic process

- Assess potential increase by simulation of biomass production

Source: Jongschaap et al. (2011)

Biomass component	Annual		Perennial	
	C3	C4	C3	C4
Lignocellulose	Italian rye grass *(Lolium multiflorum)*	Sweet sorghum *(Sorghum saccharatum)*	Reed canary grass *(Phalaris arundinacea)* Common reed (*Phragmites australis)* Perennial rye grass *(Lolium perenne)*	Miscanthus *(Miscanthus spp.)* Switch grass *(Panicum virgatum)*
Lignocellulose SCR			Eucalyptus *(Eucalyptus spp.)* Poplar *(Populus spp.)* Willow *(Salix spp.)*	
Sugar	Sugar beet *(Beta vulgaris)* Wheat *(Triticum aestivum)*	Maize *(Zea mays)*	Cassava *(Manihot esculenta)*	Sugar cane *(Saccharum officinarum)*
Starch				
Oil	Camelina *(Camelina sativa)* Oilseed rape *(Brassica napus)* Soy *(Glycine max)* Sunflower *(Helianthus annuus)*		Jatropha *(Jatropha curcas)* Oil palm *(Elaeis guineensis)*	

Source: Jongschaap et al. (2011)

Sustainable Production Scenario settings

Food security

- 1st Preserve cropland and grassland for food security
- Population growth until 2050 (per UN sub region)
- Regional diet changes in time
- Extrapolate regional productivity increase (1980-2009) for lignocellulose and oil crops until regional physiological maximum!

Source: Jongschaap et al. (2011)

Sustainable Production Scenario settings

Resource Use

- Land use as in 2000, no deforestation
- Use cropland and grazing land only
- Multiple growing seasons per year

Source: Jongschaap et al. (2011)

Sustainable Production Scenario settings

- Crop rotation
- Rotation requirements set by crop type (oil/lignocellulose 2:1 and 1:2)
- Rotate with food crops only if possible (higher production)
- Only annuals on cropland, only perennials on grazing land
- Crop mixes (to produce cellulose, oil, starch or sugar crops in an area)
- Optimization set by (local) feed stock preference

Source: Jongschaap et al. (2011)

Production volumes per region

- Calculation steps on a regional base:
- Start with acreage cropland and grazing land in year 2000
- Reduce acreage by regional land requirements for diet production (use local population growth, diet requirements and expected diet change, productivity and productivity increase)
- Set aside (do not affect) sugar cane area
- In case of shortage of cropland, use grazing land (with 25% lower productivity)
- In case of continued shortage of cropland and grazing land: import the required acreages from other regions based on the caloric productivity

Source: Jongschaap et al. (2011)

Production volumes per region

Final steps:

- Use remaining cropland and grazing land for biofuel production
- Use scenarios to explore potentials

Source: Jongschaap et al. (2011)

Scenarios: how to use excess cropland and grazing land

General

- Only annuals species on cropland, only perennial species on grazing land
- Oil palm and jatropha only on designated areas
- Maximally use 70% of available grazing land (preserve biodiversity)
- Productivity on grazing land is 75% relative to productivity on cropland

Source: Jongschaap et al. (2011)

Scenarios: how to use excess cropland and grazing land

Specific

Maximize oil or lignocellulose production

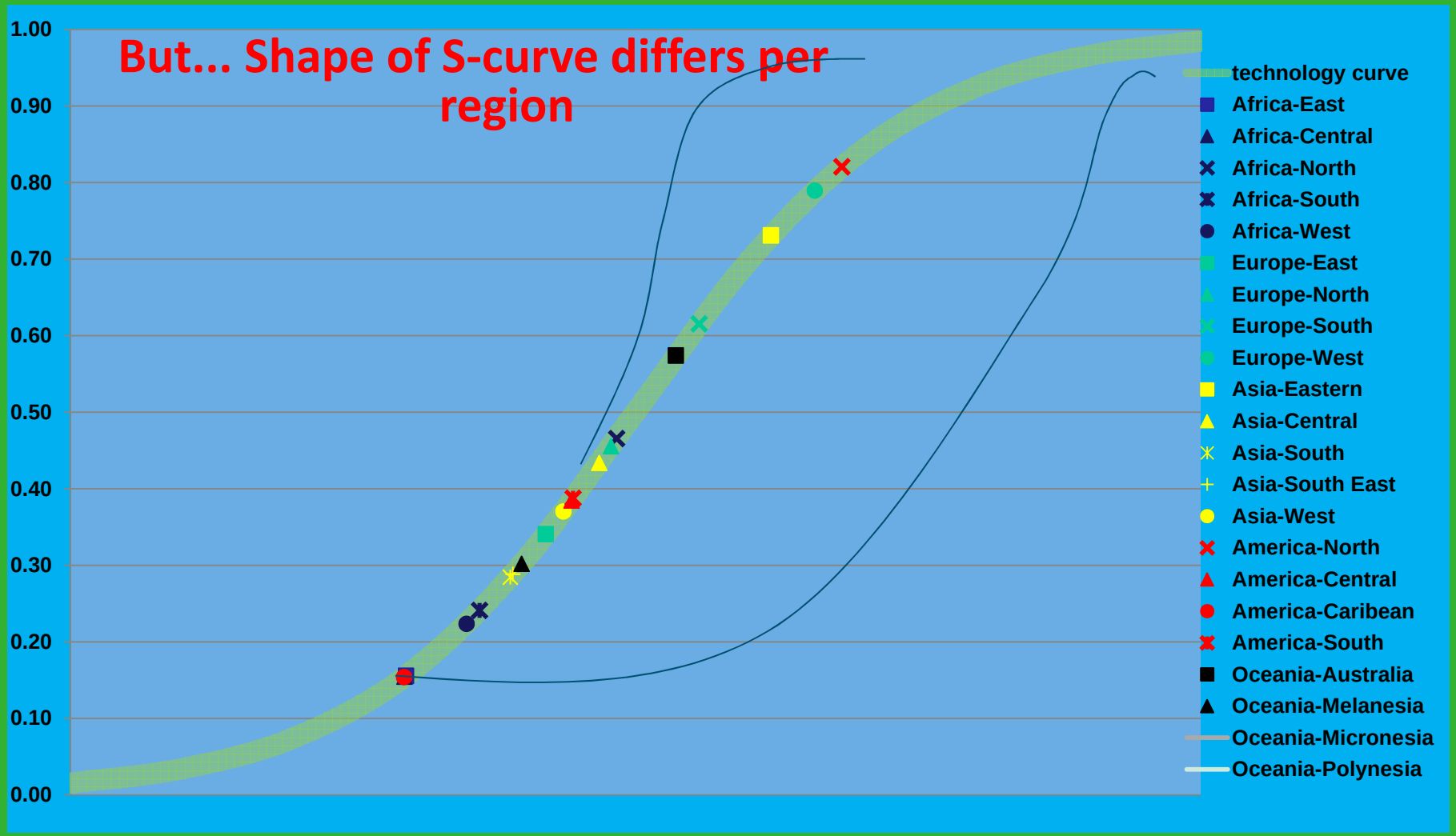
- Rotation Oil – Lignocellulose 2:1 and 1:2
- In Max oil scenario: If no perennial oil species is available, use lignocellulose crop
- Include/Exclude grazing lands for biofuel production

Technology scenario

- Solve the 'yield gap' in 2050 to the level of Europe / North America (82%)

Source: Jongschaap et al. (2011)

Regional technological development



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Source: Jongschaap et al. (2011)

Regional cropland availability

A	Year	Africa		163.0562			Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland req for diet	2000	50.6	19.6	35.9	10.3	47.6	298.1	11.2	296.2	104.7	38.5	62.3	19.3	29.7	37.5	7.7	27.0	69.5	65.3	4.7	1.4	0.1	0.1	1237.4
(Mha)	2010	64.8	24.3	36.7	9.9	54.7	316.4	9.0	309.9	107.0	38.6	55.5	20.0	28.0	37.9	8.3	29.0	70.4	69.7	4.7	1.6	0.1	0.1	1296.7
	2020	79.1	28.3	50.5	8.9	59.8	320.9	7.7	304.2	102.6	37.8	49.0	20.5	25.7	37.4	8.4	29.6	67.9	73.1	5.4	1.7	0.1	0.1	1318.7
2048	2030	93.0	32.0	56.4	8.1	64.1	315.6	6.7	294.0	97.7	36.9	43.1	20.8	29.5	36.5	8.4	29.6	64.6	75.3	5.7	1.7	0.1	0.1	1320.1
2001	2040	105.8	35.0	61.3	7.4	68.0	302.7	5.8	280.3	146.4	35.7	37.8	21.0	28.5	35.3	8.2	29.0	83.2	76.4	5.8	1.8	0.1	0.2	1375.7
(m2 p-1 y-1)	2050	116.8	37.3	65.0	6.7	70.8	284.7	5.2	264.4	147.4	34.2	33.4	21.0	27.3	33.8	7.9	27.6	81.3	76.7	5.9	1.8	0.1	0.2	1349.4

B	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland	2000	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6
available	2010	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6
(Mha)	2020	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6
	2030	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6
	2040	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6
	2050	56.6	24.1	45.1	17.2	79.9	151.1	32.1	231.6	93.2	48.4	204.6	15.4	42.1	31.5	7.3	35.4	115.6	206.0	22.8	1.3	0.1	0.2	1461.6

C	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Oil Palm acreage	2000	0.0	0.3			3.8		0.0	5.4							0.0	0.1	0.3			0.1			10.1
Sugar cane acreage	2000	0.4	0.2	0.2	0.4	0.1		1.3	2.2	5.5	0.0			0.0		1.3	1.1	6.2	0.4	0.4	0.1		0.0	19.8

D: B-A-C	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland	2000	5.6	4.0	9.0	6.5	28.5	-147.0	19.6	-72.1	-17.0	9.9	142.3	-3.9	12.3	-6.0	-1.7	7.1	39.6	140.3	17.6	-0.3	0.0	0.0	194.3
Excess / Deficit	2010	-8.6	-0.7	8.2	6.8	21.4	-165.3	21.8	-85.9	-19.3	9.8	149.1	-4.6	14.0	-6.4	-2.3	5.2	38.7	135.9	17.7	-0.5	0.0	0.0	135.0
(Mha)	2020	-23.0	-4.7	-5.6	7.9	16.2	-169.8	23.2	-80.2	-14.9	10.6	155.5	-5.1	16.3	-5.9	-2.4	4.6	41.2	132.5	16.9	-0.6	-0.1	0.0	113.0
	2030	-36.8	-8.3	-11.5	8.7	11.9	-164.4	24.2	-70.0	-10.0	11.5	161.4	-5.4	12.5	-5.0	-2.4	4.5	44.5	130.3	16.7	-0.6	-0.1	0.0	111.6
	2040	-49.7	-11.3	-16.4	9.4	8.1	-151.6	25.0	-56.2	-58.7	12.7	166.7	-5.5	13.6	-3.8	-2.2	5.2	26.0	129.2	16.5	-0.7	-0.1	0.0	56.0
	2050	-60.6	-13.6	-20.1	10.0	5.3	-133.6	25.7	-40.3	-59.7	14.2	171.2	-5.6	14.8	-2.3	-1.9	6.5	27.8	128.9	16.4	-0.7	-0.1	0.0	82.3

E	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland deficit that	2000	0.0	0.0	0.0	0.0	0.0	147.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	156.6
can be 'relieved by	2010	8.6	0.7	0.0	0.0	0.0	165.3	0.0	0.0	0.0	0.0	0.0	4.6	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	184.4
the use of grassland	2020	23.0	4.7	5.6	0.0	0.0	169.8	0.0	0.0	0.0	0.0	0.0	5.1	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	213.1
(Mha)	2030	36.8	8.3	11.5	0.0	0.0	164.4	0.0	0.0	0.0	0.0	0.0	5.4	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	231.4
	2040	49.7	11.3	16.4	0.0	0.0	151.6	0.0	0.0	0.0	0.0	0.0	5.5	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	238.3
	2050	47.0	13.6	20.1	0.0	0.0	133.6	0.0	0.0	0.0	0.0	0.0	5.6	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	222.2

F: D+E	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland	2000	5.6	4.0	9.0	6.5	28.5	0.0	19.6	-72.1	-17.0	9.9	142.3	0.0	12.3	-0.2	-1.7	7.1	39.6	140.3	17.6	-0.3	0.0	0.0	350.9
Excess / Deficit	2010	0.0	0.0	8.2	6.8	21.4	0.0	21.8	-85.9	-19.3	9.8	149.1	0.0	14.0	-1.2	-2.3	5.2	38.7	135.9	17.7	-0.5	0.0	0.0	319.5
after use of grassland	2020	0.0	0.0	0.0	7.9	16.2	0.0	23.2	-80.2	-14.9	10.6	155.5	0.0	16.3	-0.8	-2.4	4.6	41.2	132.5	16.9	-0.6	-0.1	0.0	326.1
(Mha)	2030	0.0	0.0	0.0	8.7	11.9	0.0	24.2	-70.0	-10.0	11.5	161.4	0.0	12.5	0.0	-2.4	4.5	44.5	130.3	16.7	-0.6	-0.1	0.0	343.1
	2040	0.0	0.0	0.0	9.4	8.1	0.0	25.0	-56.2	-58.7	12.7	166.7	0.0	13.6	0.0	-2.2	5.2	26.0	129.2	16.5	-0.7	-0.1	0.0	294.2
	2050	-13.7	0.0	0.0	10.0	5.3	0.0	25.7	-40.3	-59.7	14.2	171.2	0.0	14.8	0.0	-1.9	6.5	27.8	128.9	16.4	-0.7	-0.1	0.0	304.4

G	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland	2000	0.0	0.0	-0.1	0.0	-1.0	0.0	-0.6	72.0	17.0	-0.2	-49.3	0.0	-0.4	0.4	1.7	-0.1	-2.3	-54.2	-0.9	0.4	0.0	0.0	-17.8
'Imported/Exported'	2010	0.0	0.0	-0.1	-0.1	-0.6	0.0	-0.9	85.6	19.1	-0.2	-53.1	0.0	-0.5	1.9	1.9	0.0	-2.3	-51.2	-0.9	0.6	0.1	0.0	-0.8
(Mha)	2020	0.0	0.0	0.0	-0.1	-0.3	0.0	-1.3	80.4	14.8	-0.3	-56.5	0.0	-0.7	1.1	1.9	0.0	-2.7	-48.1	-0.8	0.6	0.1	0.0	-11.9
Note: based on regional difference in MJ m-2!	2030	0.0	0.0	0.0	-0.1	-0.2	0.0	-1.6	70.7	10.0	-0.3	-59.5	0.0	-0.4	0.0	1.7	0.0	-3.2	-45.7	-0.8	0.7	0.1	0.0	-28.8
	2040	0.0	0.0	0.0	-0.1	-0.1	0.0	-2.0	57.1	58.6	-0.4	-63.5	0.0	-0.5	0.0	1.4	0.0	-1.1	-45.1	-0.8	0.7	0.1	0.0	4.3
	2050	7.1	0.0	0.0	-0.2	0.0	0.0	-2.3	43.8	63.6	-0.5	-64.7	0.0	-0.5	0.0	1.2	-0.1	-1.3	-43.5	-0.7	0.7	0.1	0.0	2.6

H	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Cropland for	2000	5.6	4.0	8.9	6.4	27.5	0.0	19.0	-0.2	0.0	9.7	92.9	0.0	11.9	0.2	0.0	7.0	37.3	86.1	16.8	0.1	0.0	0.0	333.1
biofuel production	2010	0.0	0.0	8.1	6.7	20.8	0.0	20.8	-0.3	-0.2	9.6	96.0	0.0	13.5	0.7	-0.3	5.2	36.4	84.6	16.8	0.1	0.0	0.0	318.6
(Mha)	2020	0.0	0.0	0.0	7.8	15.9	0.0	21.9	0.3	-0.1	10.4	99.0	0.0	15.6	0.3	-0.5	4.6	38.5	84.4	16.1	0.1	0.0	0.0	314.2
	2030	0.0	0.0	0.0	8.5	11.7	0.0	22.5	0.7	0.0	11.2	101.9	0.0	12.1	0.0	-0.7	4.5	41.3	84.5	15.9	0.0	0.0	0.0	314.2
	2040	0.0	0.0	0.0	9.2	8.0	0.0	23.0	0.9	-0.1	12.3	103.2	0.0	13.1	0.0	-0.8	5.1	24.8	84.1	15.7	0.0	0.0	0.0	298.5
	2050	-6.6	0.0	0.0	9.8	5.2	0.0	23.4	3.4	3.8	13.7	106.5	0.0	14.3	0.0	-0.7	6.5	26.5	85.5	15.7	0.0	0.0	0.0	307.1

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Source: Jongschaap et al. (2011)

Regional grazing land availability

K		Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland req	2000	59.5	23.1	42.3	12.1	56.0	244.5	9.2	242.9	85.9	31.6	29.4	9.1	14.0	17.7	9.1	31.8	81.8	30.8	2.2	1.7	0.1	0.1	1034.9
for diet	2010	80.4	31.7	51.4	14.2	75.2	268.8	10.8	303.2	104.0	39.6	28.8	9.6	15.0	18.4	10.3	37.3	95.8	34.3	2.5	2.1	0.1	0.2	1233.6
(Mha)	2020	103.3	40.4	59.7	15.0	94.2	281.9	12.1	345.8	115.3	46.5	27.8	10.1	15.3	18.5	11.1	41.4	104.8	37.3	2.8	2.5	0.2	0.2	1386.1
966	2030	127.3	49.6	66.9	15.7	113.8	286.4	13.0	380.6	124.6	53.1	26.5	10.4	15.3	18.5	11.7	44.8	111.6	40.0	3.0	3.0	0.2	0.2	1516.2
2355	2040	151.7	58.6	72.9	16.2	134.2	283.5	13.6	407.2	131.3	58.7	25.1	10.7	15.2	18.4	12.0	47.1	115.9	42.0	3.2	3.4	0.2	0.2	1621.1
(m2 p-1 y-1)	2050	174.9	67.1	77.4	16.6	153.8	274.9	13.9	425.9	135.1	63.2	23.7	11.0	15.0	18.0	12.1	48.0	117.7	43.7	3.3	3.7	0.2	0.2	1699.2

L	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland	2000	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0
available	2010	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0
(Mha)	2020	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0
	2030	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0
	2040	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0
	2050	237.5	133.9	192.6	150.7	186.8	524.9	250.3	95.3	16.7	226.5	116.5	23.3	28.3	25.3	4.6	91.3	459.1	277.0	445.6	0.6	0.0	0.0	3487.0

M: L-K	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland	2000	178.0	110.8	150.3	138.6	130.8	280.4	241.1	-147.6	-69.2	194.9	87.1	14.2	14.3	7.6	-4.5	59.5	377.3	246.2	443.4	-1.0	-0.1	-0.1	2452.0
Excess / Deficit	2010	157.1	102.2	141.2	136.4	111.6	256.1	239.5	-207.9	-87.3	186.9	87.7	13.7	13.4	7.0	-5.7	54.0	363.3	242.7	443.1	-1.4	-0.1	-0.1	2253.4
(Mha)	2020	134.2	93.5	132.9	135.6	92.6	243.0	238.3	-250.4	-98.6	180.0	88.7	13.3	13.0	6.8	-6.4	49.9	354.3	239.6	442.8	-1.9	-0.1	-0.1	2100.9
	2030	110.1	84.3	125.7	134.9	73.0	238.5	237.3	-285.3	-107.9	173.4	90.0	12.9	13.0	6.8	-7.0	46.5	347.5	237.0	442.6	-2.3	-0.2	-0.2	1970.8
	2040	85.8	75.3	119.7	134.4	52.6	241.4	236.7	-311.9	-114.6	167.8	91.4	12.6	13.1	7.0	-7.4	44.2	343.2	235.0	442.4	-2.7	-0.2	-0.2	1865.9
	2050	62.6	66.8	115.1	134.1	33.0	249.9	236.4	-330.5	-118.4	163.2	92.8	12.4	13.4	7.3	-7.4	43.3	341.4	233.3	442.3	-3.1	-0.2	-0.2	1787.8

N: E / I	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland used for	2000	0.0	0.0	0.0	0.0	0.0	-195.9	0.0	0.0	0.0	0.0	0.0	-5.2	0.0	-7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-208.8
crop production	2010	-11.5	-0.9	0.0	0.0	0.0	-220.4	0.0	0.0	0.0	0.0	0.0	-6.1	0.0	-7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-245.9
	2020	-30.6	-6.2	-7.4	0.0	0.0	-226.4	0.0	0.0	0.0	0.0	0.0	-6.8	0.0	-6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-284.2
	2030	-49.1	-11.1	-15.3	0.0	0.0	-219.2	0.0	0.0	0.0	0.0	0.0	-7.2	0.0	-6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-308.6
	2040	-66.2	-15.1	-21.9	0.0	0.0	-202.1	0.0	0.0	0.0	0.0	0.0	-7.4	0.0	-5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-317.7
	2050	-62.6	-18.2	-26.8	0.0	0.0	-178.1	0.0	0.0	0.0	0.0	0.0	-7.5	0.0	-3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-296.2

O: M+N	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland	2000	178.0	110.8	150.3	138.6	130.8	84.4	241.1	-147.6	-69.2	194.9	87.1	9.0	14.3	0.0	-4.5	59.5	377.3	246.2	443.4	-1.0	-0.1	-0.1	2243.2
Excess / Deficit	2010	145.5	101.3	141.2	136.4	111.6	35.7	239.5	-207.9	-87.3	186.9	87.7	7.6	13.4	0.0	-5.7	54.0	363.3	242.7	443.1	-1.4	-0.1	-0.1	2007.4
after crop production	2020	103.6	87.3	125.5	135.6	92.6	16.6	238.3	-250.4	-98.6	180.0	88.7	6.5	13.0	0.0	-6.4	49.9	354.3	239.6	442.8	-1.9	-0.1	-0.1	1816.7
(Mha)	2030	61.0	73.3	110.4	134.9	73.0	19.3	237.3	-285.3	-107.9	173.4	90.0	5.7	13.0	0.1	-7.0	46.5	347.5	237.0	442.6	-2.3	-0.2	-0.2	1662.2
	2040	19.6	60.2	97.8	134.4	52.6	39.3	236.7	-311.9	-114.6	167.8	91.4	5.2	13.1	2.0	-7.4	44.2	343.2	235.0	442.4	-2.7	-0.2	-0.2	1548.2
	2050	0.0	48.6	88.4	134.1	33.0	71.8	236.4	-330.5	-118.4	163.2	92.8	4.9	13.4	4.3	-7.4	43.3	341.4	233.3	442.3	-3.1	-0.2	-0.2	1491.5

P	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland	2000	-16.1	-10.0	-13.6	-12.5	-11.8	-7.6	-21.8	147.6	69.2	-17.6	-7.9	-0.8	-1.3	0.0	4.5	-5.4	-34.0	-22.2	-40.0	1.0	0.1	0.1	0.0
'Imported/Exported'	2010	-19.1	-13.3	-18.5	-17.9	-14.6	-4.7	-31.4	207.9	87.3	-24.5	-11.5	-1.0	-1.7	0.0	5.7	-7.1	-47.6	-31.8	-58.0	1.4	0.1	0.1	0.0
(Mha)	2020	-17.0	-14.4	-20.6	-22.3	-15.2	-2.7	-39.2	250.4	98.6	-29.6	-14.6	-1.1	-2.1	0.0	6.4	-8.2	-58.3	-39.4	-72.8	1.9	0.1	0.1	0.0
Note: based on	2030	-11.9	-14.3	-21.5	-26.3	-14.2	-3.8	-46.3	285.3	107.9	-33.8	-17.6	-1.1	-2.5	0.0	7.0	-9.1	-67.8	-46.2	-86.4	2.3	0.2	0.2	0.0
equal productivity	2040	-4.3	-13.2	-21.5	-29.6	-11.6	-8.6	-52.1	311.9	114.6	-36.9	-20.1	-1.2	-2.9	-0.4	7.4	-9.7	-75.5	-51.7	-97.4	2.7	0.2	0.2	0.0
between regions	2050	0.0	-11.5	-20.8	-31.6	-7.8	-16.9	-55.7	330.5	118.4	-38.5	-21.9	-1.2	-3.1	-1.0	7.4	-10.2	-80.5	-55.0	-104.2	3.1	0.2	0.2	0.0

Q: O+P	Year	Africa					Asia					Europe				Latin America			Northern	Oceania				World
		Eastern Africa	Middle Af	Northern	Southern	Western A	Eastern A	Central A	Southern	Southeas	Western A	Eastern E	Northern	Southern	Western E	Caribbea	Central A	South Am	Northern	Australia	Melanesia	Micronesi	Polynesia	
Grassland	2000	161.9	100.8	136.7	126.1	119.0	76.8	219.4	0.0	0.0	177.3	79.3	8.2	13.0	0.0	0.0	54.1	343.3	224.0	403.4	0.0	0.0	0.0	2243.2
for bioenergy prod	2010	126.5	88.0	122.7	118.6	97.0	31.0	208.1	0.0	0.0	162.4	76.2	6.6	11.6	0.0	0.0	46.9	315.7	210.9	385.1	0.0	0.0	0.0	2007.4
(Mha)	2020	86.5	72.9	104.8	113.3	77.4	13.9	199.1	0.0	0.0	150.4	74.1	5.5	10.9	0.0	0.0	41.7	296.0	200.2	370.0	0.0	0.0	0.0	1816.7
	2030	49.1	59.0	88.8	108.6	58.7	15.5	191.0	0.0	0.0	139.6	72.4	4.6	10.5	0.1	0.0	37.4	279.7	190.8	356.3	0.0	0.0	0.0	1662.2
	2040	15.3	46.9	76.3	104.9	41.0	30.6	184.6	0.0	0.0	130.9	71.3	4.1	10.2	1.5	0.0	34.5	267.7	183.2	345.1	0.0	0.0	0.0	1548.2
	2050	0.0	37.2	67.5	102.5	25.3	54.9	180.7	0.0	0.0	124.8	70.9	3.7	10.2	3.3	0.0	33.1	261.0	178.3	338.1	0.0	0.0	0.0	1491.5

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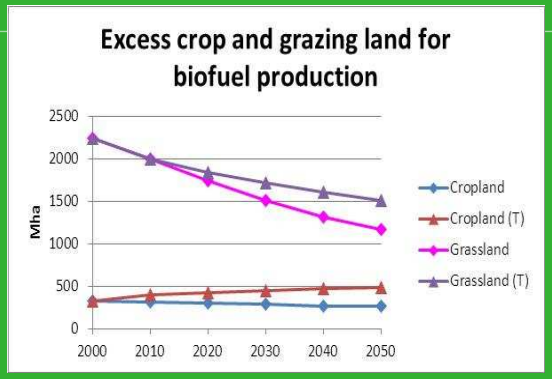
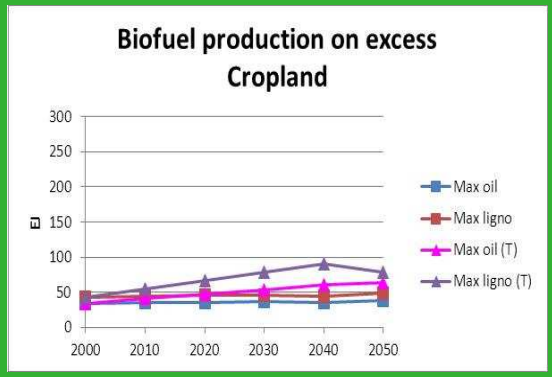
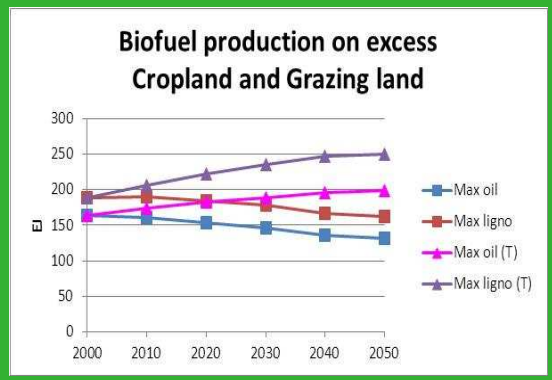
Source: Jongschaap et al. (2011)

Scenario results

- Technology development (closing the 'yield gap') avails 186 Mha cropland and 236 Mha grazing land for other purposes (Total 422 Mha)
- Increasing productivity of grazing land is difficult
- Huge and remote areas, less productive
- Effects through livestock products (feed conversion ratios) lag behind







Source: Jongschaap et al. (2011)

Conclusions

Solar energy

Enormous potential, but …

- Biology inefficient to fix solar energy
- 10% of all tranport fuels needs 26% or all crop production!
- Totality of world's crops would produce 13% of world's primary energy (9% when efficiencies in appropration included)

(V0 version HPLE report Biofuels and Food Security: www.fao.org/cfs/cfs-hple)

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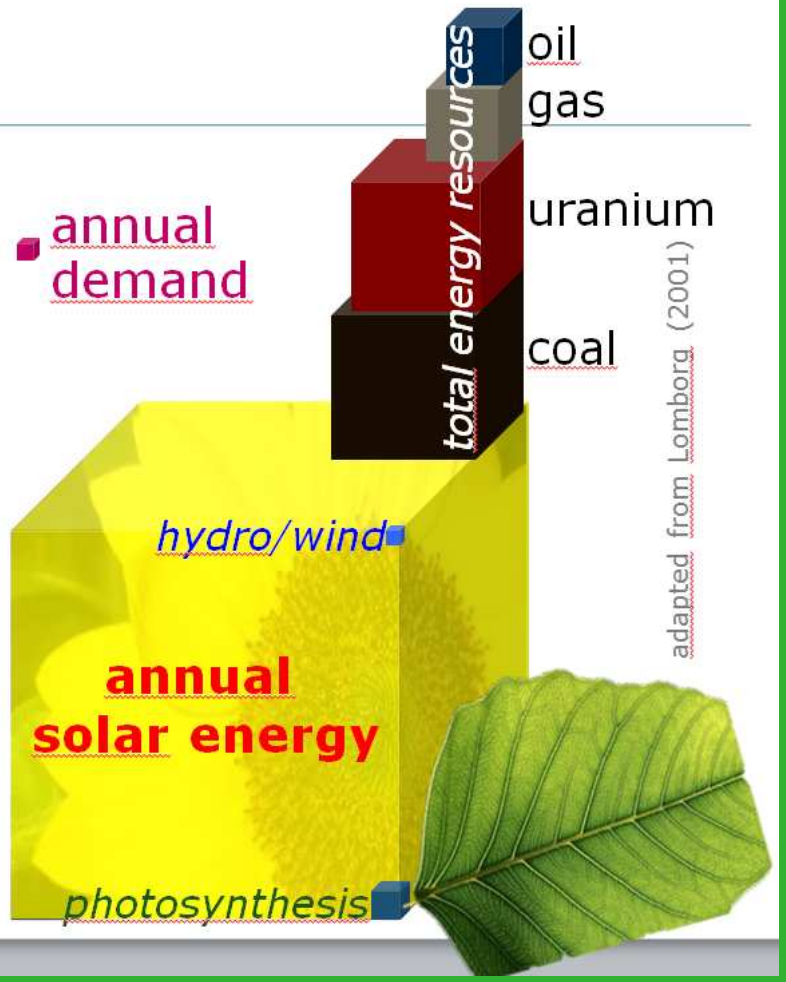
For quality of life



Courtesy: Bindraban (2013)

Conclusions

We have a food problem !

We have no energy problem !

Courtesy: Bindraban (2013)

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