NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
AARHUS UNIVERSITY

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Cultivation of *Ulva lactuca* for bioenergy

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AlgeCenter Danmark

Ulva lactuca

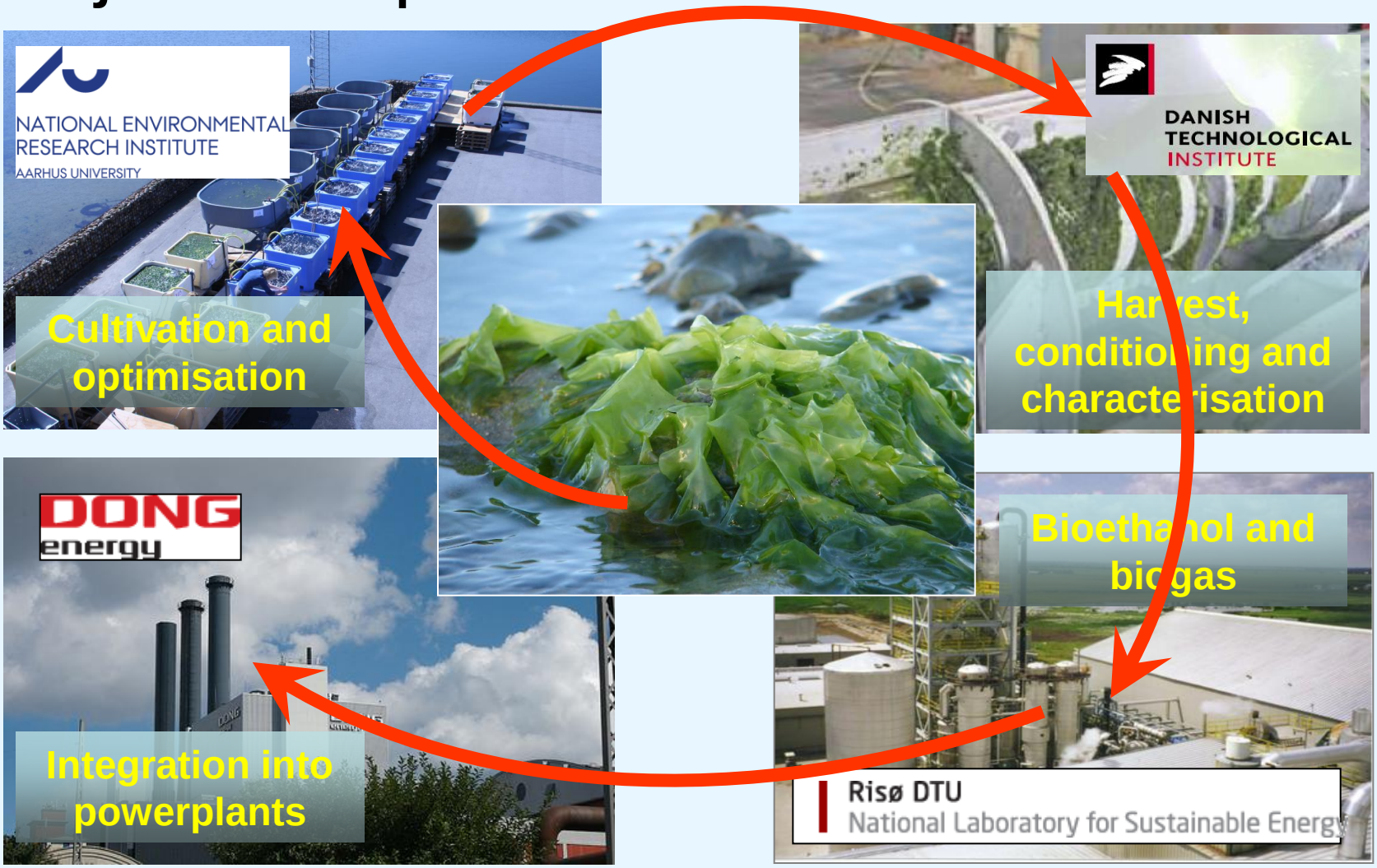
- **High growth rates in natural Danish habitats (35% d^{-1})[1]**
- **High production potential [2,3]**
- **Green tide species**
- **Easy to grow**
- **High content of carbohydrates (>50%) [4]**
- **Good model macroalgae for R & D on energy production from marine biomass**

1: Pedersen & Borum 1996. 2: Msuya & Neori 2008. 3: Robertson-Anderson *et al* 2008. 4: Smith & Montgomery 1959.

”Energy production from marine biomass (*Ulva lactuca*)”

- **Funded by Energinet.dk (8.5 mio DKR = 1.5 mio USD)**
- **2008-2011**
- **Aims:**
  - **Production potential**
  - **Suitability for energy conversion**
    - **Combustion**
    - **Gasification**
    - **Bioethanol**
    - **Biogas (methane)**
  - **Integration into power plants**
    - **CO_2 capture**
    - **prolonging of growth season by heat from cooling water**

Project and partners



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Bioenergy potential of *Ulva lactuca*: Biomass yield, methane production and combustion

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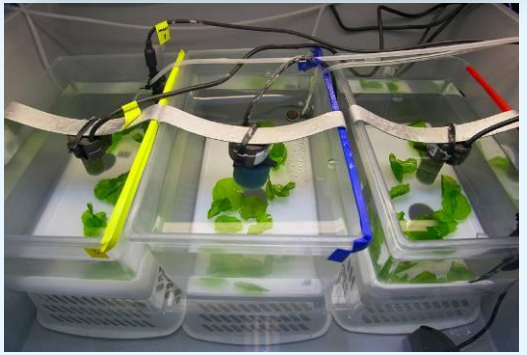
Midway status

Results

- **Production potential**
- **Optimisation of growth by CO_2 capture**
- **Conditioning and storage**
- **Energy conversion**
  - **Combustion**
  - **Ethanol**
  - **Biogas (methane)**

Summary

Future aims



Production potential

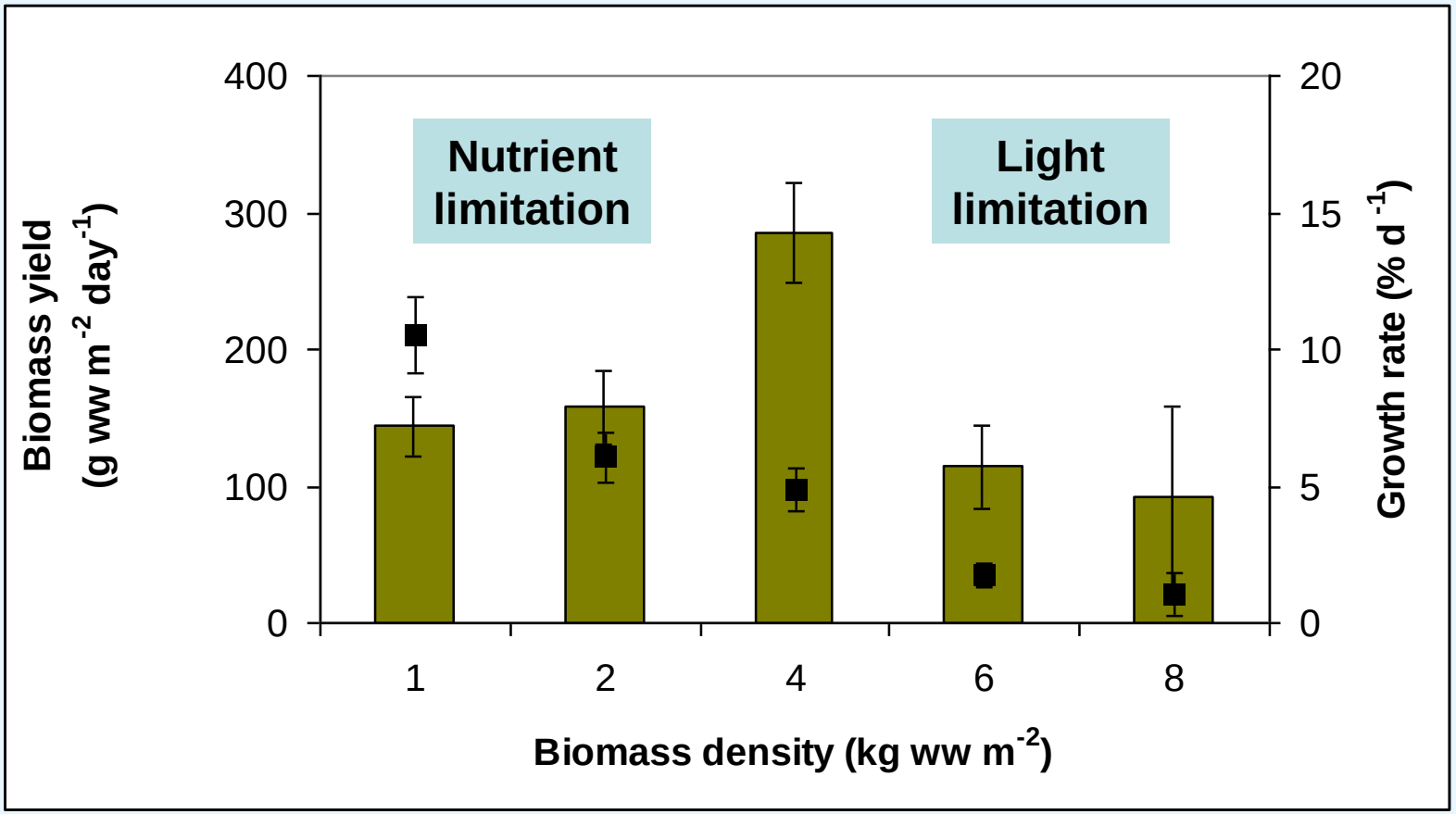
Cultivation facility [5]

- 56º 47’ 16’’ North (Mors)
- 1 m^2 tanks
- continuous aeration
- addition of N and P
- water exchange 6 times per day
- salinity 25-28.5 psu
- weekly adjustment of stocking density

5: Bidwell 1985

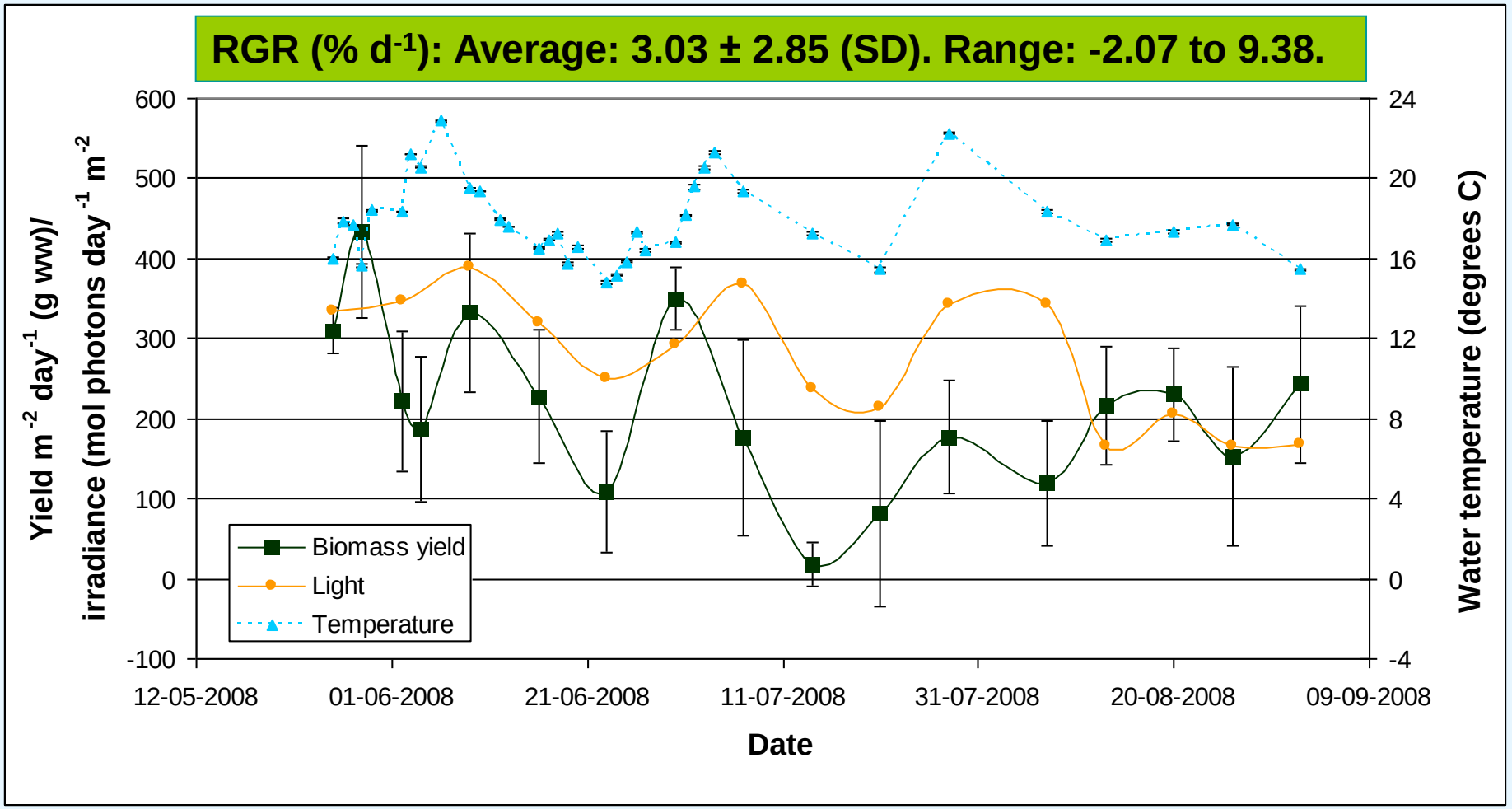
Production potential

Optimal stocking density = 4 kg m^{-2} (N=3)



6: Bruhn *et al*, 2010

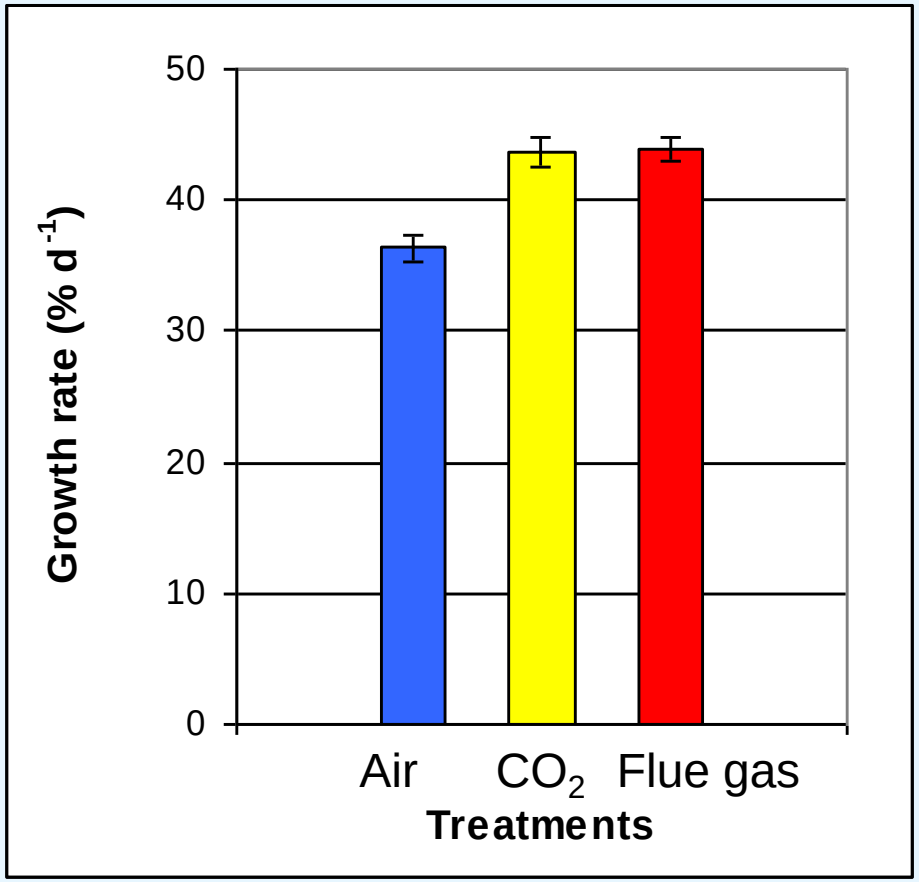
Production potential (4 kg m^{-2})



6: Bruhn *et al*, 2010

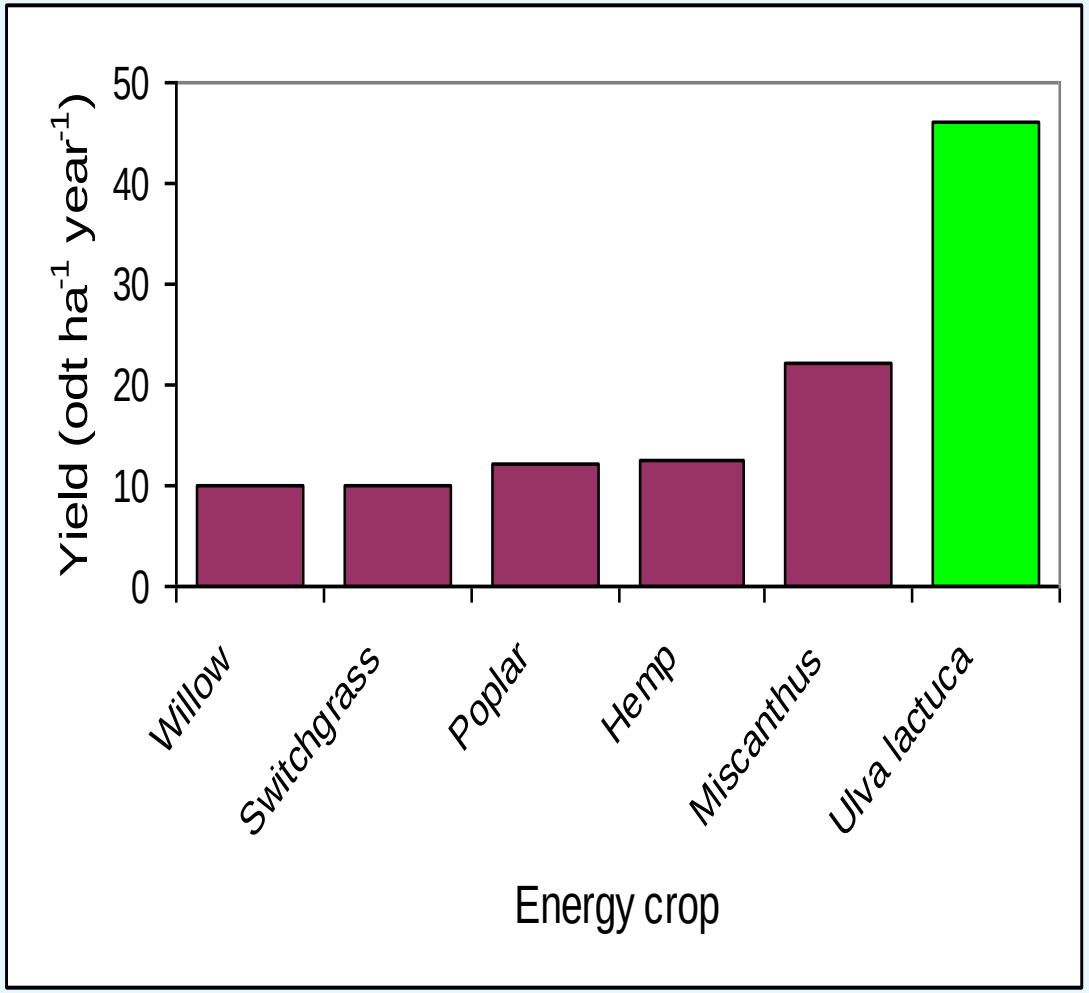
CO_2 capture from fluegas

- **pH controlled (7.5)**
- **three treatments**
  - **atmospheric air**
  - **CO_2 12%, O_2 6%**
  - **flue gas from wood pellets**
- **nutrient replete**
- **three replicates**
- **duplicate experiments**
- **increase of production by up to 25%**
- **fluegas = CO_2**



Production potential - summary

- **45 T dw ha^{-1} season^{-1}**
- **2-5 times landbased energy crops**
- **production can be optimised regarding**
  - CO_2 addition
  - fertilisation – more N and P
  - minimising sporulation
  - more light

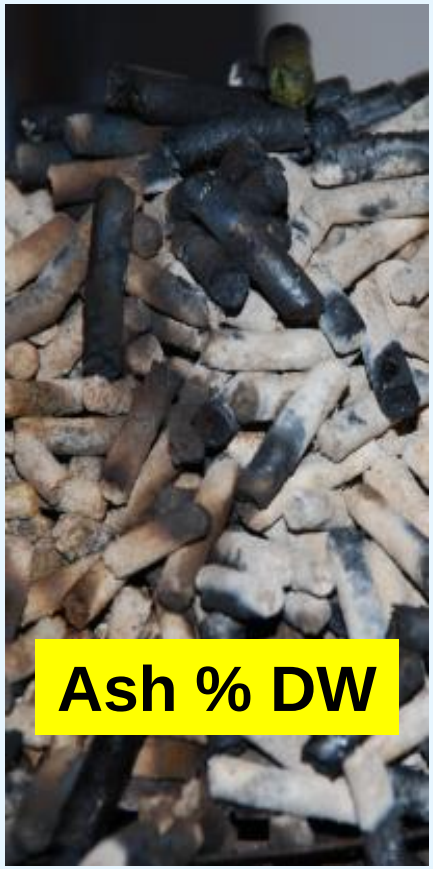


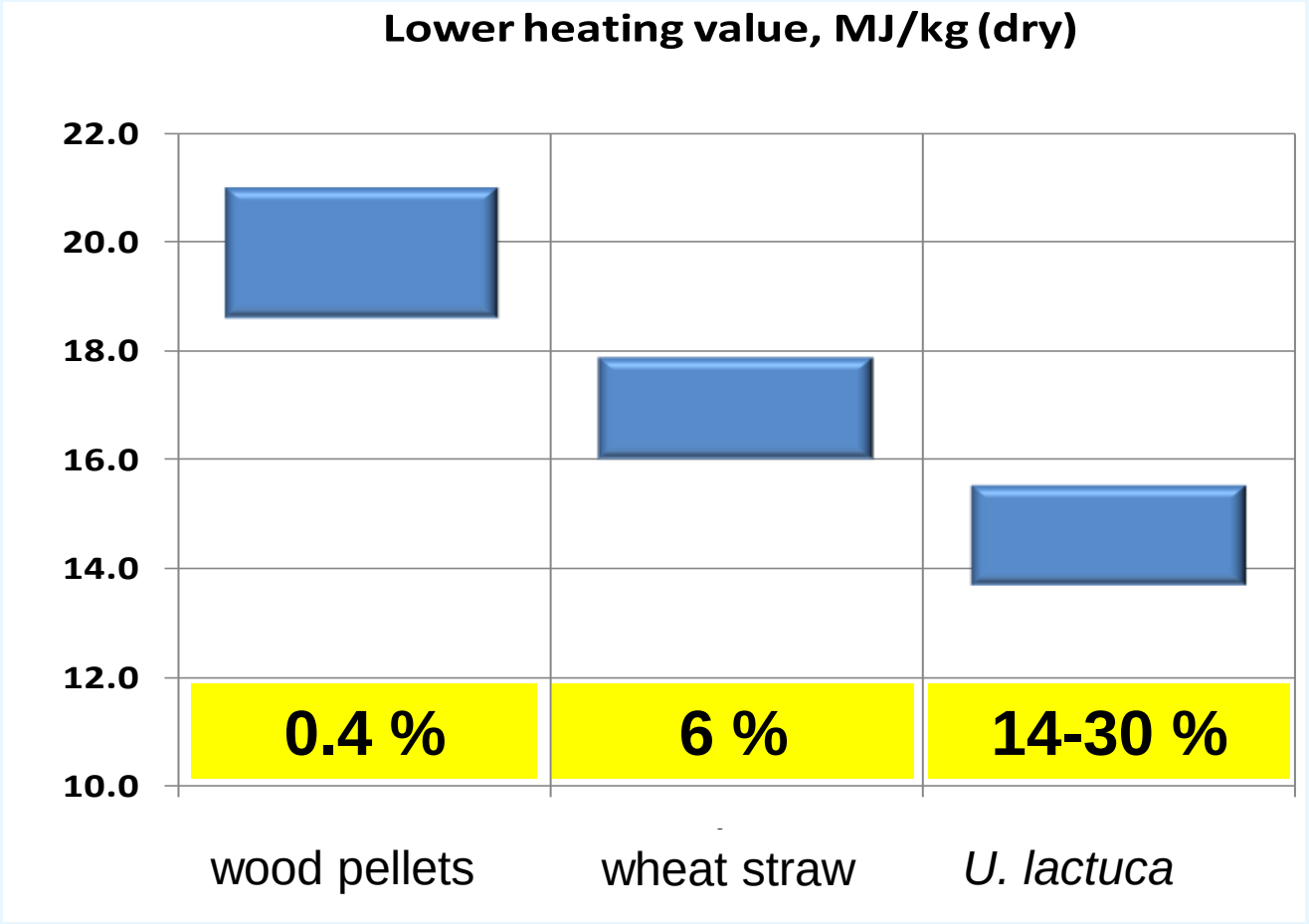
Conditioning and storage

- **For futher processes**
  - **Avoid sand at harvest**
  - **Avoid salt – or rinse**
- **Screwpress**
  - **reduction to 30 % water content**
- **Pelletisation**
  - **Unproblematic**
  - **Water content of 17.5 % and a density of 800 kg m^{-3}**
  - **Compression of biomass by a factor 12**

Combustion

Heating value





Combustion

	Unit (dry basis)	*Ulva lactuca*	*Laminaria digitata*[7]	Wheat straw	Debarked softwood
Ash	Wt%	16.5	25.75	6	0.4
K	mg/kg	26,400	36,600	2,725	183
Na	mg/kg	16,500	43,300	177	7
Mg	mg/kg	18,150	9,325	781	127
S	mg/kg	19,800	-	2,100	150
Cl	mg/kg	15,840	-	3,522	76
P	mg/kg	1,617	8,750	155	20

Alkali index (moderate to severe fouling): 0.17-0.34 [7]

Alkali index algae ulva/brown: 1.2–5.03[6]/2.034-6.163[8]

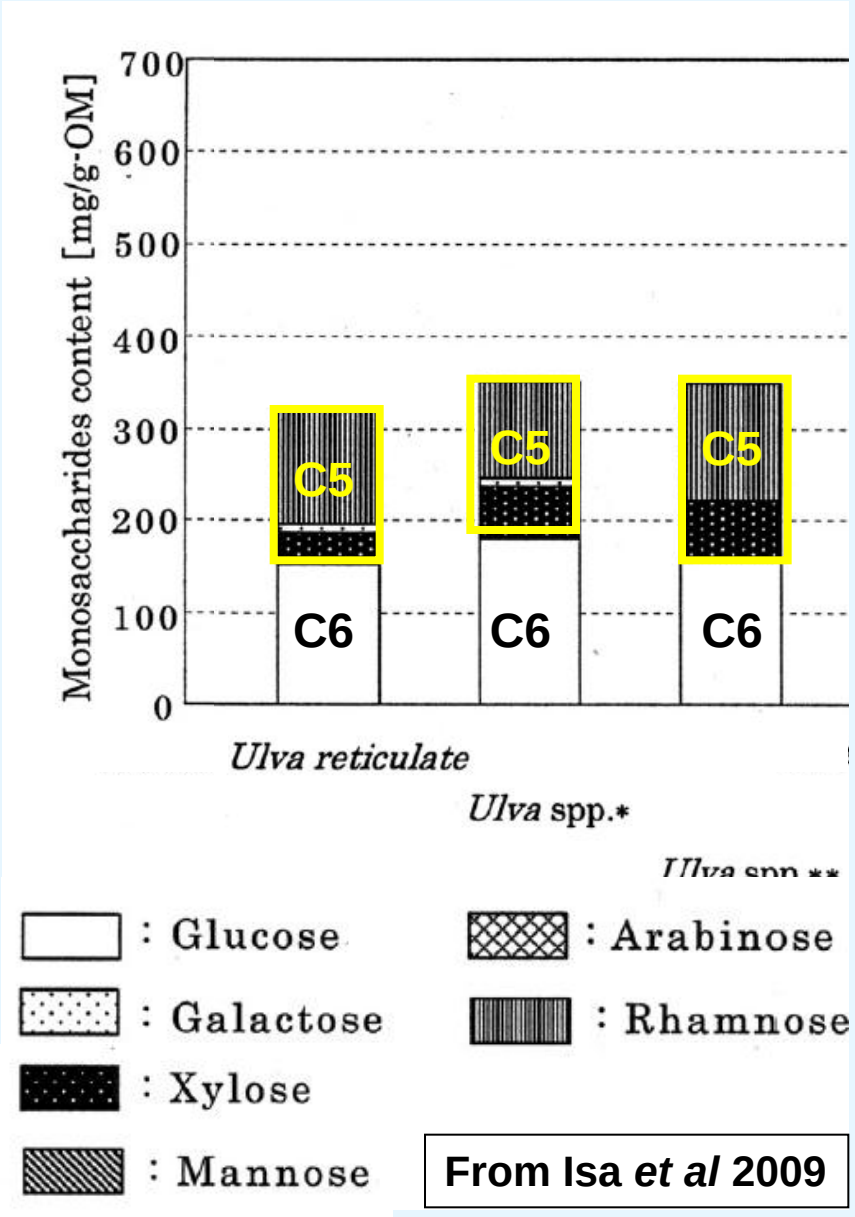
6: Bruhn *et al*, 2010. 7: Jenkins *et al* 1998. 8: Ross *et al* 2008.

Combustion – summary

- **High ash content – lower heating value**
- **High alkali content**
- **Not recommendable for direct combustion**
- **Potential for use in co-firing with other fuel types**

Bioethanol

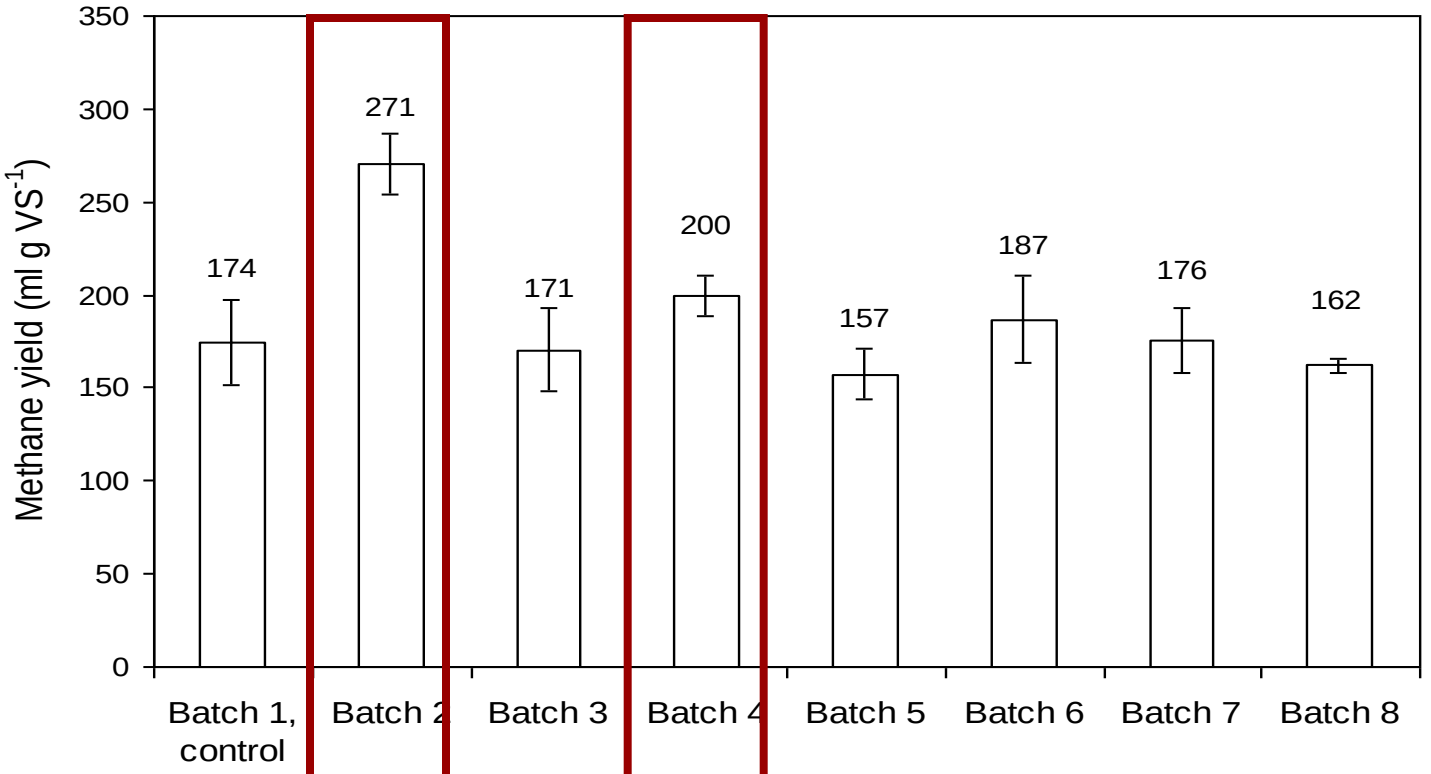
- **Large fraction of *Ulva lactuca* sugars are C5 sugars**
- **Poor *Saccaromyces* fermentation**
- **Approximately 4 % ethanol yield (ww) (9)**
- **Salt inhibits fermentation**
- **alternative microorganisms for fermentation**



From Isa *et al* 2009

9: Isa *et al* 2009

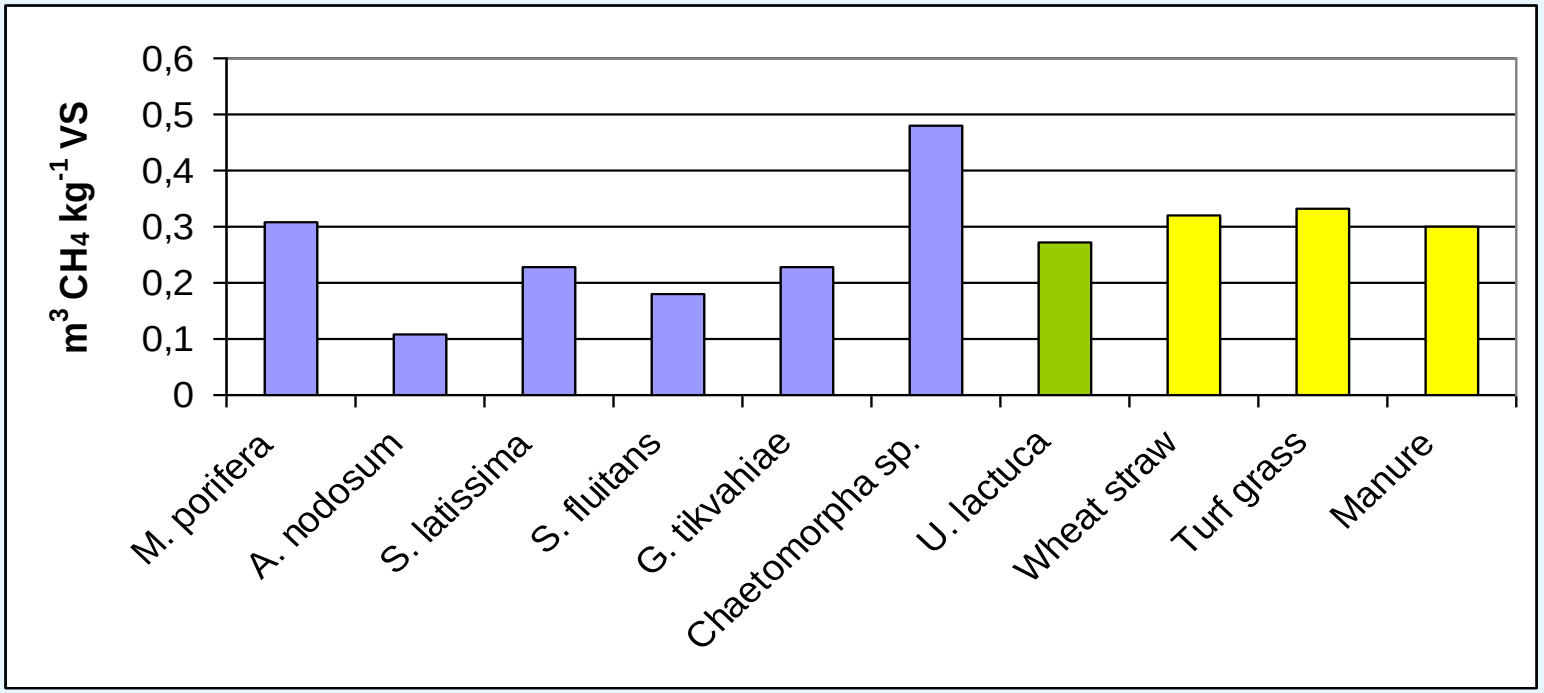
Biogas



	Batch 1, control	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6	Batch 7	Batch 8
washed	-	-	+	+	+	+	-	-
dried	-	-	-	-	-	-	+	-
macerated/chopped	C	M	C	M	C	C	-	C
55°C/37°C	55	55	55	55	55	55	55	37
pretreatment					110°C/20 min	130°C/20 min		

Biogas - summary

- **yield in same range as other algae [10]**
- **lower/same range as landbased energy crops and manure [10,11, 12]**
- **optimisation by N starvation**
- **removal of inhibitors – salt & sulphur**



10: Gunaseelan *et al* 1997. 11: Lehtomäki *et al* 2008. 12: Hansen *et al* 2006

Midway project summary

- **High production potential – 45T DW ha^{-1} $season^{-1}$**
- **Potential for increase of production by CO_2/fluegas addition**
- **Excellent pellitisation**
- **Not recommendable for direct combustion**
- **Low bioethanol yields with *Saccharomyces***
- **Reasonable biogas yields with existing technology**

Future aims - 2011and beyond

- Production
  - growth on municipal waste water and manure
  - optimisation of carbohydrates composition through nutrient starvation
- Combustion
  - co-firing capacities
  - gasification
- Bioethanol
  - alternative strains
- Biogas
  - sulphur stripping
  - optimisation of inoculum
- Integration into power plants
  - effect on growth of flue gas from coal and straw

Algae Center Denmark

- 12 tanks of 2 m^3
- 2 separate lines * 6 tanks
- recirculated seawater (freshwater)
- automated addition of air/nutrients/CO_2/heat
- National Environmental Research Institute, Technological Institute, Kattegatcentret, House of the Ocean

In a broader perspective

- **landbased cultivation of Ulva will not be economically viable for energy production only**
  - **extraction of high value products – then use waste products for energy**
    - **protein fraction for feed/food/fertiliser**
    - **applications for the ulvan fraction (up to 29%of DW) [13]**
  - **value of ecosystem services - biomitigation**
    - **CO_2 capture**
    - **N and P removal and recycling**
  - **sustainable harvest from natural populations**
    - **necessary studies on the management of wild stocks**

13: Lahaye & Robic 2007.

Thank you for your attention

Bruhn, *et al*, 2010: http://dx.doi.org/10.1016/j.biortech.2010.10.010

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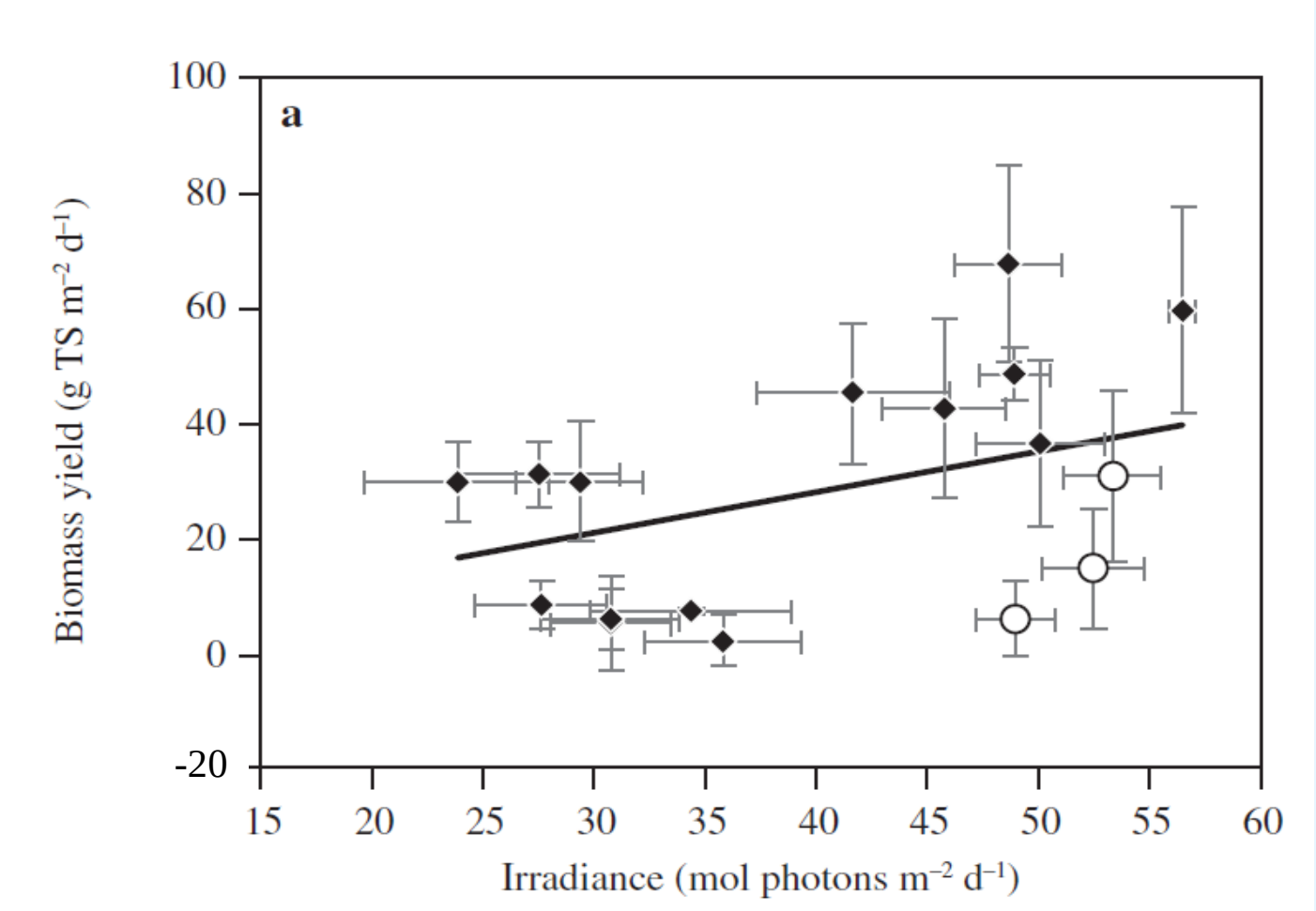
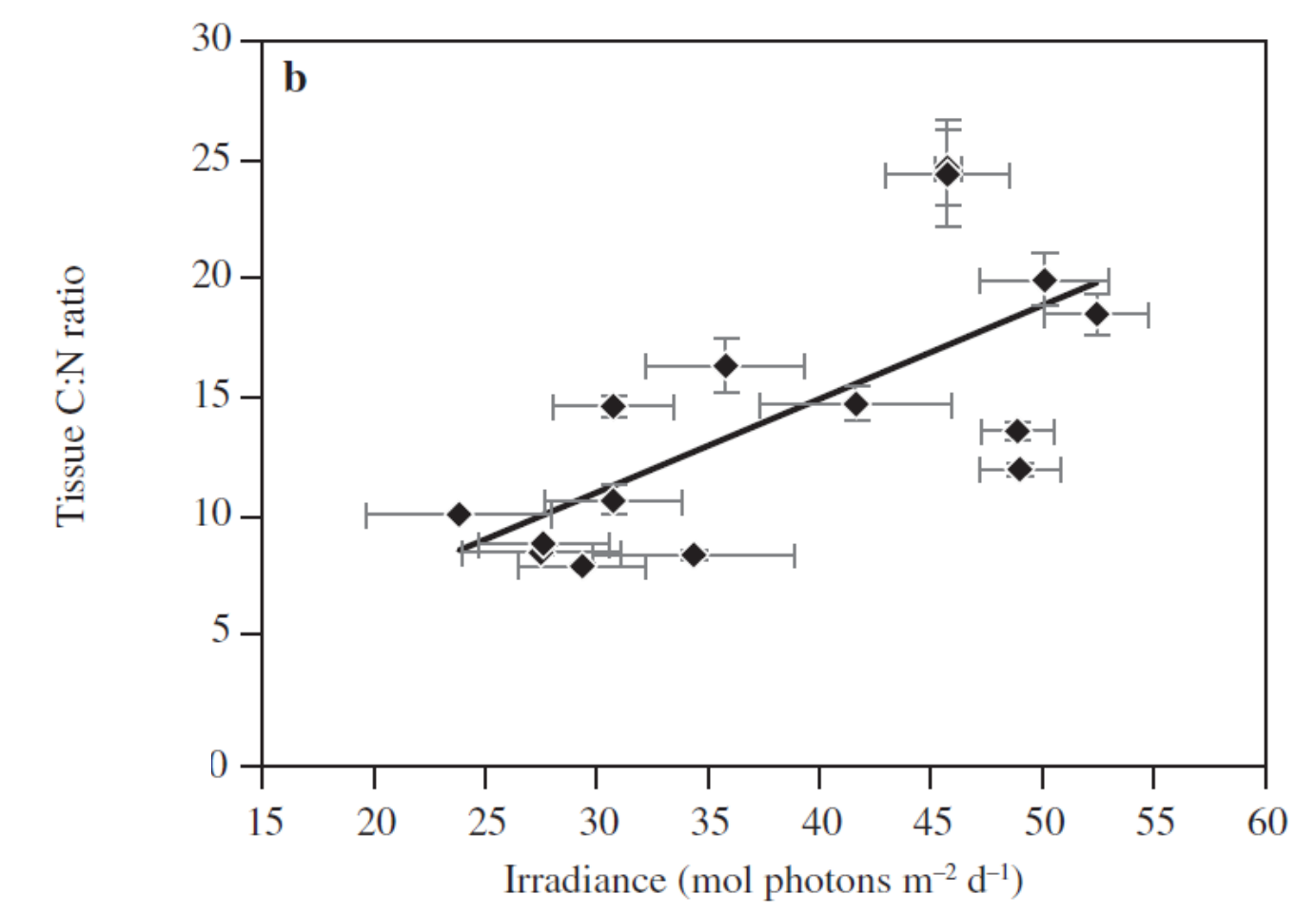
Productivity and light



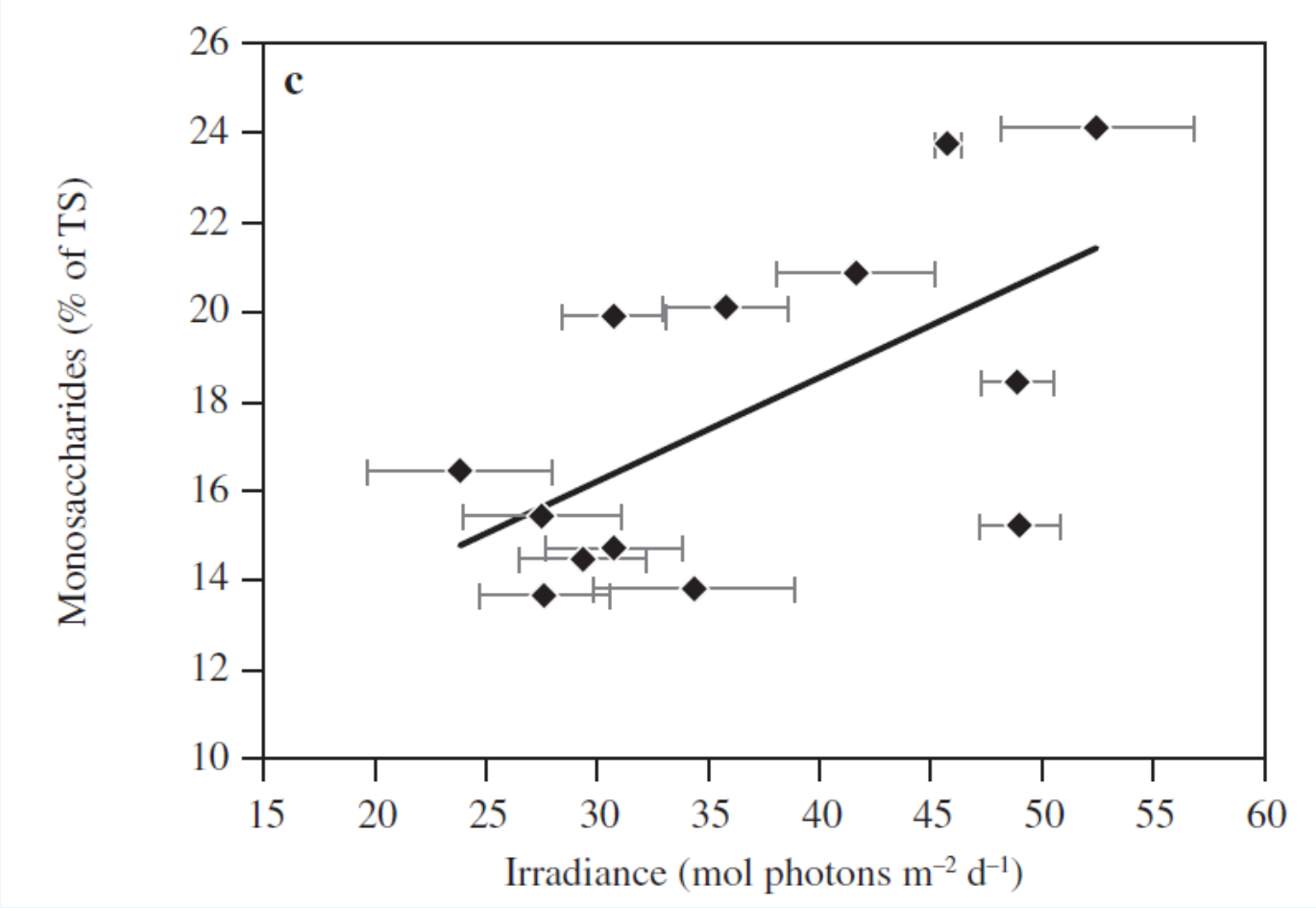
6: Bruhn *et al*, 2010

Tissue C:N and light



6: Bruhn *et al*, 2010

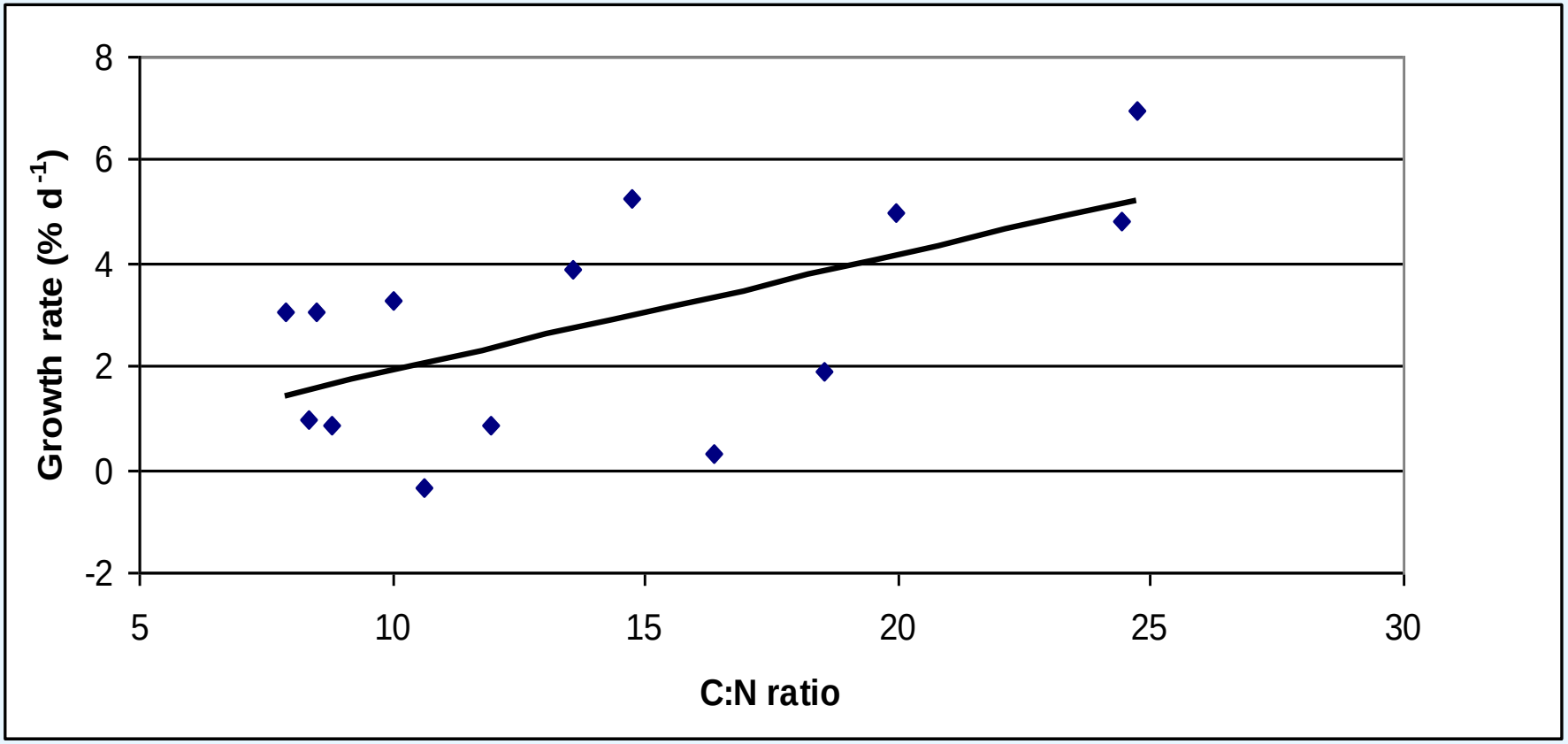
Monosaccharides and light



6: Bruhn *et al*, 2010

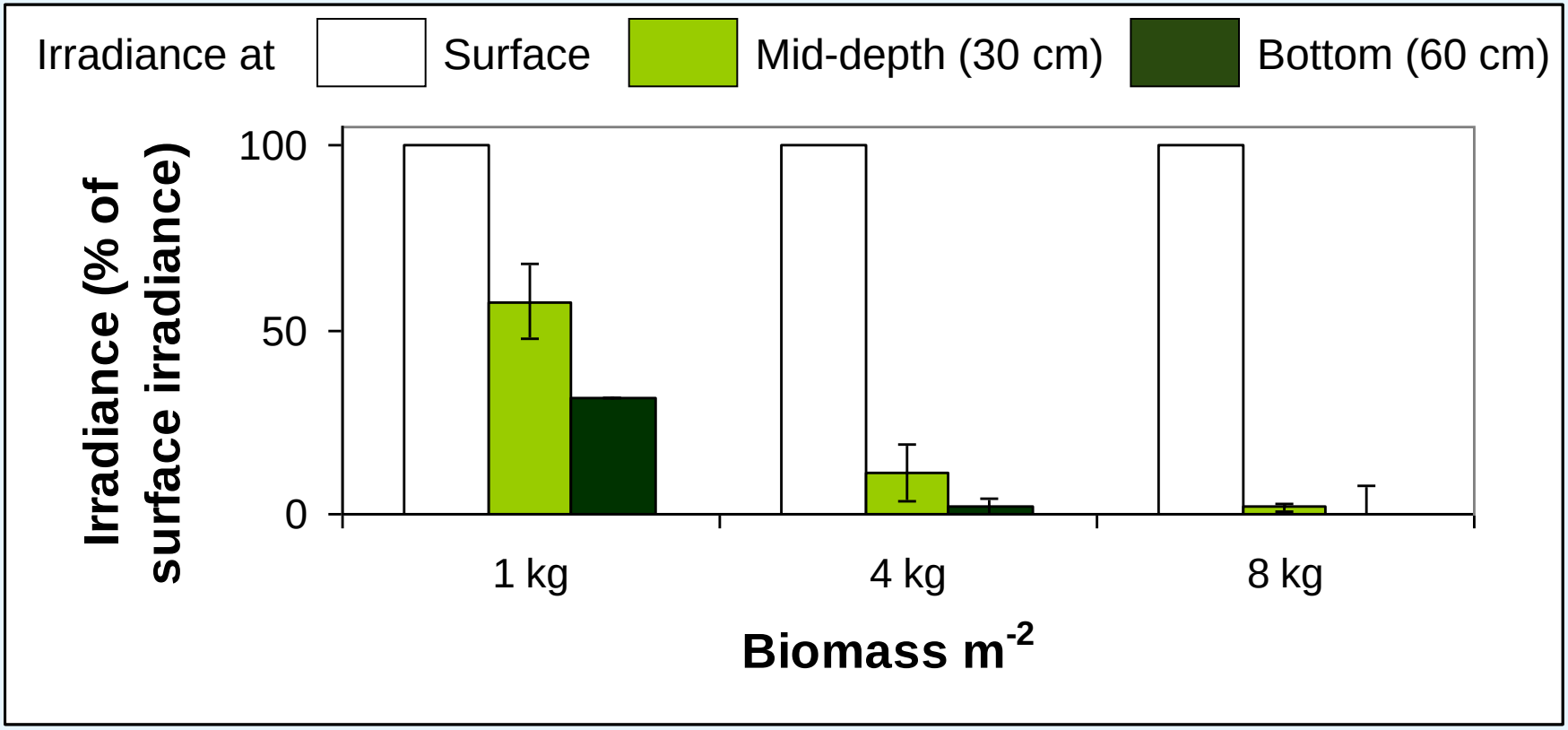
Production limitations

- **Nutrient limitation at low biomass densities**



Production limitations

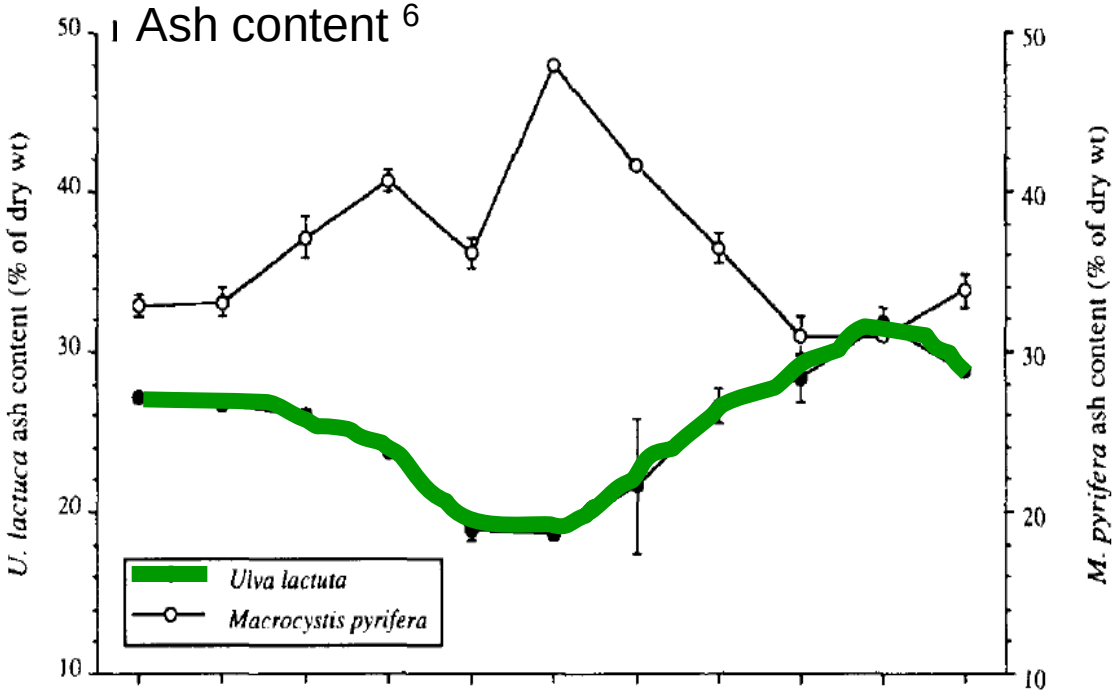
- **Light limitation at high biomass densities**



Combustion

6: Lamare & Wing 2001

Ash content [6]



Daylength / sea temperature [6]