GRASSMARGINS BIORESOURCE BIOVALUE SPIR AARHUS UNIVERSITY

Sustainable intensification of agricultural systems in combination with biorefinery processing can produce more biomass for bioenergy without imposing iLUC

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AARHUS UNIVERSITY

Faculties:

- Science and Technology
- Arts
- Health
- Aarhus BSS

Statistics:

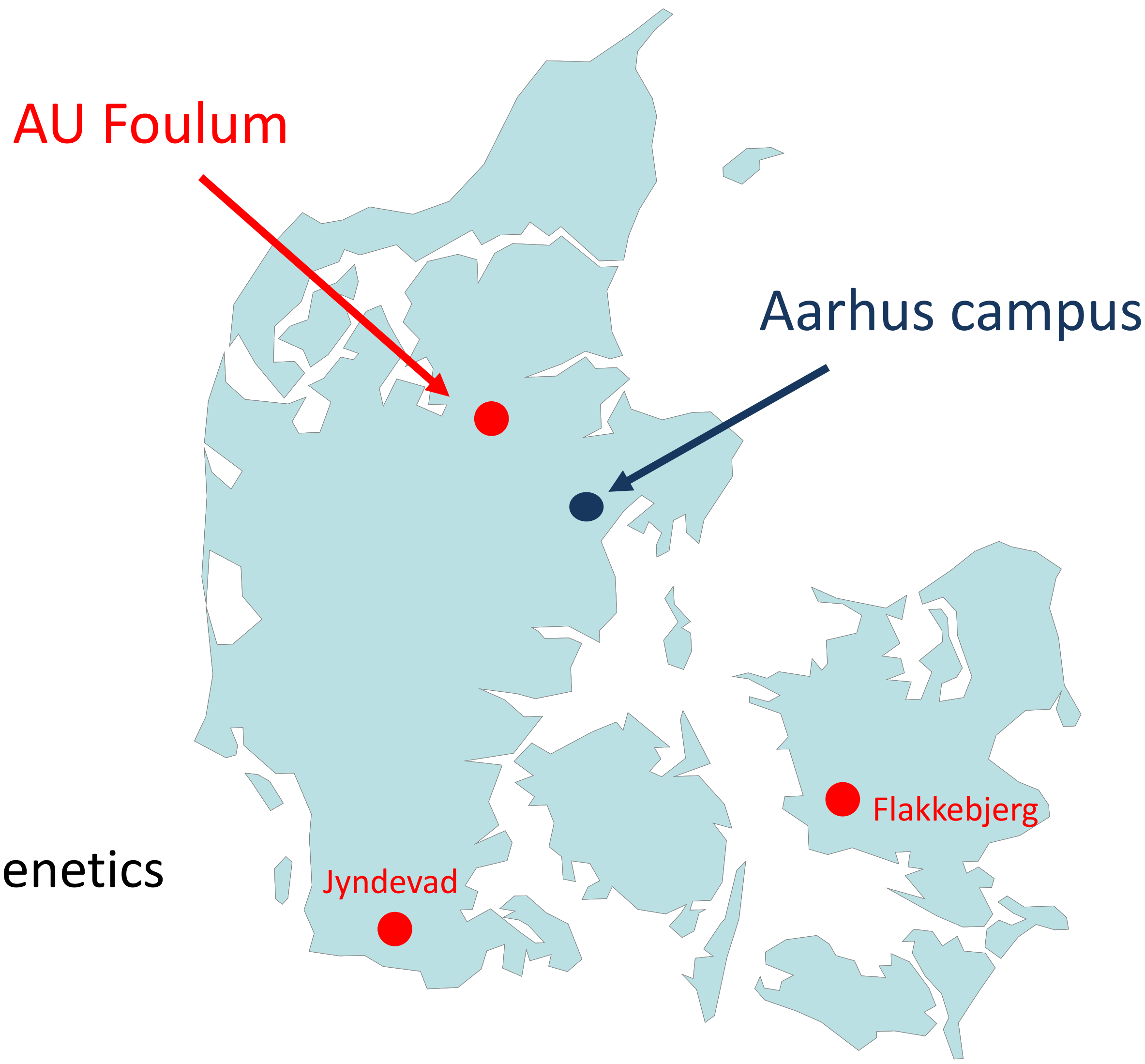
No. of students: 42,500

No. of staff: 11,500

Aarhus University, Science and Technology

Departments:

- Agroecology
- Animal Science
- Bioscience
- Chemistry
- Computer Science
- Engineering
- Environmental Science
- Food Science
- Geoscience
- Mathematics
- Molecular Biology and Genetics
- Physics and Astronomy



Denmark: 2.6 mill. ha agriculture, ~ 60% of the area


AU FOULUM

European agriculture faces numerous challenges

Productivity

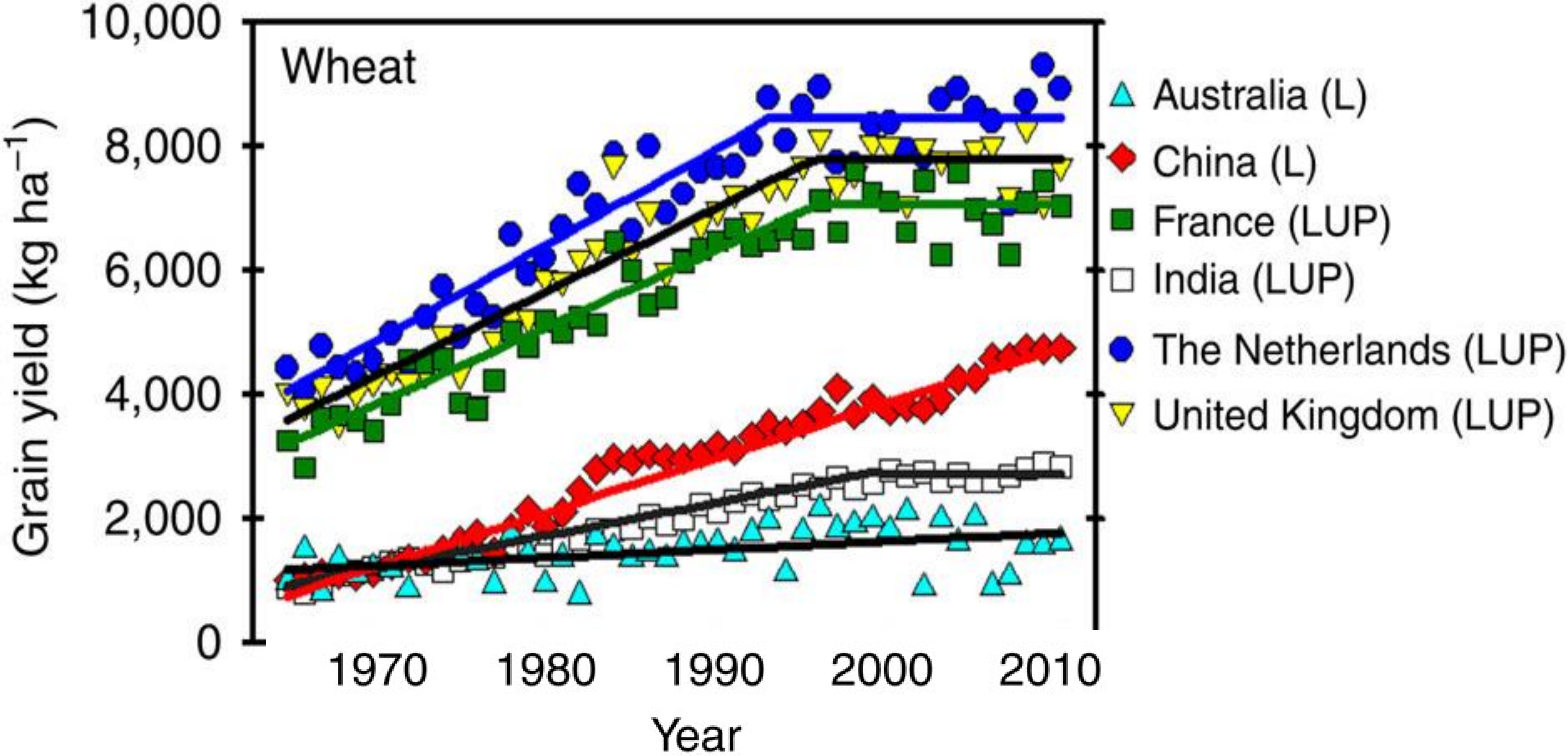
- Biomass for food, feed, material and energy
- Large import of feed especially soy bean products (97% imported)
- Stagnating yields

Environment

- High nutrient leaching (Nitrate and Water Framework Directives)
- High pesticide use
- Agriculture must contribute to EU climate goals (EU climate policy)

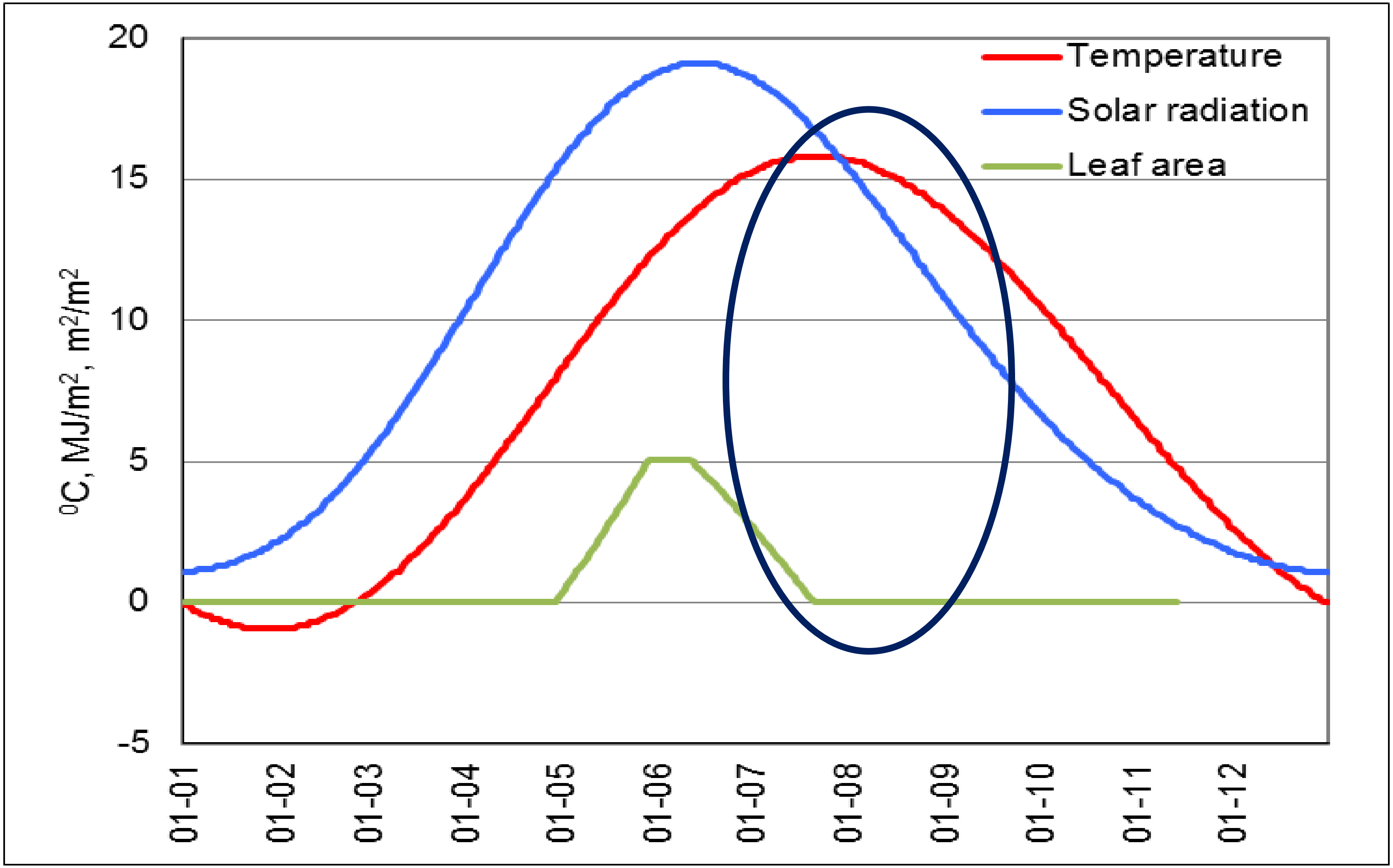
The answer may be sustainable intensification – more with less!

Further increase in yields of existing crops seems difficult in Europe



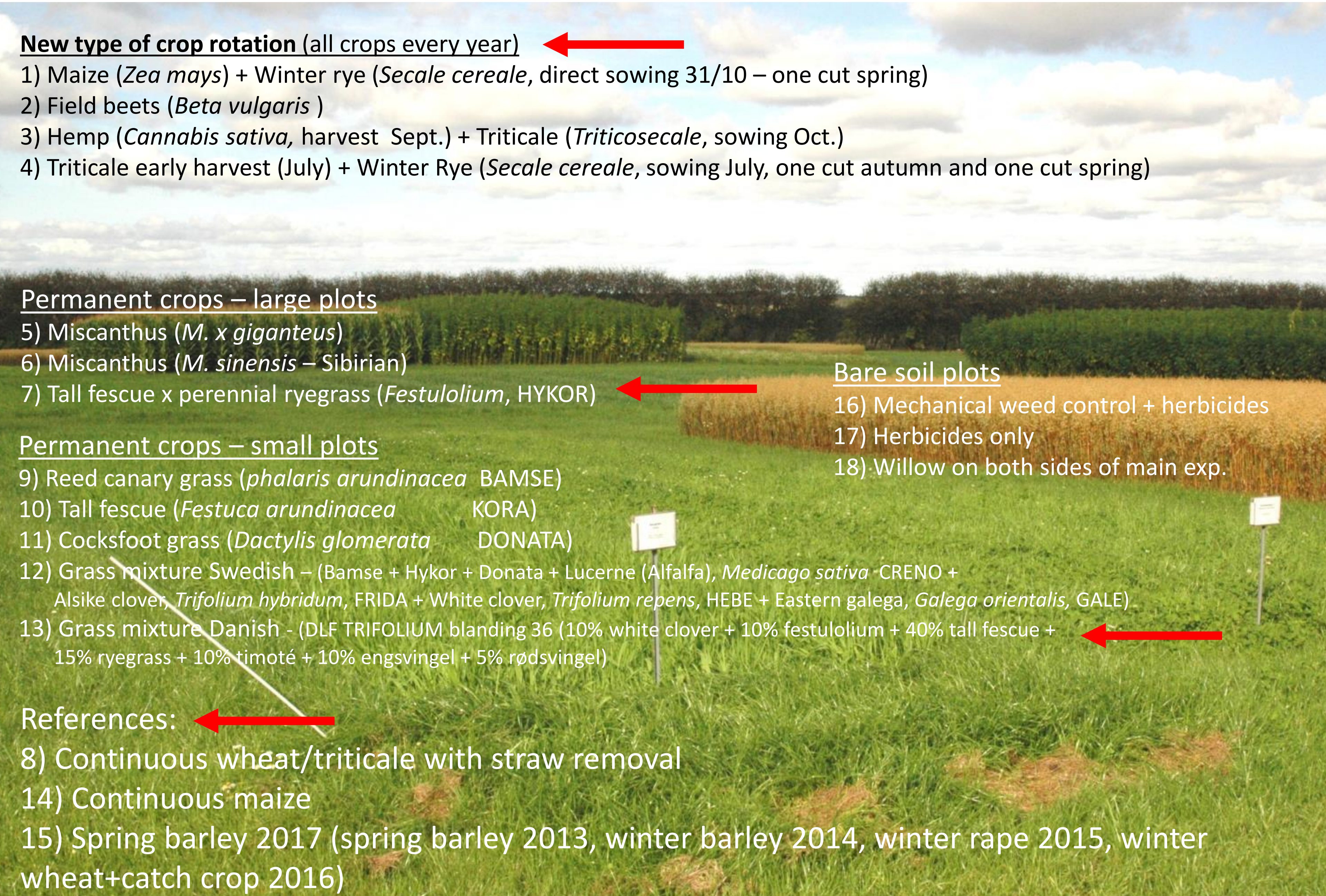
Patricio Grassini, Kent M. Eskridge & Kenneth G. Cassman, 2013.Nature Communications 4, no. 2918

Grain crops utilize only part of the growing season
Case: spring barley in Denmark



Field experiment was established with different crops aimed for bio-refining in 2012

16 different crop or cropping systems in Foulum



New type of crop rotation (all crops every year)

1) Maize (*Zea mays*) + Winter rye (*Secale cereale*, direct sowing 31/10 – one cut spring)
2) Field beets (*Beta vulgaris*)
3) Hemp (*Cannabis sativa,* harvest Sept.) + Triticale (*Triticosecale*, sowing Oct.)
4) Triticale early harvest (July) + Winter Rye (*Secale cereale*, sowing July, one cut autumn and one cut spring)

Permanent crops – large plots

5) Miscanthus (*M. x giganteus*)
6) Miscanthus (*M. sinensis* – Sibirian)
7) Tall fescue x perennial ryegrass (*Festulolium*, HYKOR)

Permanent crops – small plots

9) Reed canary grass (*phalaris arundinacea* BAMSE)
10) Tall fescue (*Festuca arundinacea* KORA)
11) Cocksfoot grass (*Dactylis glomerata* DONATA)
12) Grass mixture Swedish – (Bamse + Hykor + Donata + Lucerne (Alfalfa), *Medicago sativa* CRENO + Alsike clover, *Trifolium hybridum*, FRIDA + White clover, *Trifolium repens*, HEBE + Eastern galega, *Galega orientalis*, GALE)
13) Grass mixture Danish - (DLF TRIFOLIUM blanding 36 (10% white clover + 10% festulolium + 40% tall fescue + 15% ryegrass + 10% timoté + 10% engsvingel + 5% rødsvingel)

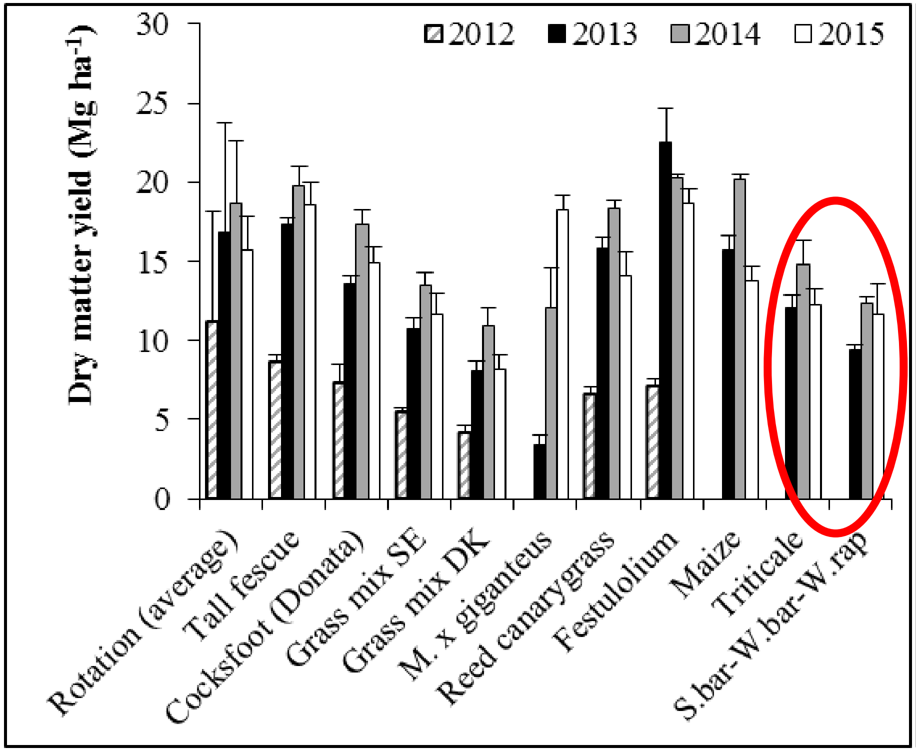
Bare soil plots

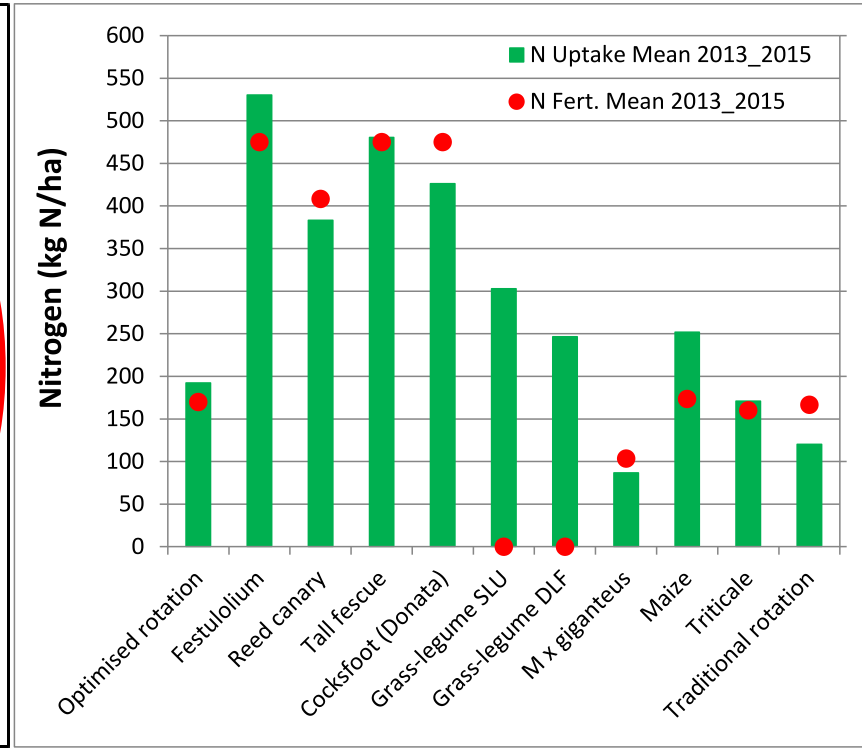
16) Mechanical weed control + herbicides
17) Herbicides only
18) Willow on both sides of main exp.

References:

8) Continuous wheat/triticale with straw removal
14) Continuous maize
15) Spring barley 2017 (spring barley 2013, winter barley 2014, winter rape 2015, winter wheat+catch crop 2016)

Biomass yield and N balance

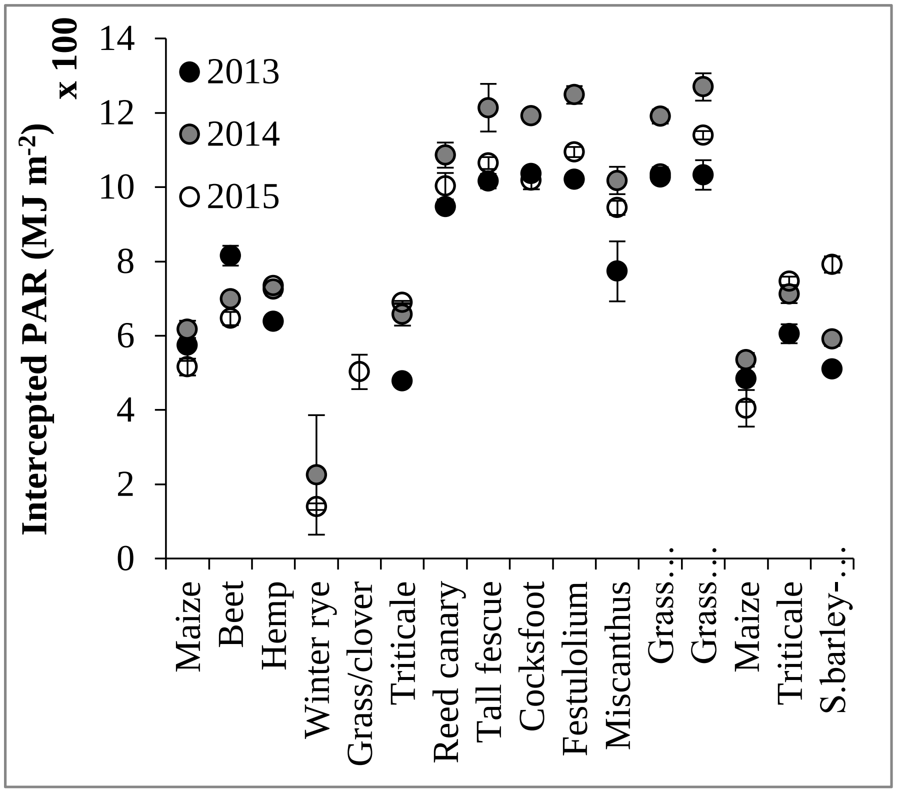


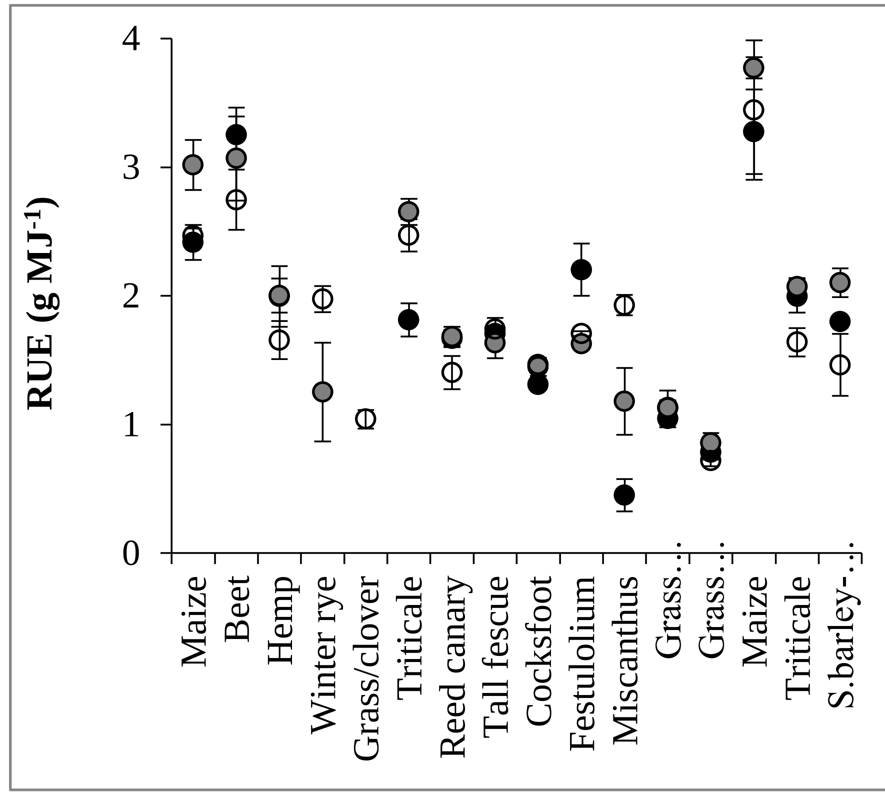


Manevski et al. (2017) *Agricultural and Forest Meteorology* 233:250-264.

Harvest of festulolium

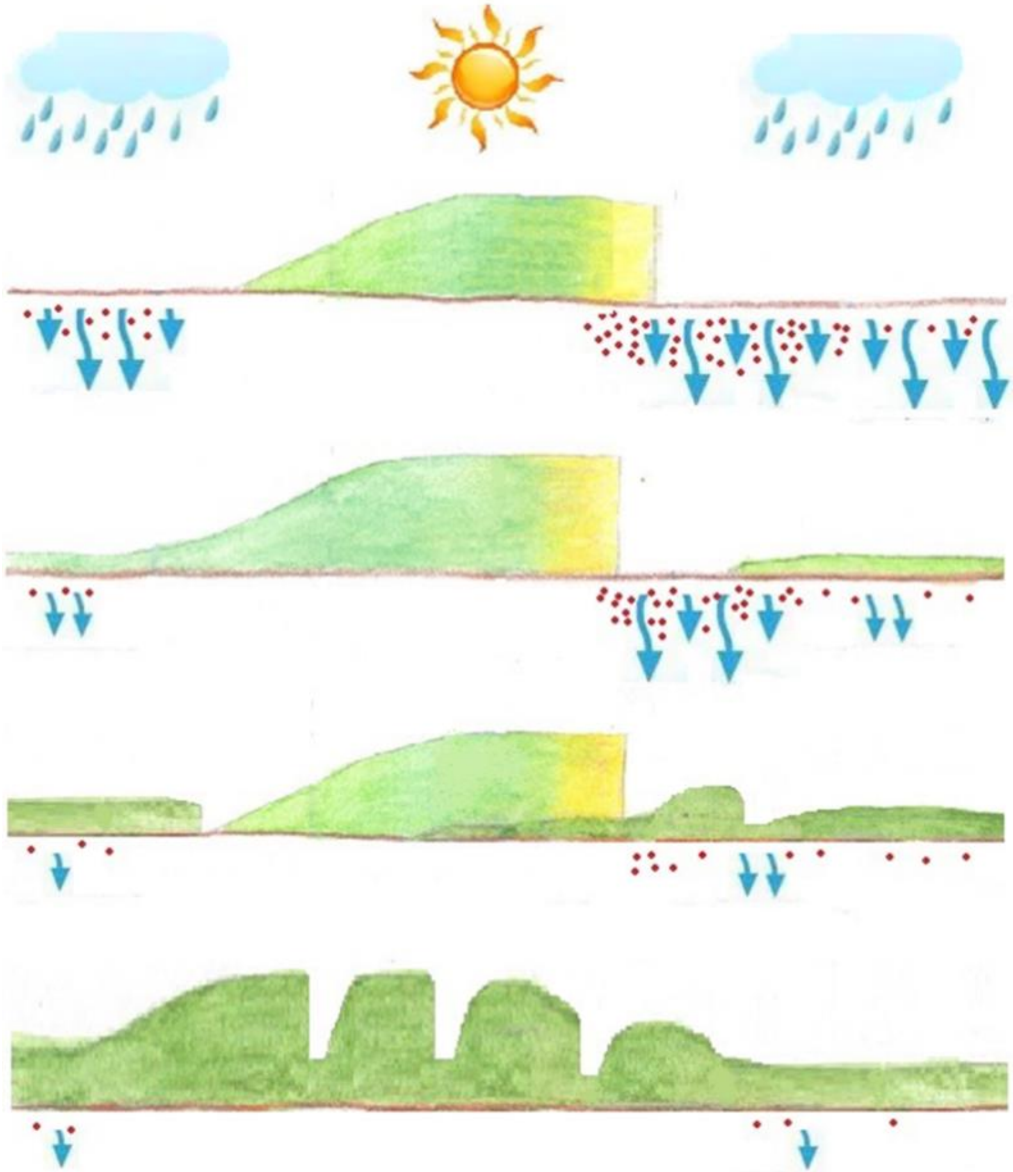
Annual
Intercepted photosynthetic active radiation (PAR) and Radiation use efficiency (RUE) – g biomass per MJ





Manevski et al. (2017) *Agricultural and Forest Meteorology* 233:250-264.

Nutrient leaching from the field



Spring barley

Perennial grass

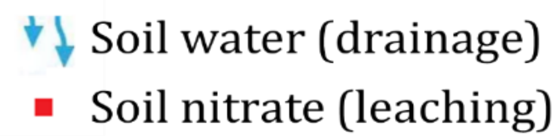
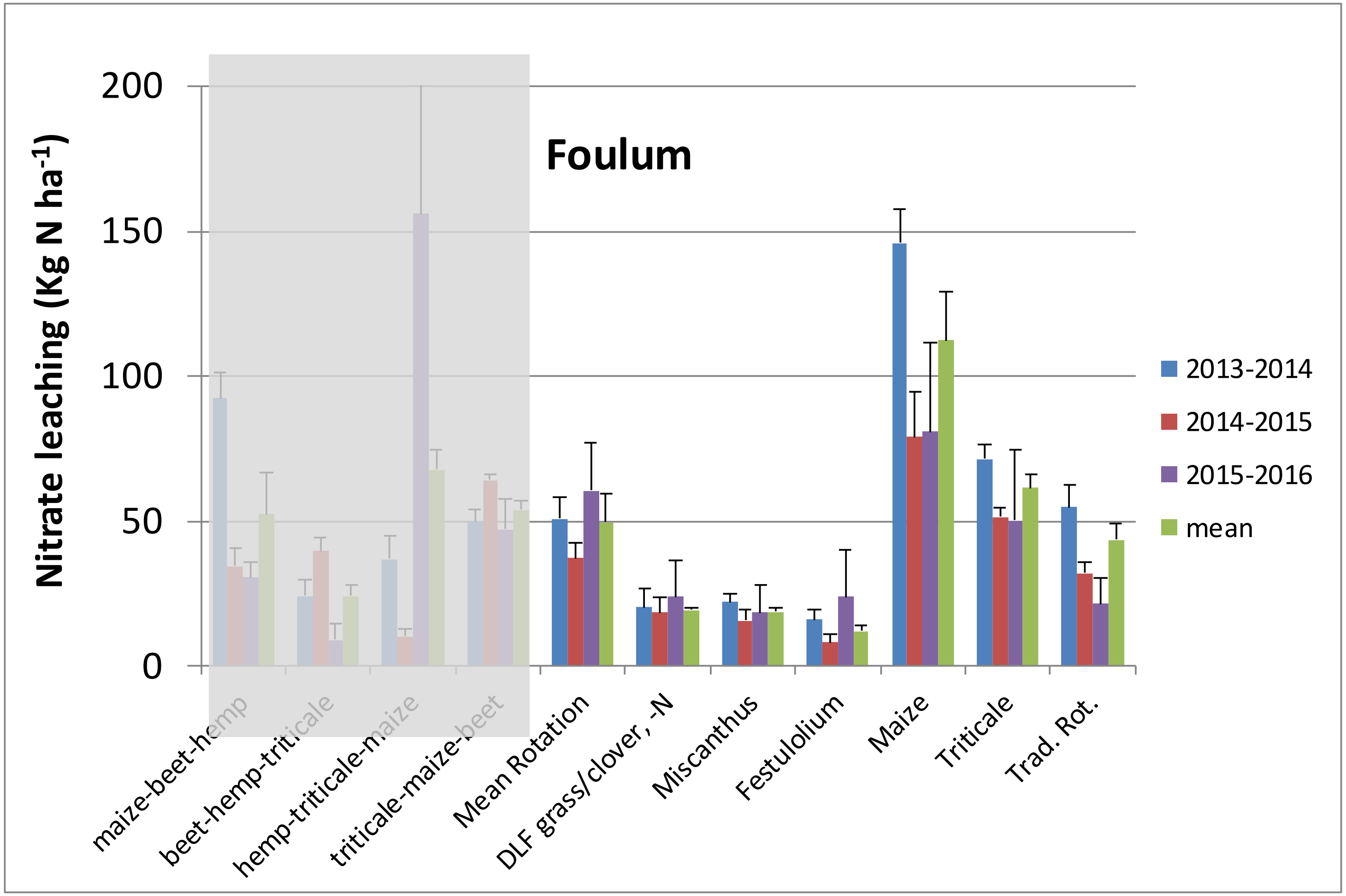


Figure adapted from E.M. Hansen, Aarhus University.

N leaching from the root zone

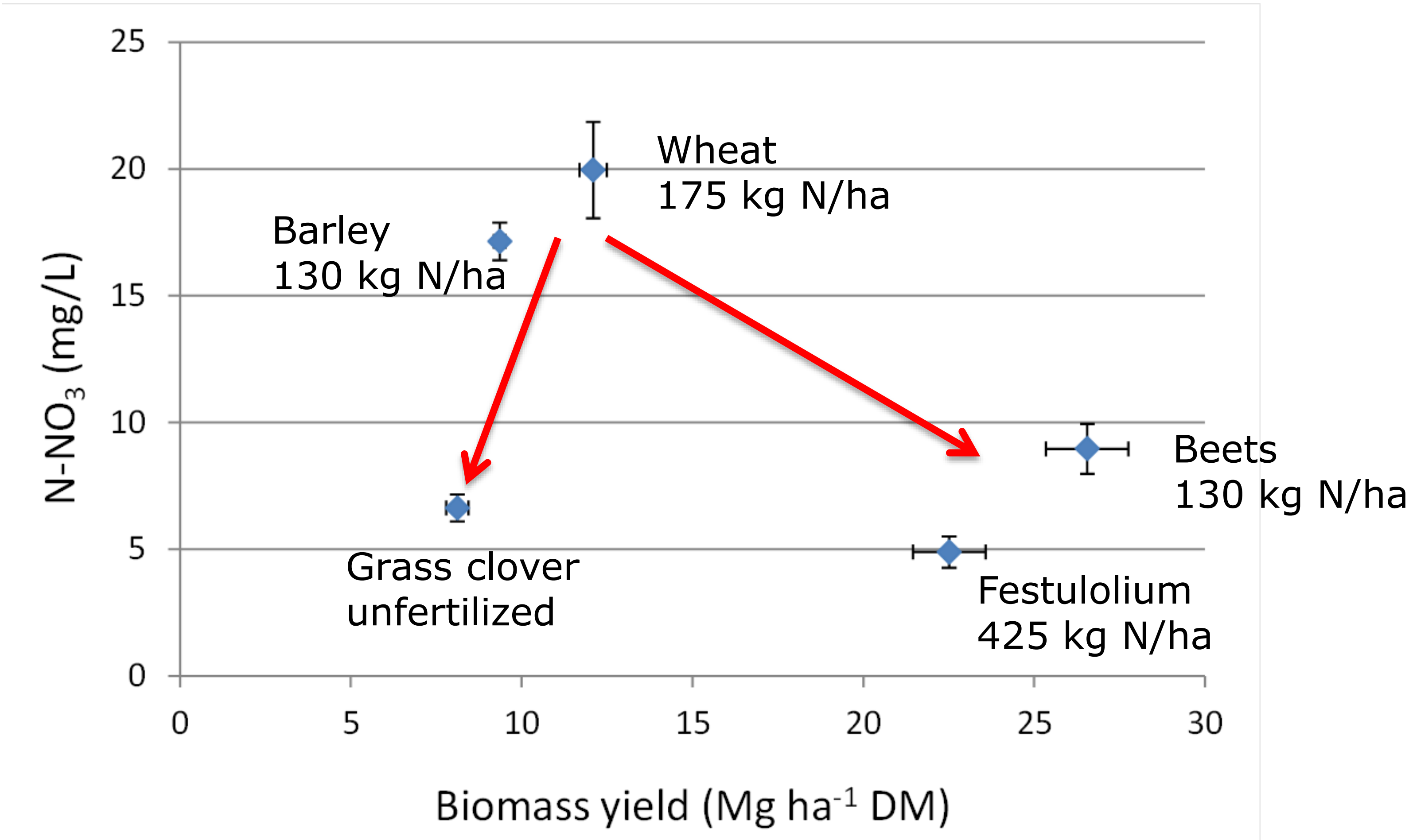
(Suction cups and DAISY model)



N leaching is up to six times lower in perennial grass than in annual crops

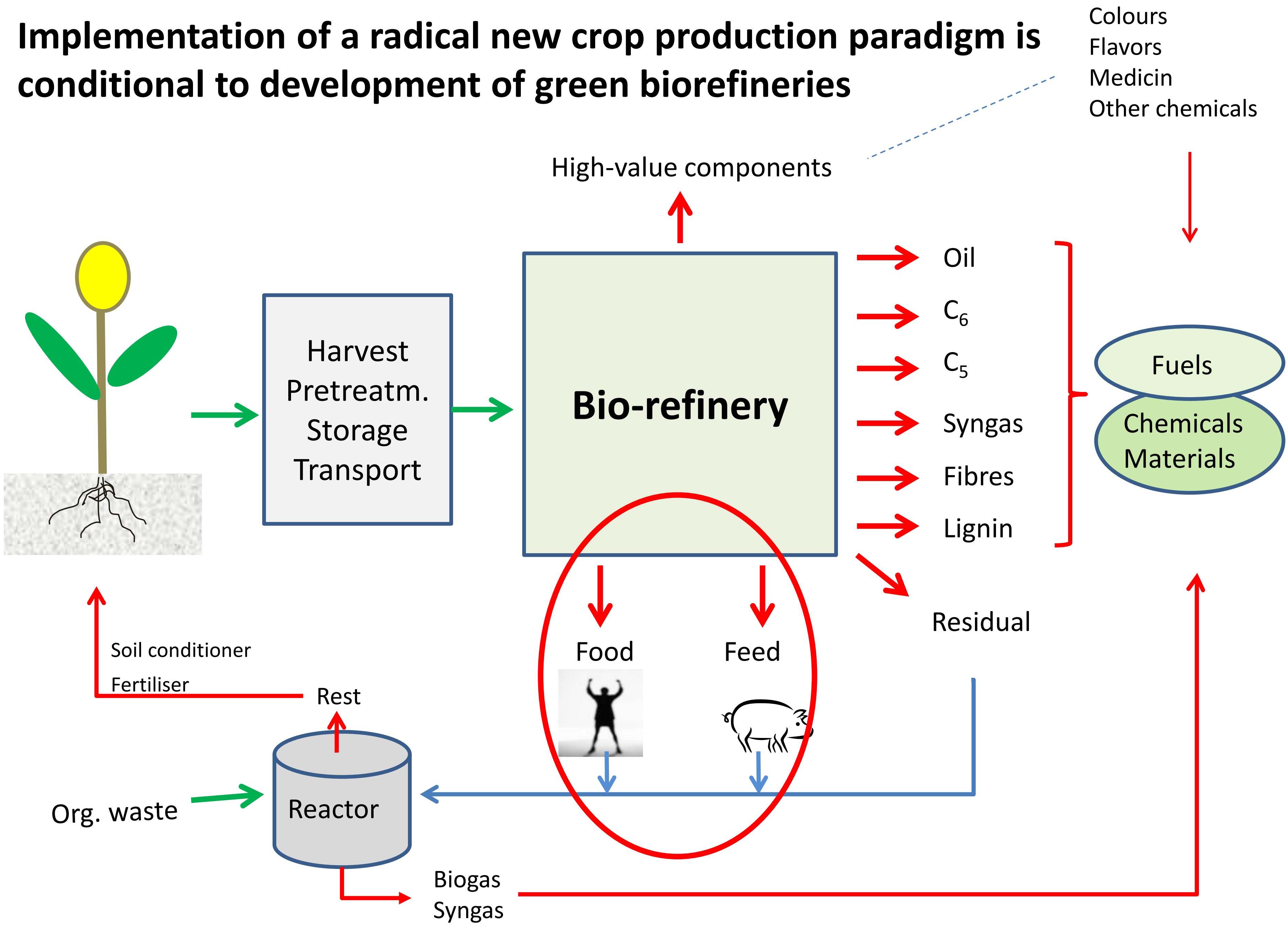
Manevski et al. (2018) Nitrogen balances of innovative cropping systems for feedstock production to future biorefineries. *Science of the Total Environment 633C pp. 372-390* (in press)

It is possible to increase yield and decrease nitrate leaching

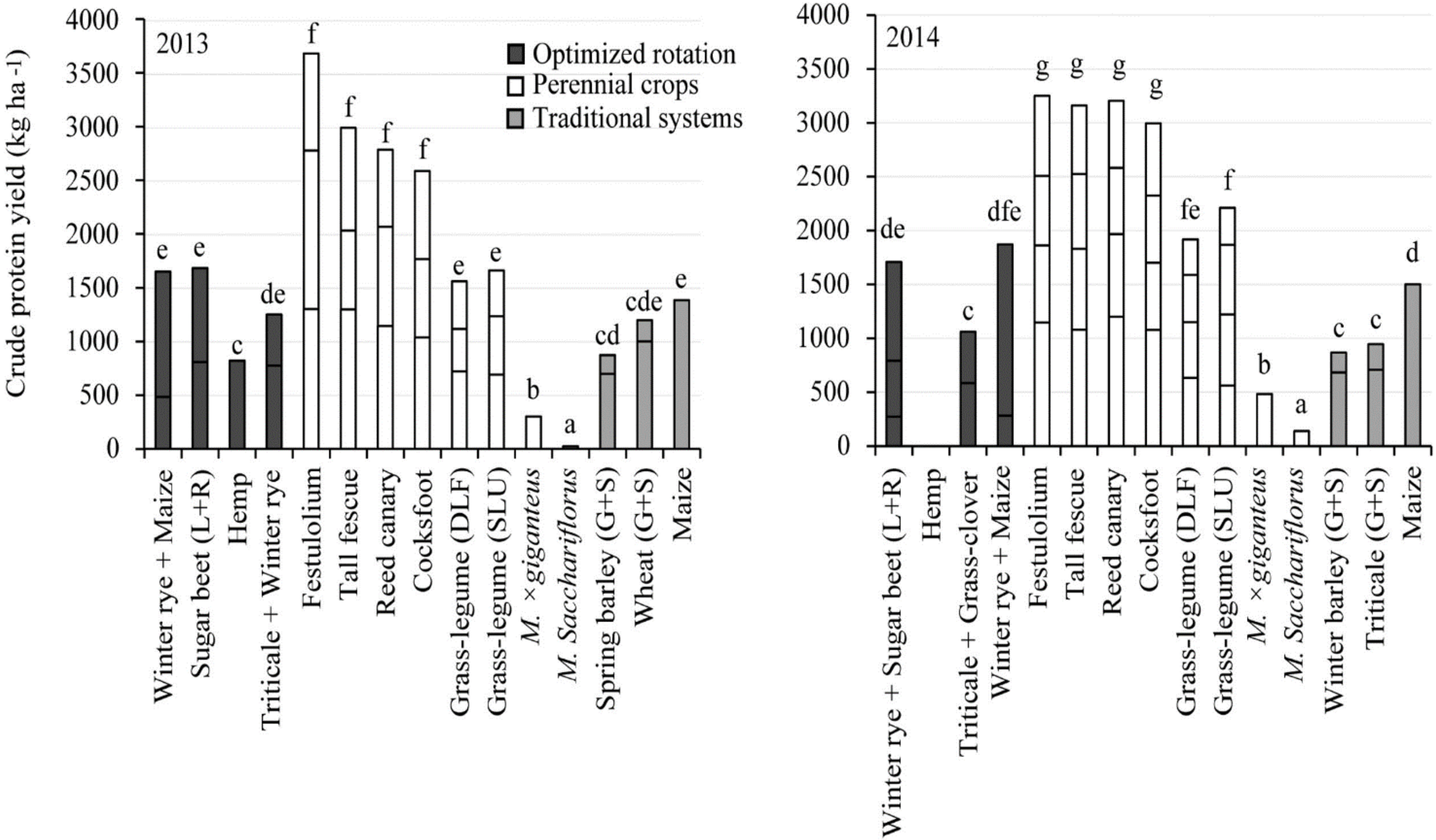


Jørgensen & Lærke, 2016

Implementation of a radical new crop production paradigm is conditional to development of green biorefineries

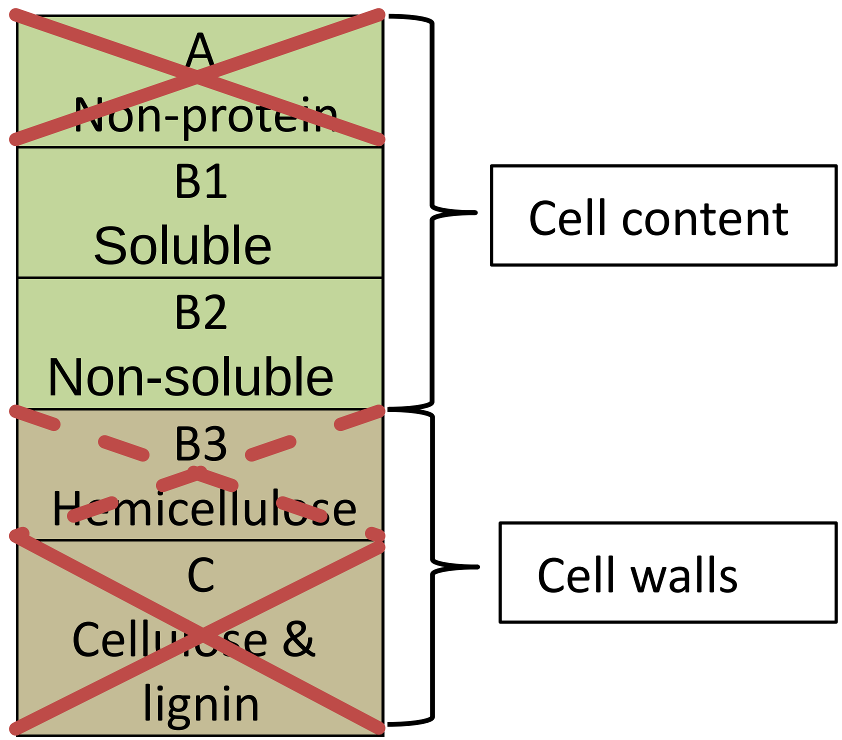


Crude protein production



Solati, Z. et al. (2018) *Industrial Crops & Products* 115:214-226. (https://doi.org/10.1016/j.indcrop.2018.02.010).

Available protein-N in plant material



Cornell Net Carbohydrate and Protein System (CNCPS)

Jørgen Eriksen

Pilot plant for grass protein ekstraktion processing 1 ton fresh biomass per hour

Located at Aarhus University, Center for Biorefinery Technologies (CBT), Foulum

Processing

Raw material → **Screw press** → **Pulp**: Fiber/ Insoluble protein; Ruminants

30-60 % of protein

Juice ↓

40-70 % of protein

Protein precipitation
pH 4; 80 °C

→ **Protein fraction**: Soluble protein/ soluble fibre; Protein feed - monogastric

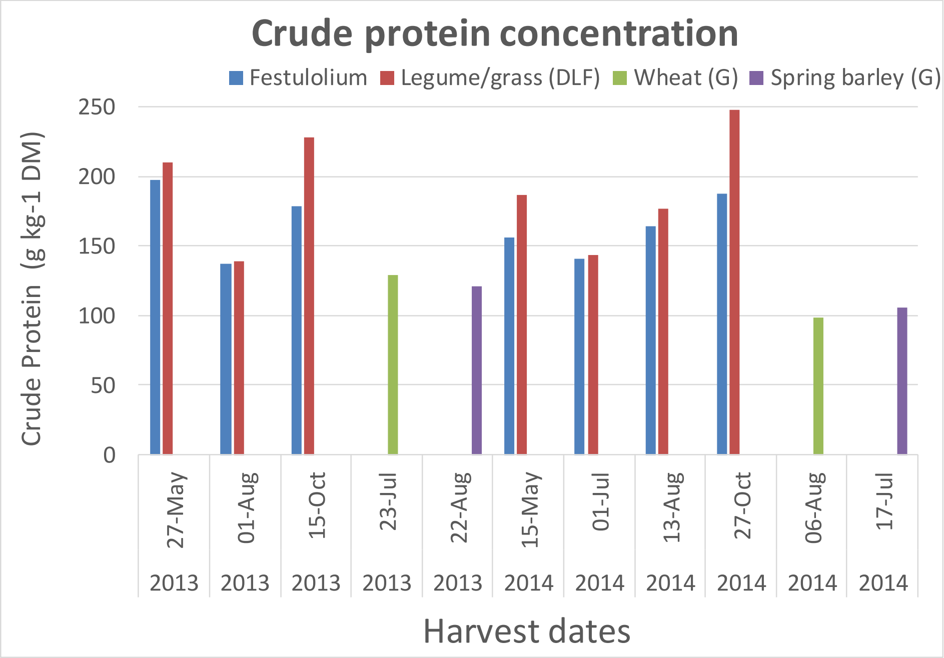
↓

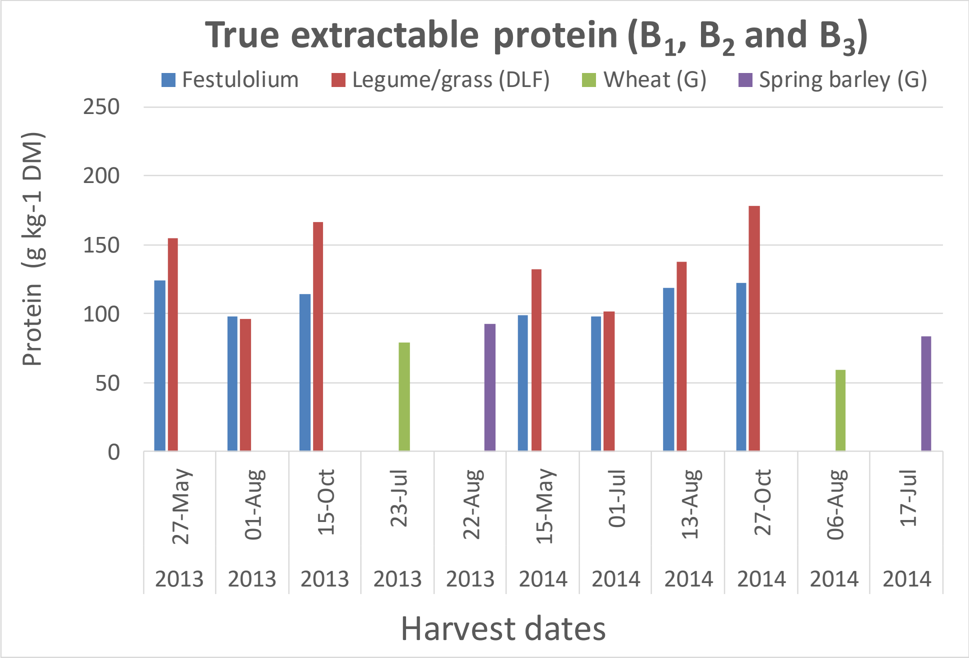
Supernatant: Salt, sugars; Non protein nitrogen

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

Søren Krogh Jensen

Protein concentrations in grass, grass/legume and grain crop



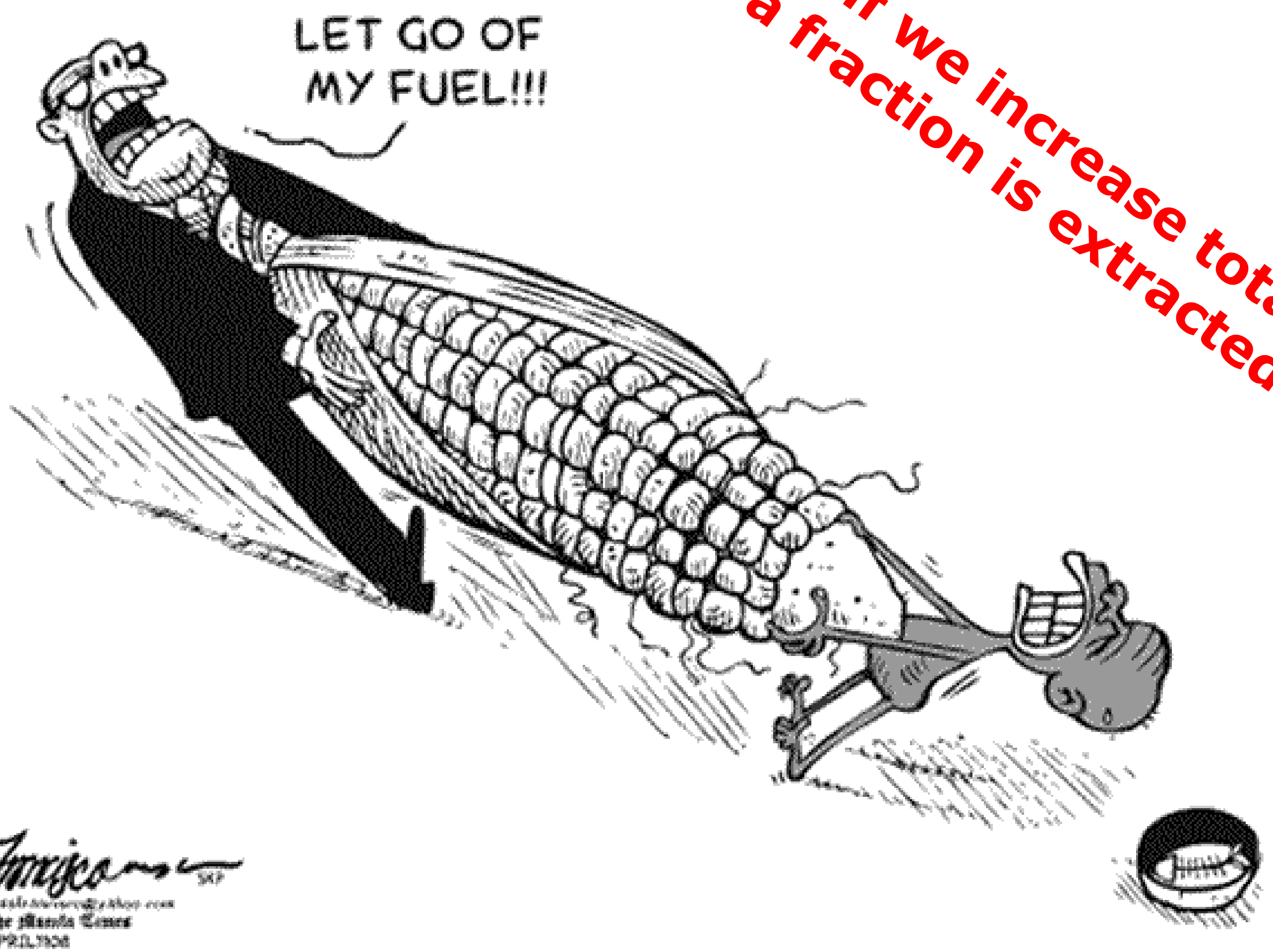


Solati, Z. et al (2018) Crude protein yield and theoretical extractable true protein of potential biorefinery feedstocks. *Industrial Crops & Products* 115:214-226. (https://doi.org/10.1016/j.indcrop.2018.02.010).

Some experimental conclusions

- Maize and beets have high above-ground RUE
- But grasses are more efficient than annual crops in intercepting **annual** radiation
- Perennial grasses can produce large amounts of harvestable biomass and probably also soil carbon
- Nitrate losses can be kept low even at high N input
- We should extract the high contents of protein in grass & legumes

Production of biomass crops will not reduce food availability



….if we increase total yield per ha and a fraction is extracted for food or feed

The bioindustry (e.g. DONG Energy/Ørsted & Novozymes) is concerned about the bio-resource

Will there be enough biomass for establishing a significant biorefinery industry in Denmark?

- Will it be sustainable (soil C, pesticides, GHG, nutrient leaching, biodiversity…..) ?
- What about iLUC?
- Which types of biomass can be available for which technologies?

This was answered by a scenario analysis
(Gylling et al., 2013 – updated in 2016)

Prerequisite: No change in Danish food production

See more in
http://curis.ku.dk/ws/files/167352444/TimioplanUKrevideret_1310_2016.pdf

Three Danish biomass scenarios for 2020

Business as usual:

- No changes in crops or technologies
- Existing resources (straw, manure, rape oil etc.)

Biomass optimised:

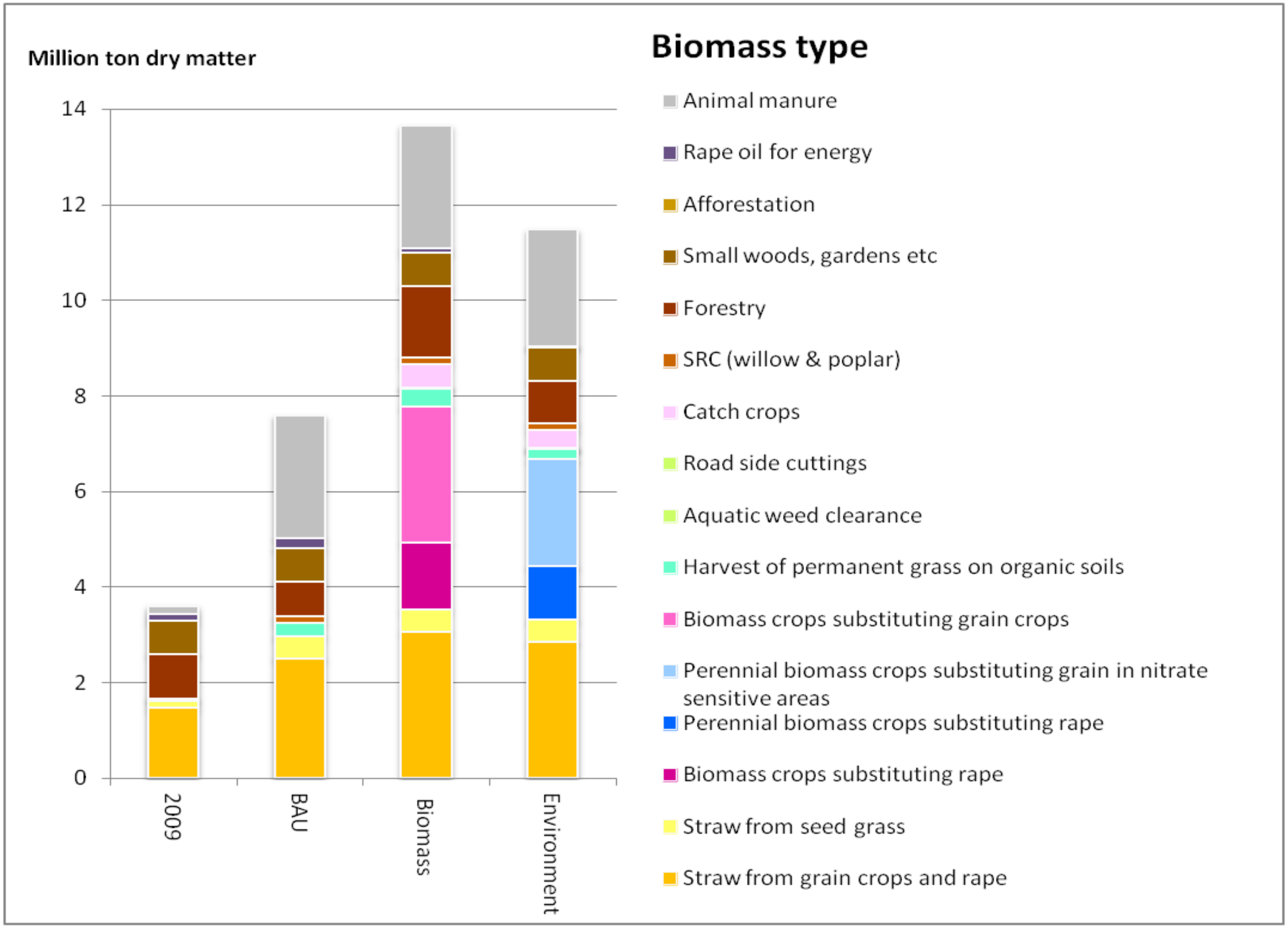
- Straw rich grain varieties
- Increased straw harvest
- Less grain and rape –> high productive biomass crops (beets 19 t ha^{-1} DM)
- Fertilization of natural grasslands
- Road sides, aquatic weeds, catch crops etc.

Environmentally optimised:

- No straw removal from land with critical low carbon content
- Perennial biomass crops (grass 15 t ha^{-1} DM)
- More catch crops
- No grain crop production in nitrate sensitive areas
- No fertilization of natural grasslands
- Increased afforestation

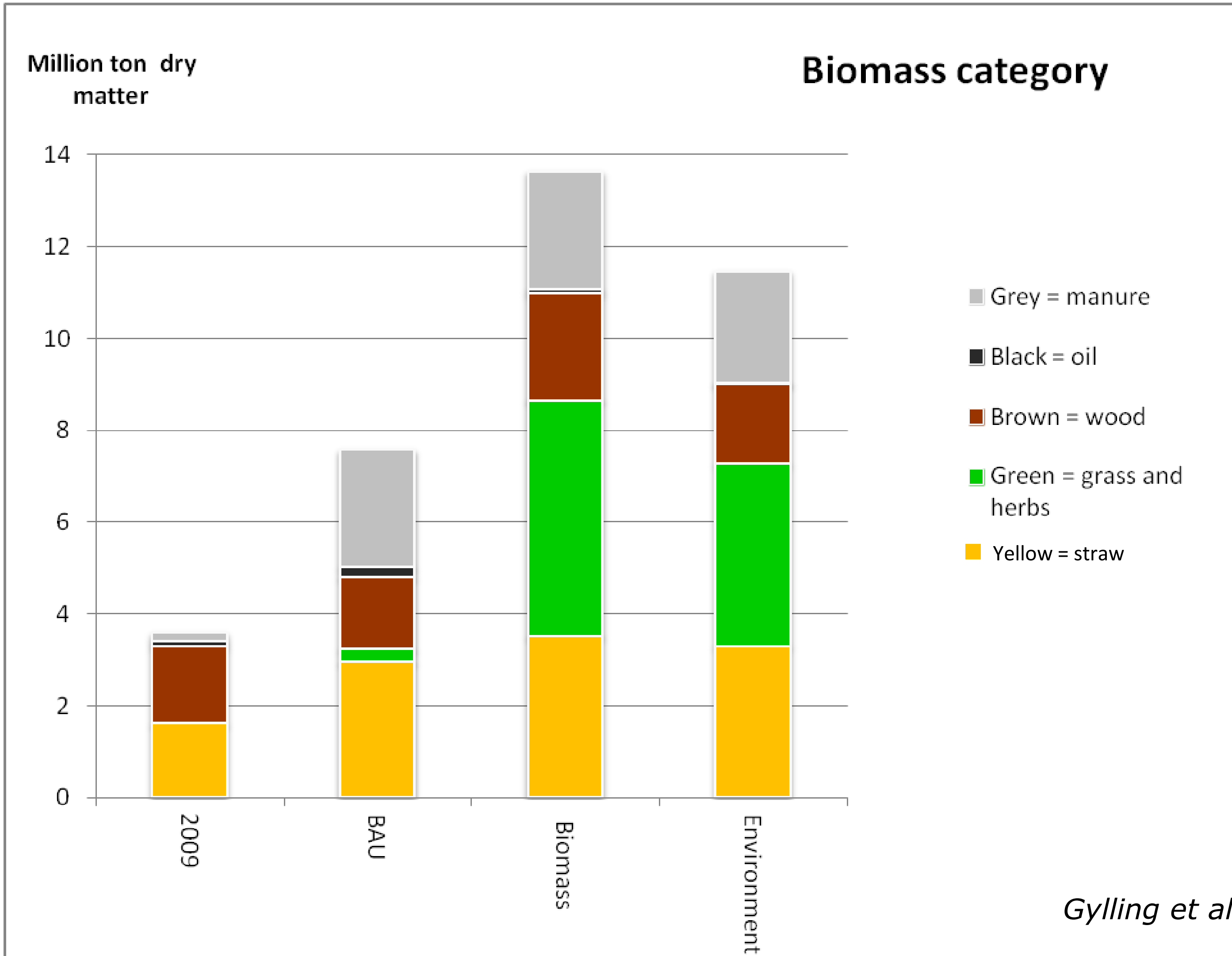
Gylling et al., 2013

Danish agriculture and forestry can deliver 3-4 times more biomass in 2020



Gylling et al., 2013

Different biomass types for different conversion technologies



Gylling et al., 2013

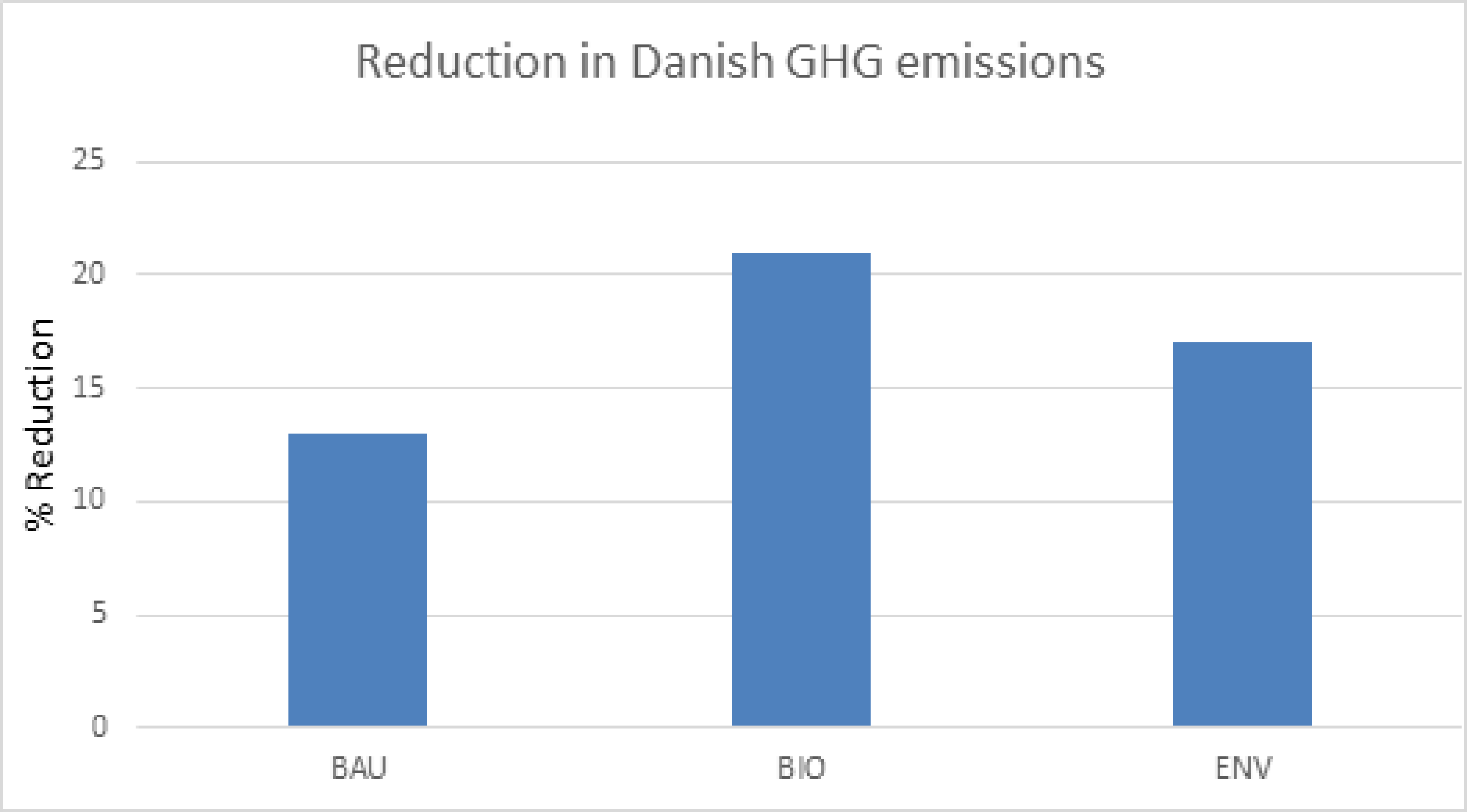
Increased biomass utilisation can reduce nitrate leaching

	Change in nitrate leaching for Denmark (ton N y^{-1})		
	BAU	**Biomass**	**Environment**
Animal manure	-5.752	-5.752	-5.487
SRC	-248	-248	-248
New biomass crops substituting rape		-3.142	-6.085
New biomass crops substituting grain crops		775	-5.040
Afforestation	-847	-847	-2.005
Additional catch crops			-4.598
Total	**-6.846**	**-9.214**	**-23.463**

Will fulfil the demands of the EU Water Framework Directive

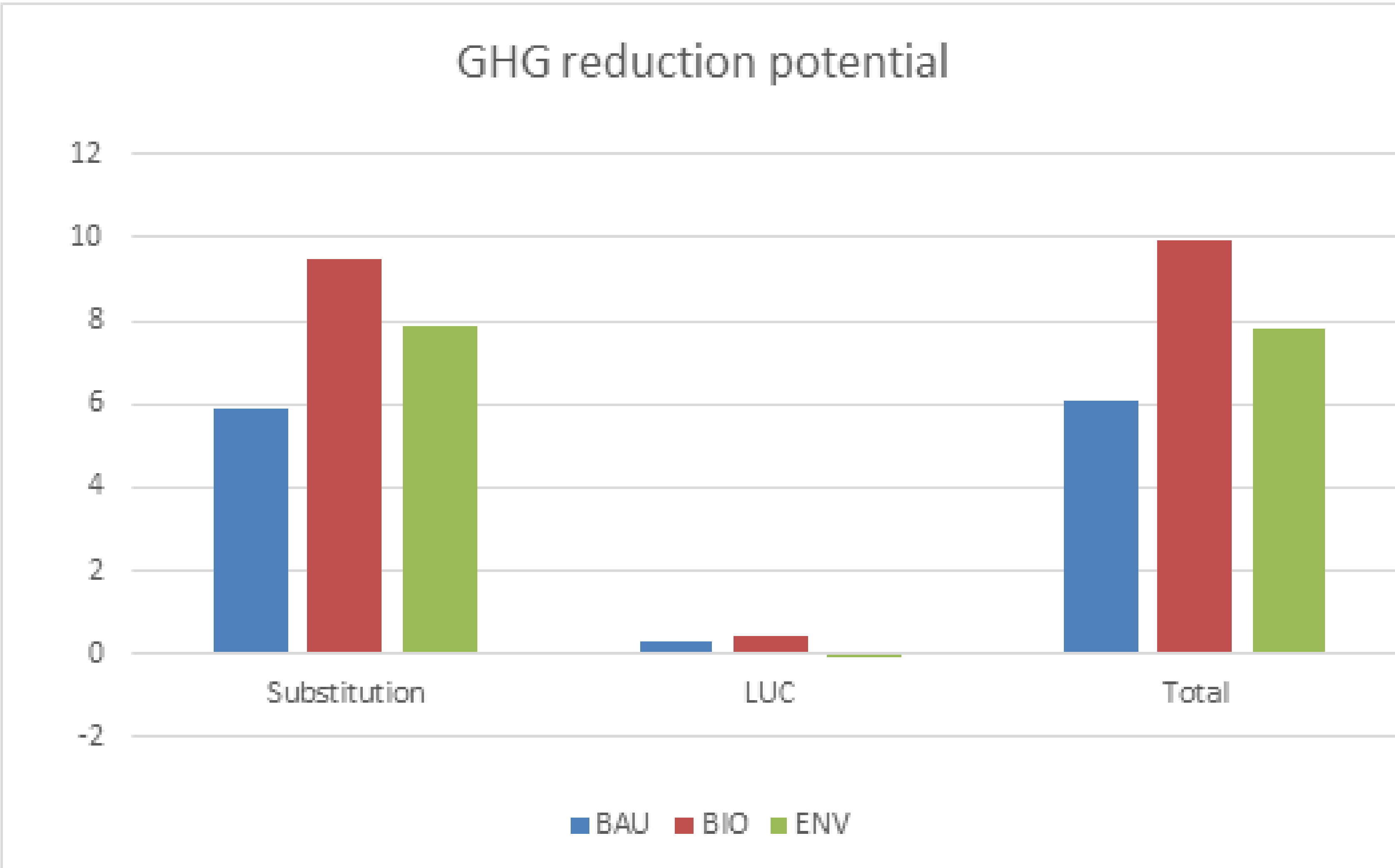
Jørgensen et al., 2013

Energy system scenarios were defined to analyse the effect on TOTAL Danish Greenhouse Gas emissions



Gylling et al., 2016

The scenario effects on fossil fuel substitution and on Land Use Change (Mt CO_2 eq.)



Gylling et al., 2016

What is needed to double productivity and halve environmental impact from Danish agriculture?

New crop production paradigm

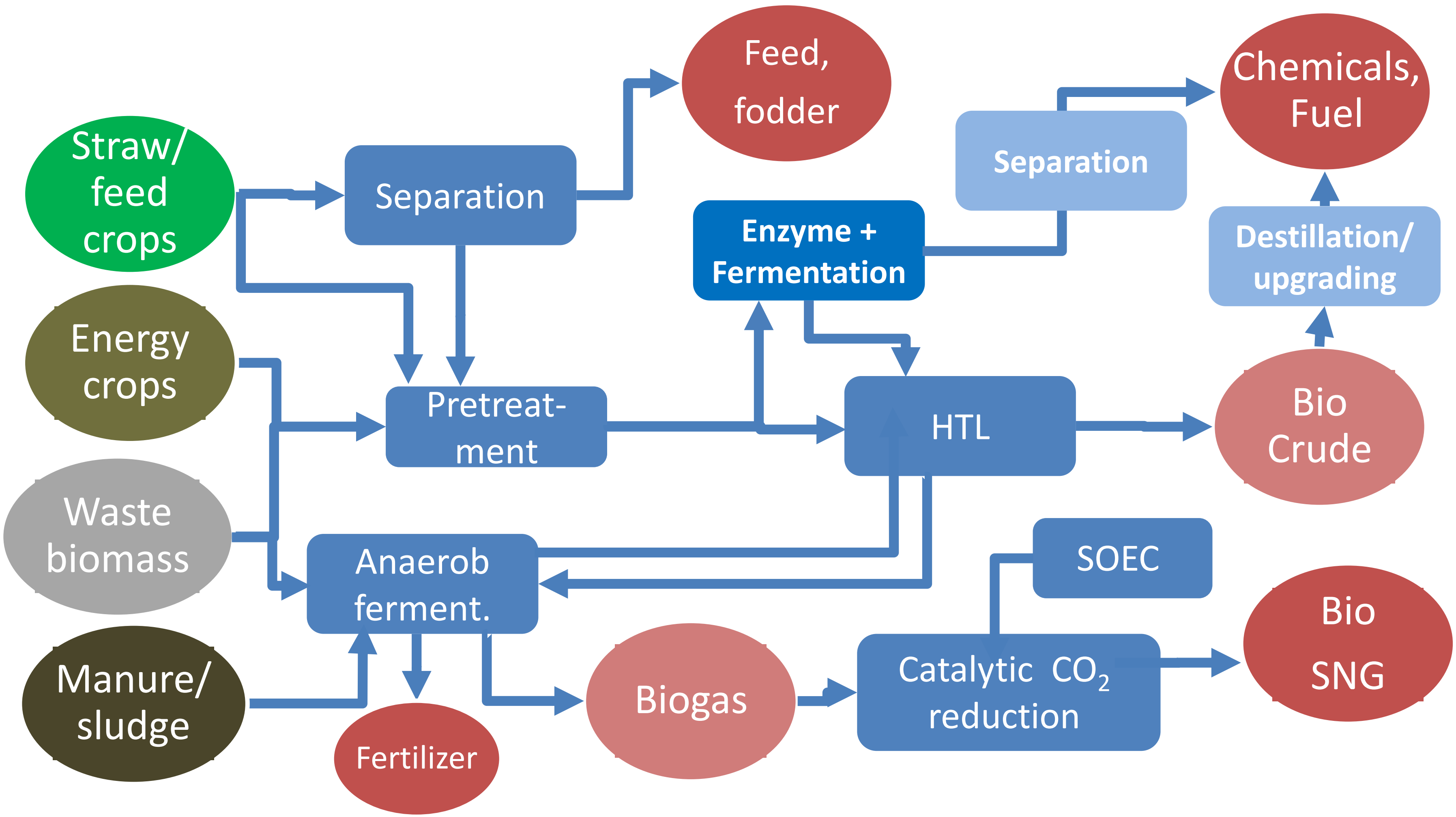
- Annual crops -> perennial crops
- Improved application of cover crops
- Harvest green crops (maximum biomass & protein)
- Green biorefinery to produce food, feed, bioenergy & materials

Research and development

- Increase productivity of grasses and legumes
- Breeding for biorefinery quality (extractable protein, low ANF content)
- Biorefinery processes – protein extraction etc.
- Demonstration of new concepts (high production low emission crops, animal feeding, logistics & conversion)
- Optimized integration with bioenergy technologies (biogas, HTL, ethanol….)
- Nutrient leaching after grass renewal, N2O emission, soil C

Center for Biorefinery Technologies

(kg to ton/hour)



AU-CBT

Bioenergy: an important side product in production chains

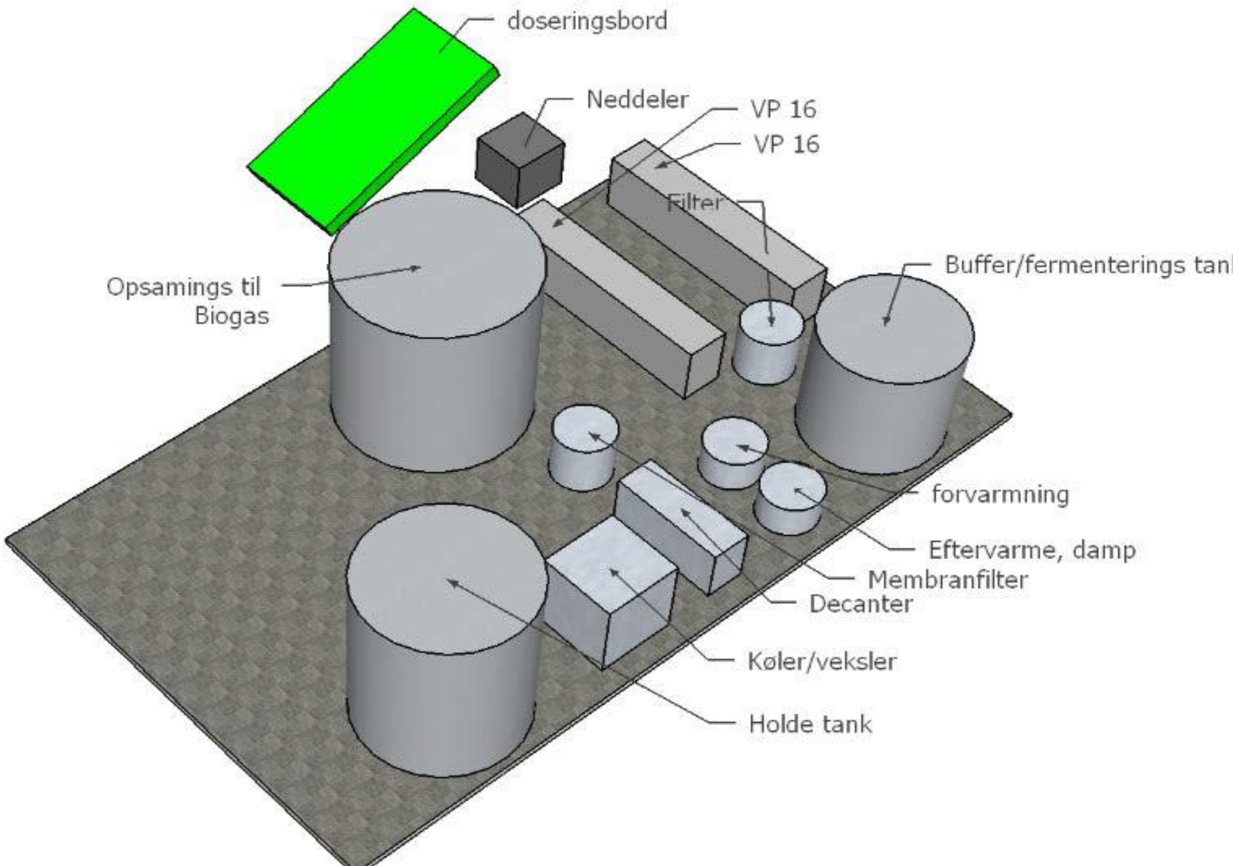
Biogas fermenters from 1-1.200.000 L & unique pilot upgrading

AU-CBT

CBIO
AARHUS UNIVERSITETS CENTER FOR
CIRKULÆR BIOØKONOMI

Demonstration facility for protein extraction from 2019
40 tons biomass per hour

financed by GUDP, Central Region Denmark, Arla, DLF and DLG



We can sustainably increase productivity by combining the best from agronomy with the best from industry!