Grass based biorefinery systems

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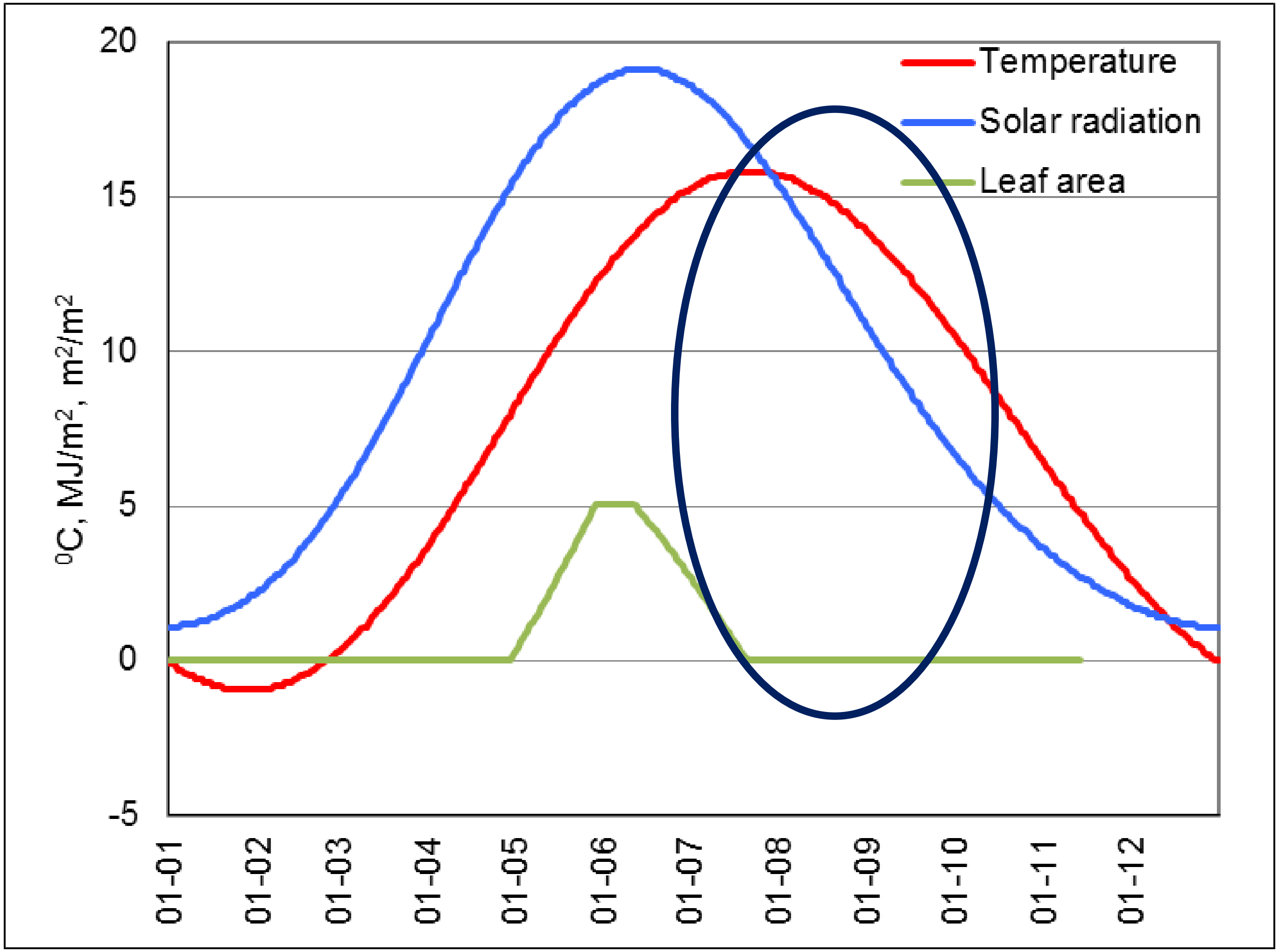
Keywords

- Grass production
- Land use efficiency
- Protein separation
- Biorefineries

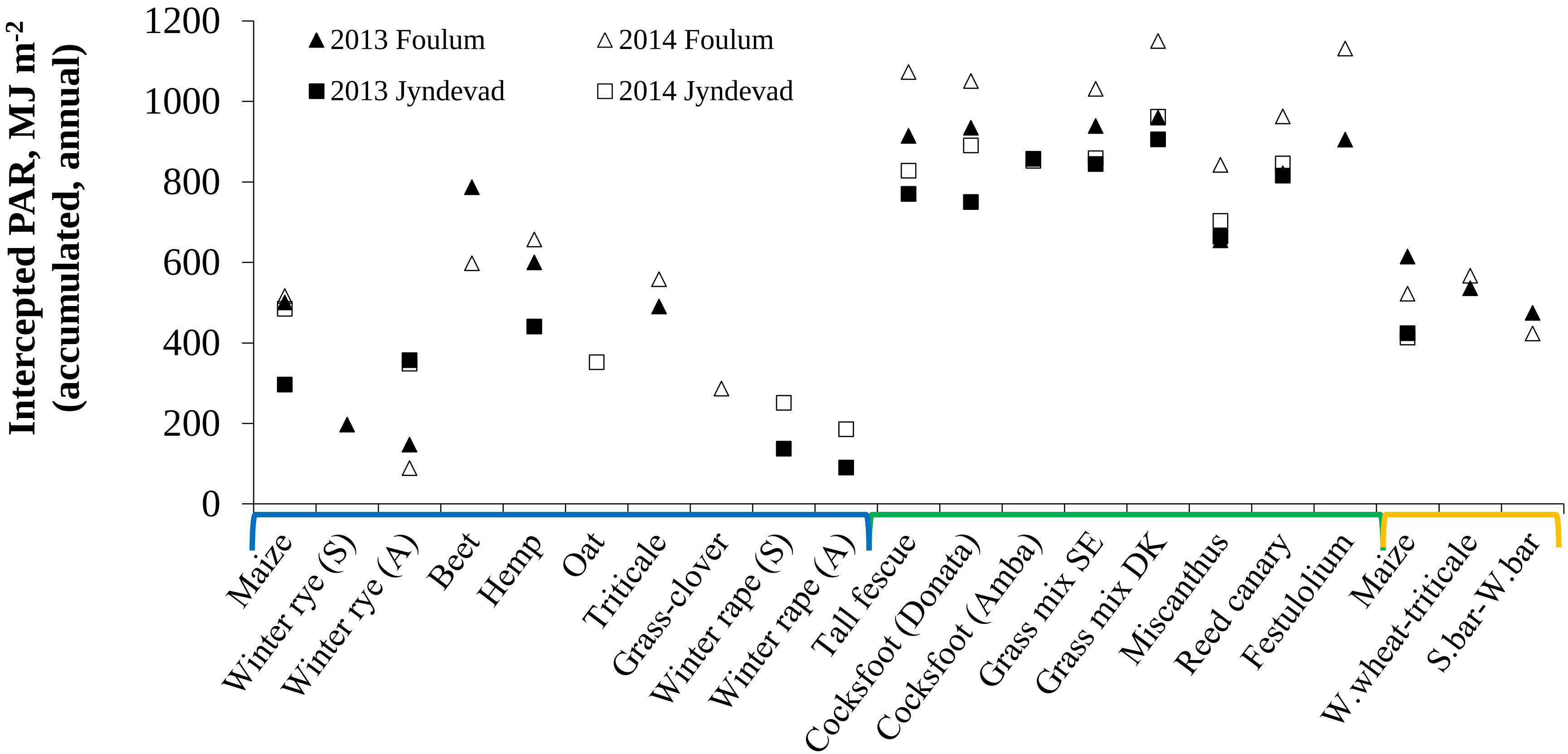
Grain crops utilize only part of the growing season



Case:

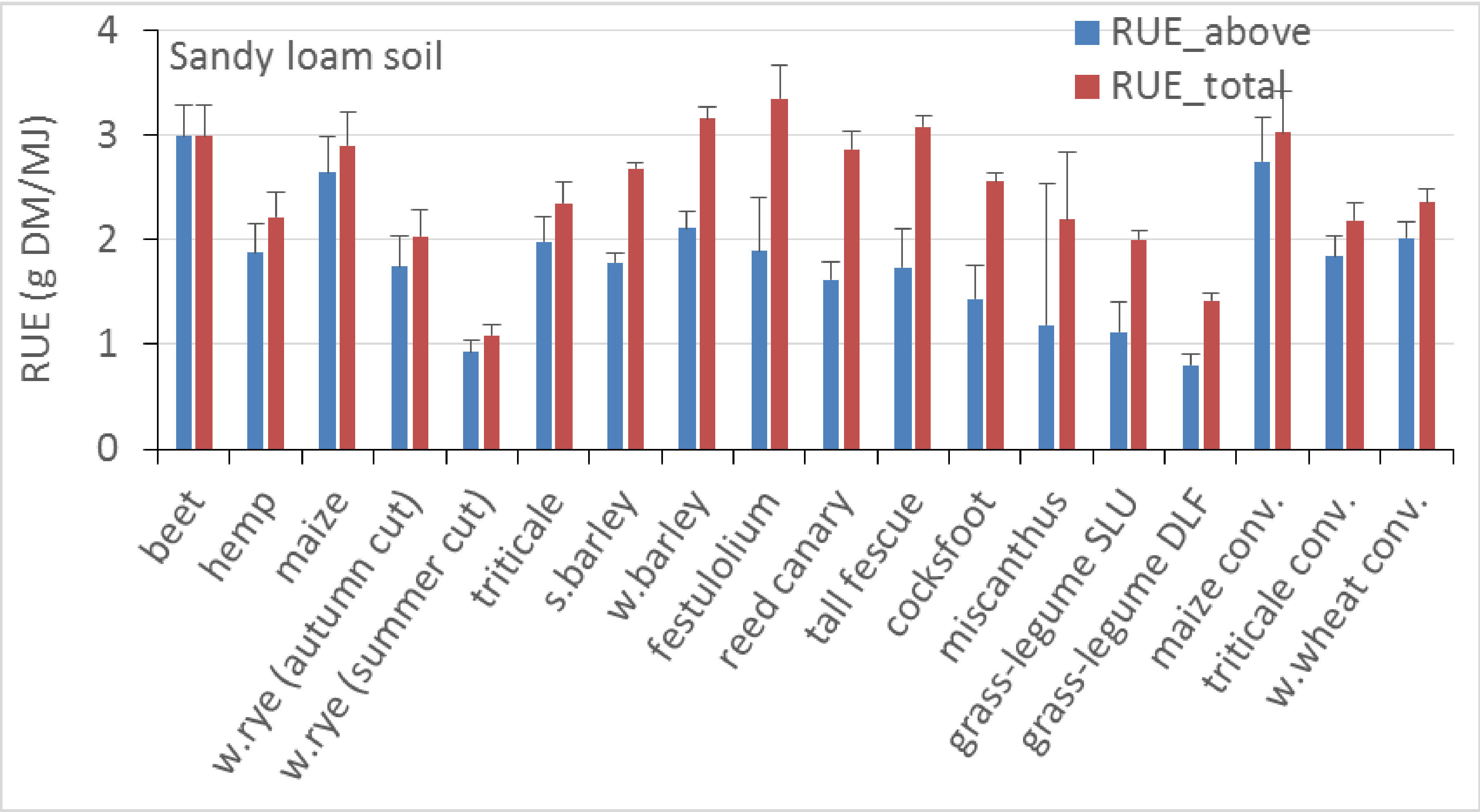
Spring barley in Denmark

Perennial crops intercept approx. double as much solar radiation as do annual crops

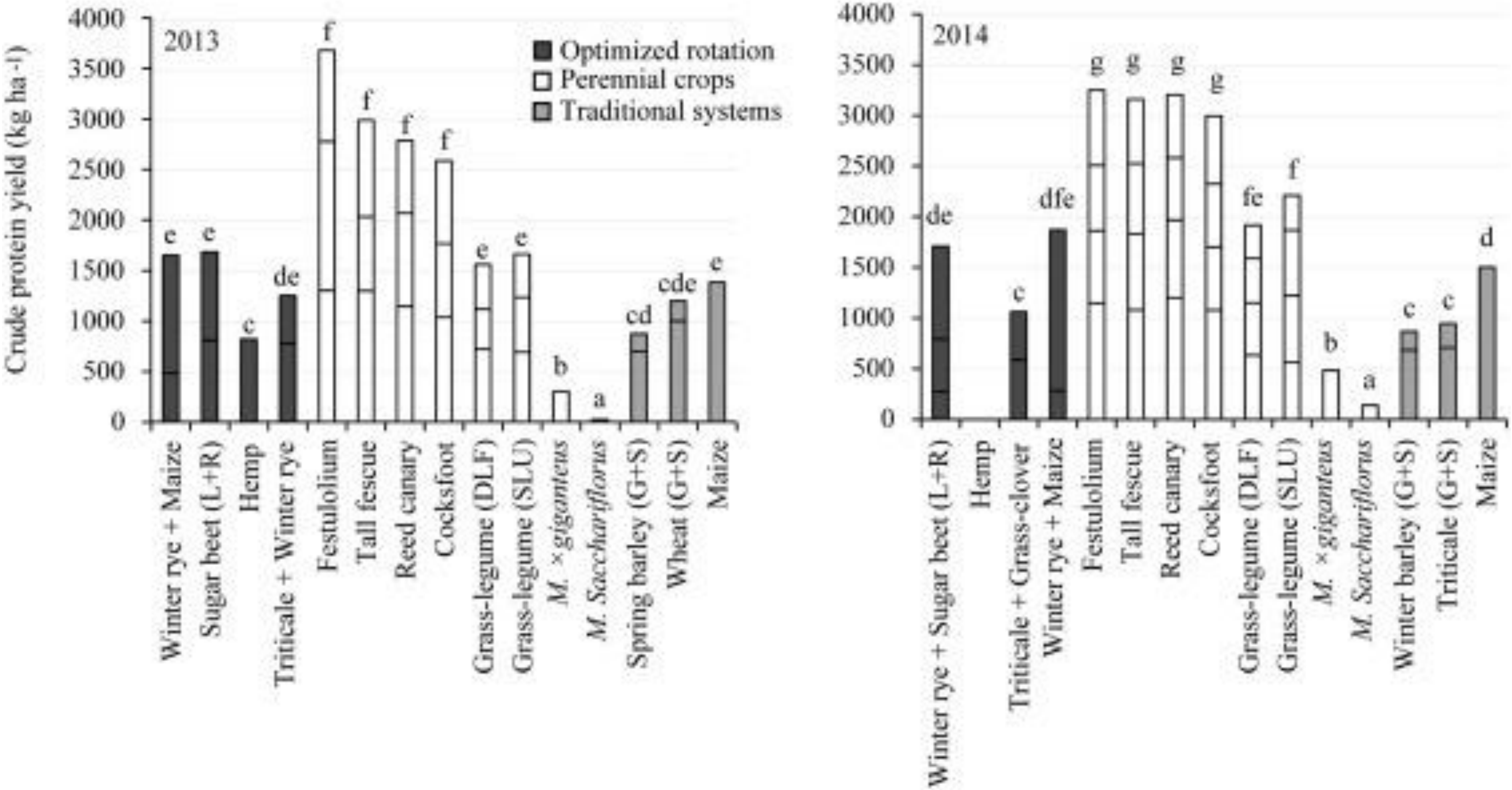


Manevski, K., Lærke, P. E., Jiao, X., Santhome, S., & Jørgensen, U. (2017). Biomass productivity and radiation utilisation of innovative cropping systems for biorefinery. *Agricultural and Forest Meteorology*, *233*, 250-264.

Radiation Use Efficiency incl. root growth (preliminary results)



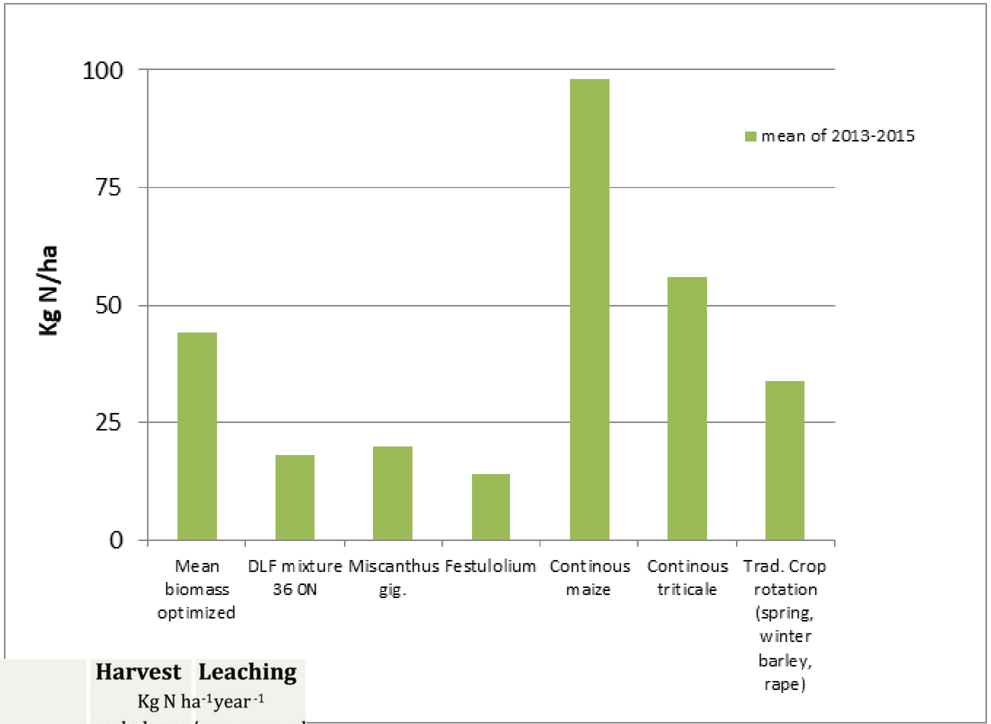
Total crude protein yield



Solati, Z., Manevski, K., Jørgensen, U., Labouriau, R., Shahbazi, S., & Lærke, P. E. (2018). Crude protein yield and theoretical extractable true protein of potential biorefinery feedstocks. *Industrial Crops and Products*, *115*, 214-226.

What about the environment?

Cumulated leaching is up to six times higher in annual crops than in grass crops.



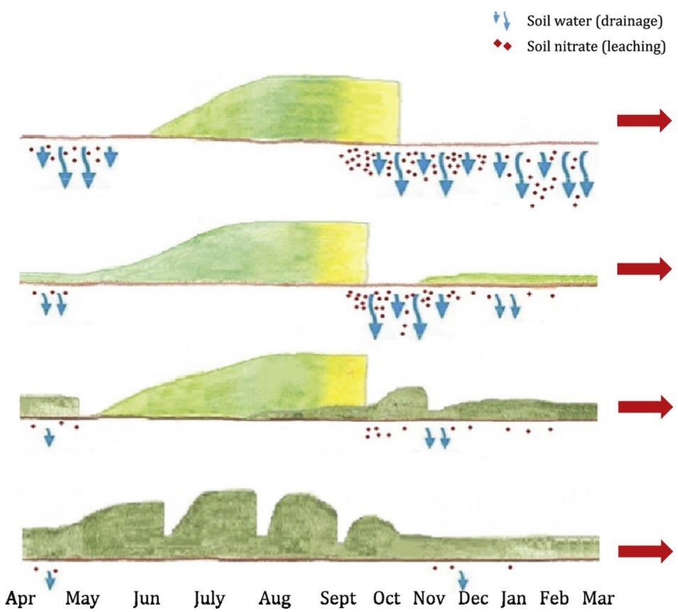


Figure from Elly M. Hansen, Aarhus University (modified).

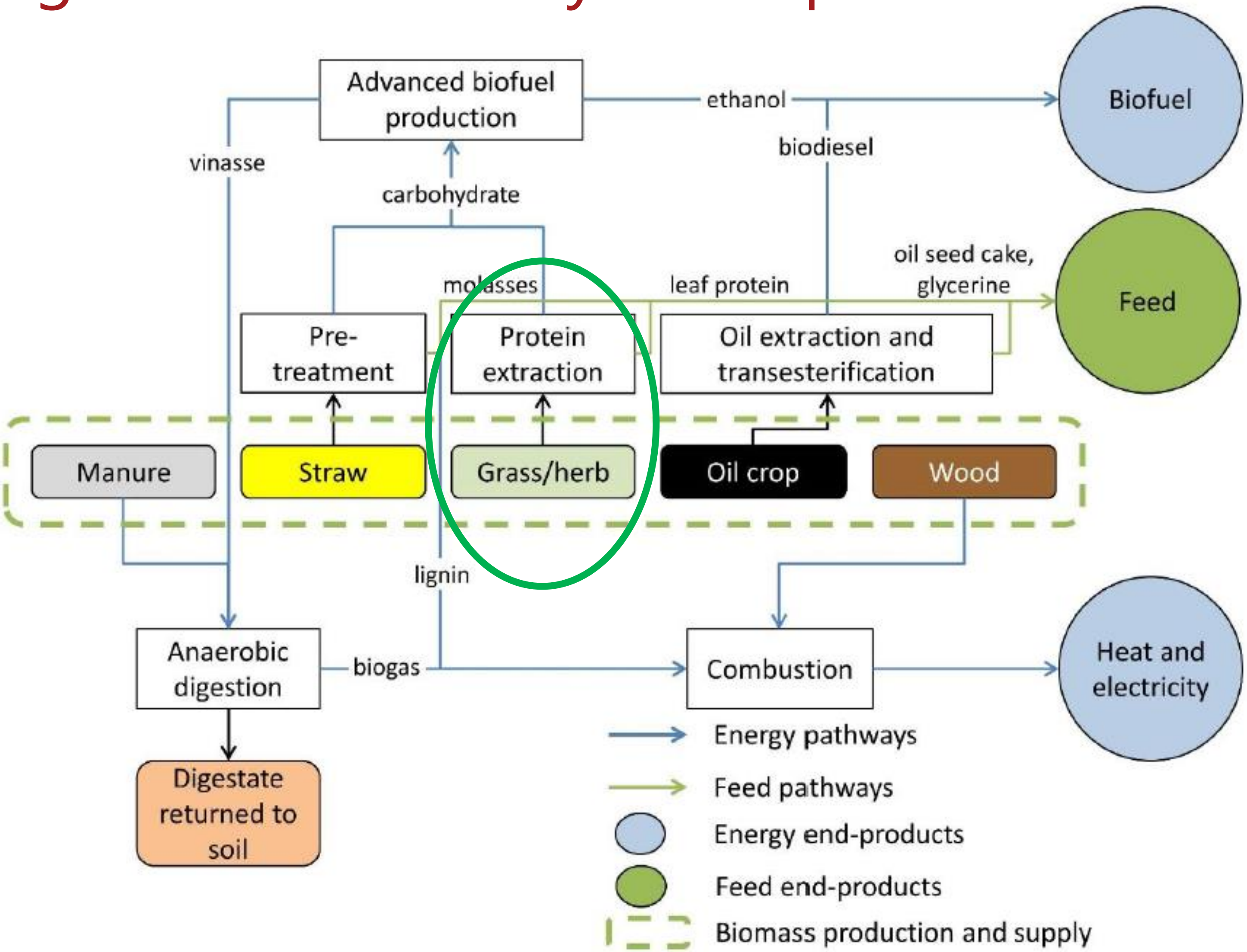
System	Harvest	Leaching
	Kg N $ha^{-1}year^{-1}$ sandy loam/coarse sand	
Traditional maize (continuous, monoculture)	200/100	100/180
Traditional titicale (continuous, monoculture)	170/-	60/-
Optimised rotation with annual crops	190/160	40/110
Perennial grasses		
Highly fertilised	450/320	15/50
Unfertilised	250/200	18/20

Values are means of three-years. Dash denotes no data

Manevski, K., Lærke, P. E., Olesen, J. E., & Jørgensen, U. (2018). Nitrogen balances of innovative cropping systems for feedstock production to future biorefineries. *Science of the Total Environment*, *633*, 372-390.

So, what to do with all that grass?

An integrated biorefinery concept



Larsen, S., Bentsen, N. S., Dalgaard, T., Jørgensen, U., Olesen, J. E., & Felby, C. (2017). Possibilities for near-term bioenergy production and GHG-mitigation through sustainable intensification of agriculture and forestry in Denmark. *Environmental Research Letters*, *12*(11), 114032.

Processing of green forages

Raw material → Screw press → Pulp

30-60 % of protein

Screw press ↓

Juice

40-70 % of protein

↓

pH
Precipitation
/Heat

→ Protein concentrate

30-65 % of protein

↓

Brown juice

5-10 % of protein, 10-15 % of total N

Protein separation – Why bother? Theoretical considerations

Synthesis of different plant compounds require different amounts of solar energy and thus land

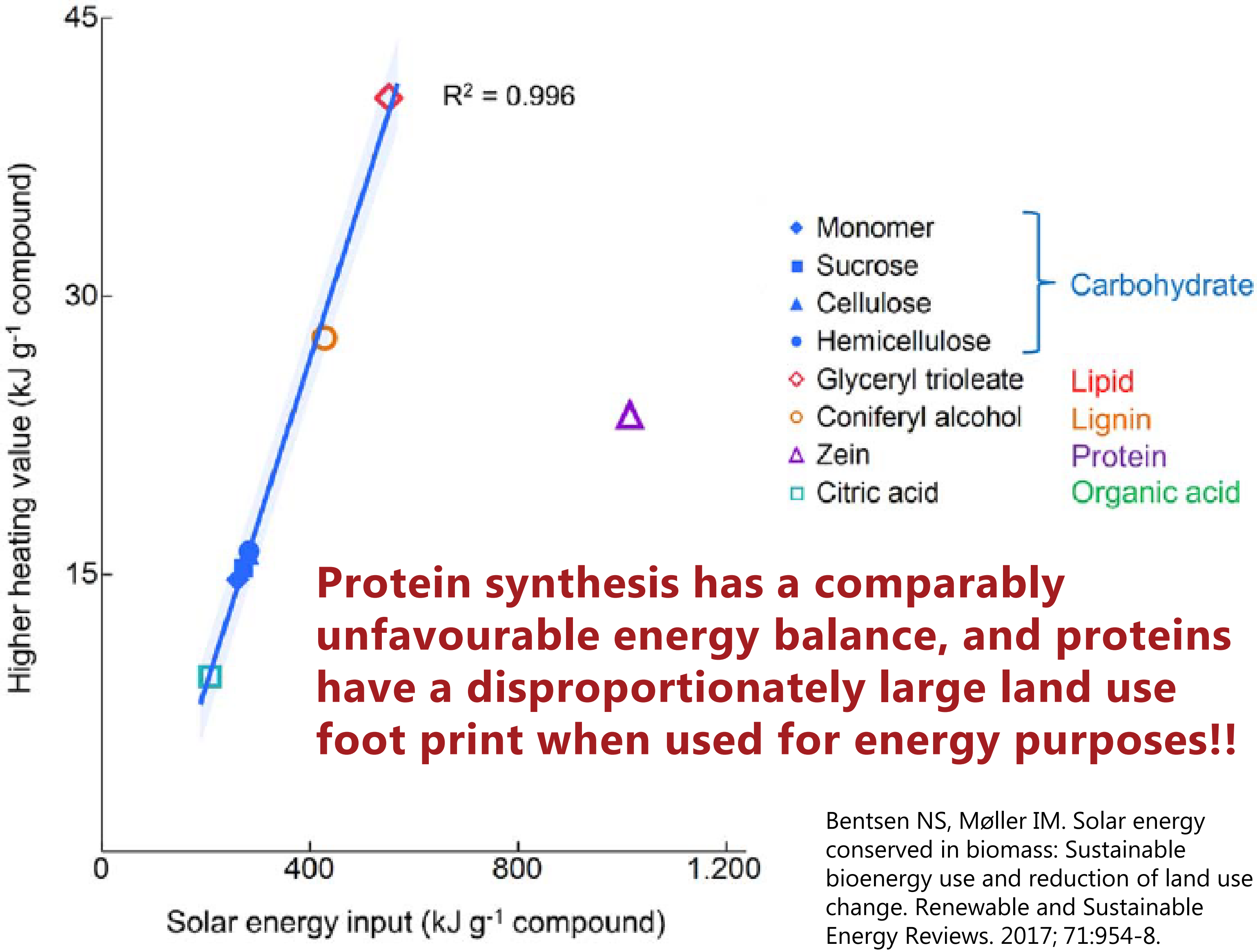
Table 1

Solar energy conserved in plant compounds. Solar energy input was estimated on the basis of substrate requirement for growth and maintenance respiration of plant compounds. Energy content was calculated as the higher heating value (HHV) based on the mass fraction of carbon, hydrogen, oxygen and nitrogen in the compounds.

Plant compound	Representative compound	Representative molecular formula[a]	Respiration cost (g glucose (g compound)$^{-1}$)				Energy input[d] (kJ g^{-1})
			Growth[a]	Protein turnover[b]	Solute gradient maintenance[c]	Total	
Carbohydrate	Monomer	$C_6H_{12}O_6$	1.00		0.43	1.43	261.9
	Sucrose	$C_{12}H_{22}O_{11}$	1.05		0.43	1.48	271.6
	Cellulose	$C_6H_{10}O_5$	1.11		0.43	1.54	282.3
	Hemicellulose	$C_{11}H_{18}O_9$	1.12		0.43	1.55	284.3
Lipid	Glyceryl trioleate	$C_{57}H_{101}O_6$	2.59		0.43	3.02	553.3
Lignin	Coniferyl alcohol	$C_{10}H_{12}O_3$	1.92		0.43	2.35	429.7
Protein	Zein	$C_{4.6}H_{7.0}N_{1.0}O_{1.4}S_{0.02}$	2.08	3.04	0.43	5.55	1016.8
Organic acid	Citric acid	$C_6H_8O_7$	0.70		0.43	1.13	207.7

Bentsen NS, Møller IM. Solar energy conserved in biomass: Sustainable bioenergy use and reduction of land use change. Renewable and Sustainable Energy Reviews. 2017; 71:954-8.

Energy balance of protein synthesis



Protein synthesis has a comparably unfavourable energy balance, and proteins have a disproportionately large land use foot print when used for energy purposes!!

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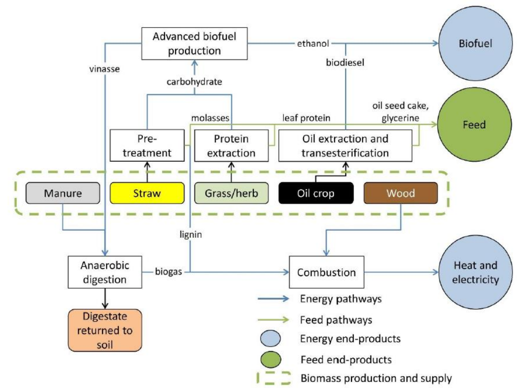
Protein separation – Why bother? A modelling example



Three scenarios:

REF – Historical development continued

BIO – Focus on boosting production

ENV – As BIO, but with extensive environmental constraints

		Scenario 2020		
	2009	REF	BIO	ENV
Biomass resource		Tg dry matter		
Straw	1.62	2.92	3.47	3.27
Oil crops	0.13	0.21	0.11	0.02
Grass/herbs	0.00	0.28	5.14	3.97
Wood	1.67	1.57	2.32	1.73
Manure	0.18	2.57	2.57	2.44
Total	3.60	7.54	13.61	11.43
Protein rich feed (extracted from the Total)			1.14	1.13

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Sustainable intensification?

Table 4: Greenhouse gas emissions from land use and management change between 2009 and 2020. In addition: emissions from fossil fuel substitution in 2020 and the total emission as % of the projected Danish emissions in 2020. Negative values are reductions in emissions.

	Emissions from CH_4	Emissions from N_2O	Emissions from soil C turnover	Total emissions from land use and management change	Effects of fossil fuel substitution	Sum of LU and management change and substitution	Change in total Danish emissions in 2020
Scenario			Tg CO_2 eq. year^{-1}				%
REF	-0.38	-0.20	0.32	-0.25	-5.9	-6.1	-13.2
BIO	-0.38	-0.43	0.43	-0.38	-9.5	-9.9	-21.4
ENV	-0.36	0.62	-0.19	0.07	-7.9	-7.8	-16.9

Larsen, S., Bentsen, N. S., Dalgaard, T., Jørgensen, U., Olesen, J. E., & Felby, C. (2017). Possibilities for near-term bioenergy production and GHG-mitigation through sustainable intensification of agriculture and forestry in Denmark. *Environmental Research Letters*, *12*(11), 114032.

Perspectives and take home messages

- Grass production can double productivity and halve environmental impacts per ha
- Conserving 50% of the proteins from 88 EJ of grassy energy crops would yield the same amount of protein as approx. $600*10^6$ ha of world average cereals
- In extracting protein prior to energy conversion a limited amount of bioenergy potential is lost. Less than 10% of the total energy output is attributable to the protein content
- Extract the high protein content in grass and legumes and feed the fibre to dairy cattle
- Processing of grass and legume biomass is optimised to ensure high protein contents

Thank you for your attention

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