CO_2 in greenhouse horticulture

Horticultural growers Union, Fludir 3 October 2011

Agricultural University, Hveragerdi 4 October 2011

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Wageningen UR Greenhouse Horticulture

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Program

- Introduction
  - Dutch greenhouse sector
  - Wageningen UR Greenhouse Horticulture
- CO_2 supply
  - Requirements
  - Photosynthesis
  - Relation CO_2 level and yield
  - Extra yield
  - Dutch situation
  - CO_2 concentration, ventilation and efficiency
  - Economics
  - Humidity control
- Questions

Dutch greenhouse area:

10000 ha, ± 45% in Westland-Oostland

	2009
Total area (ha)	10325
Food	4890
Vegetables	**4560**
Fruit	**330**
Floriculture	5435
Cut flowers	**2690**
Potplants	**1460**
Other (eg. gardenplants)	**1285**

Companiesize 2 -20 ha

Greenhouse Horticulture:

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Greenhouse Horticulture:






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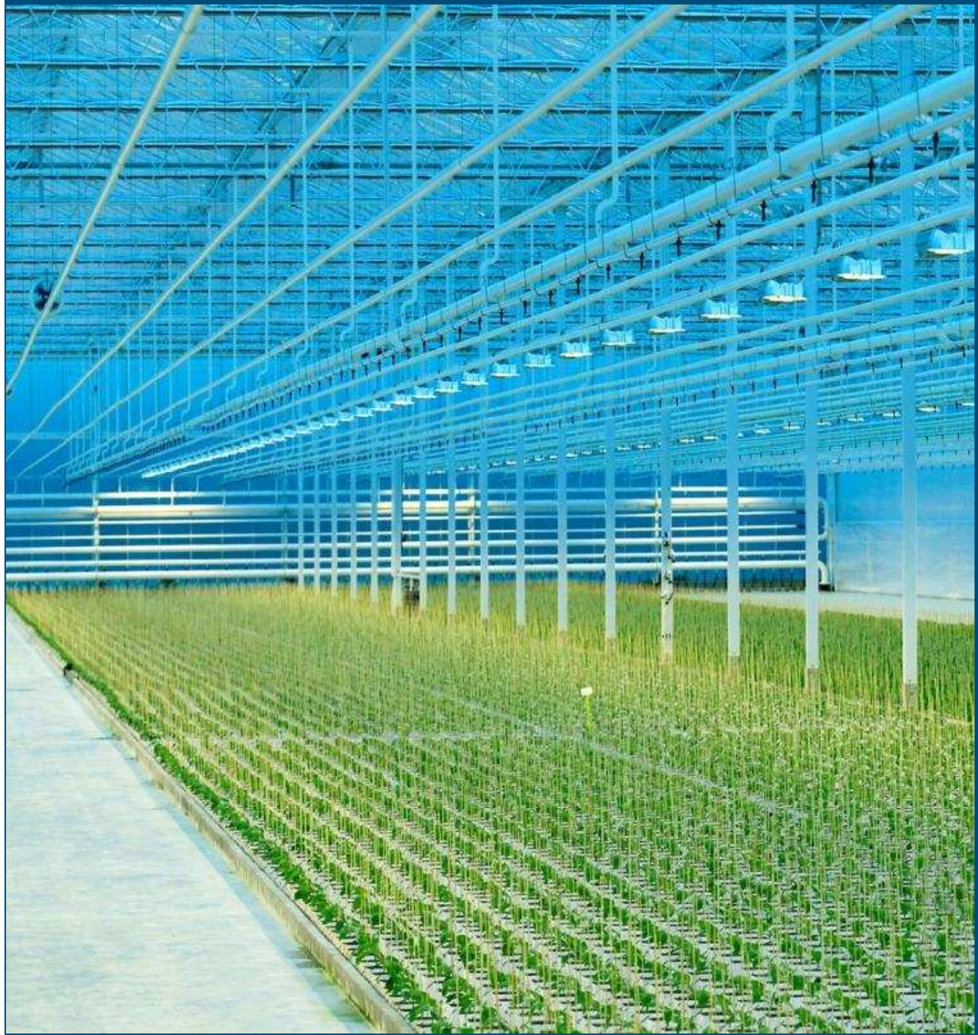
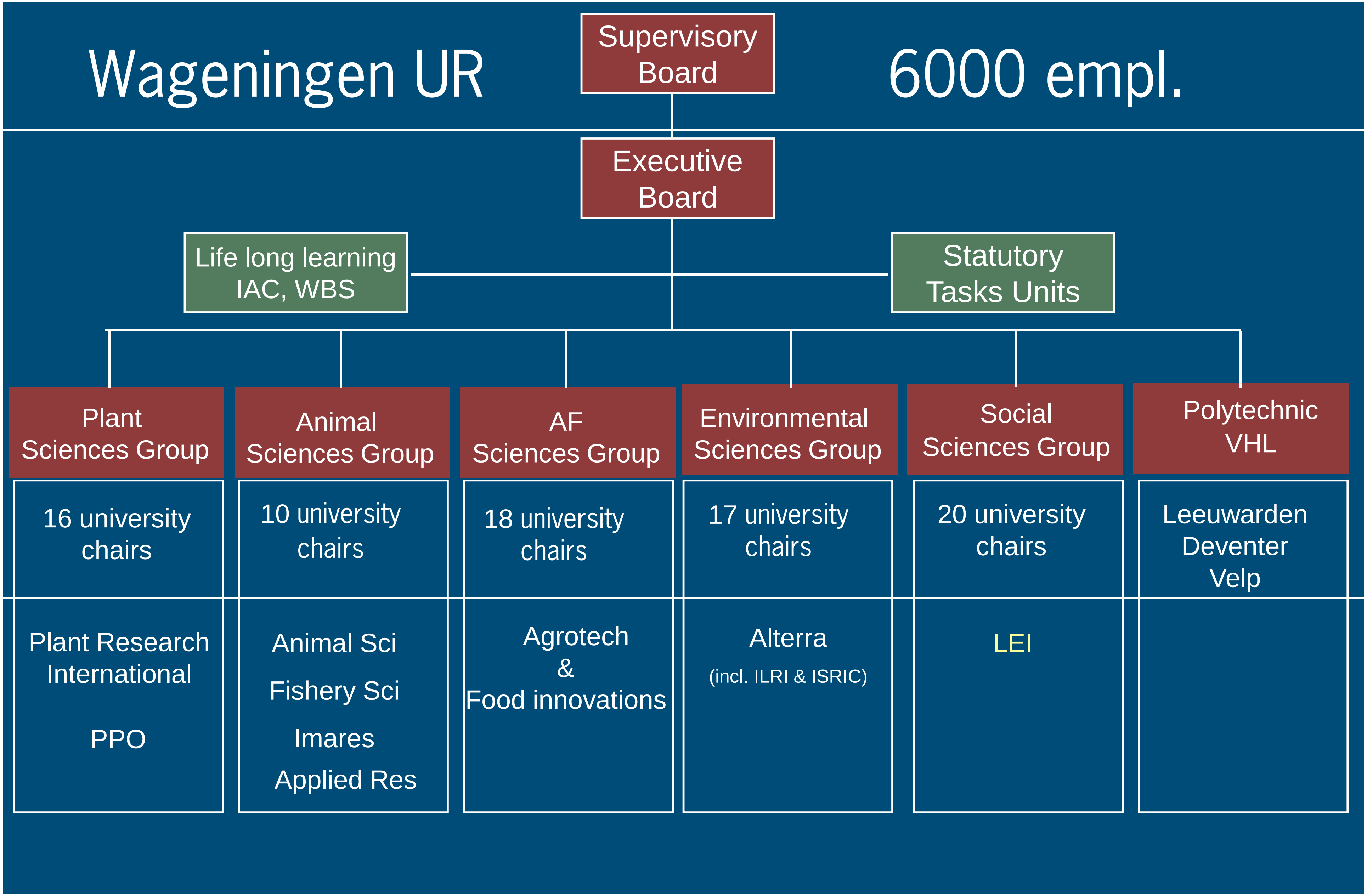
Current high priority issues in Dutch Horticulture



- Economic viability
- Production efficiency
- Costs of energy
- Labour costs and availability
- Chain integration
- Food safety
- Sustainability
- Higher requirements from society



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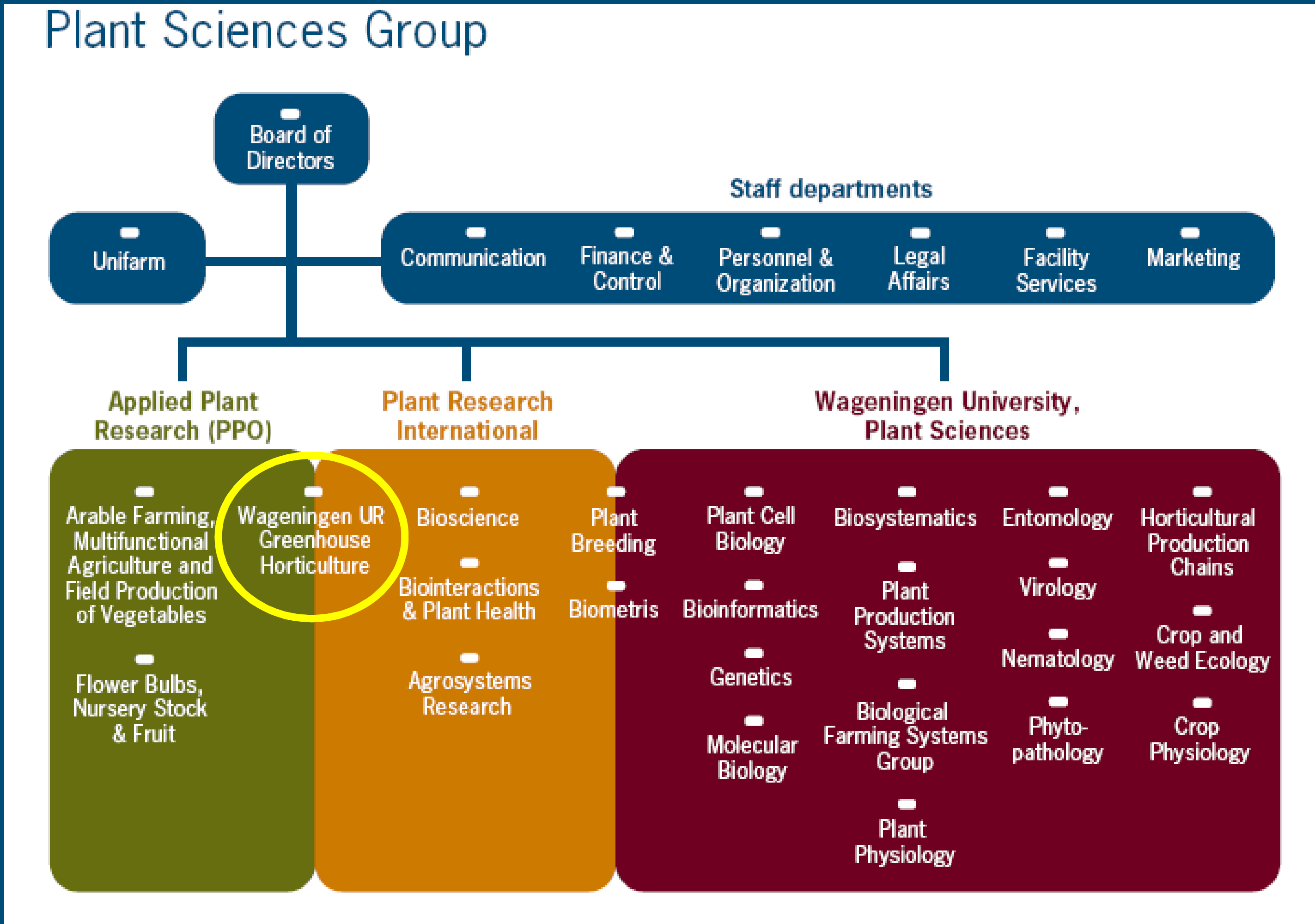
WUR Greenhouse Horticulture = 100 empl.



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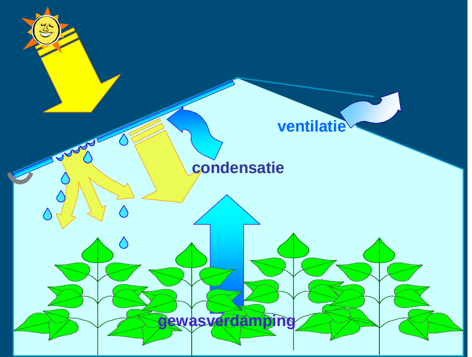
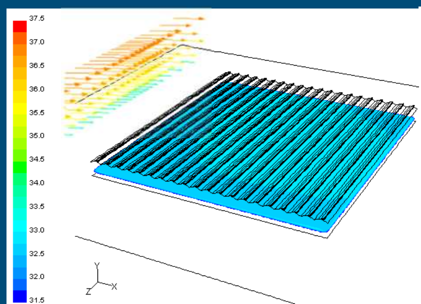
Research topics:

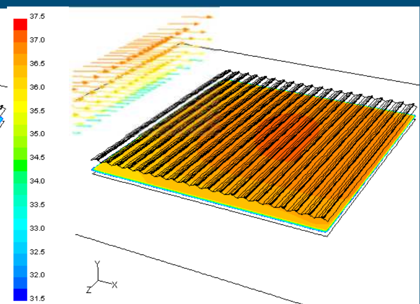
- Climate and energy
- Sustainable crop protection
- Water and emission
- Advanced cropping systems
- Quality of crop and product
- International (Adaptive greenhouse)

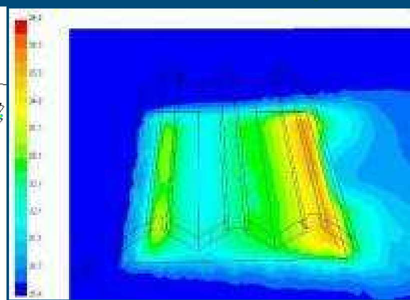
Greenhouse climate

- Dehumidification / cooling systems
- Artificial light
- Physical modelling and CFD
- Wireless sensors/Smart dust
- Climate monitoring commercial greenhouses









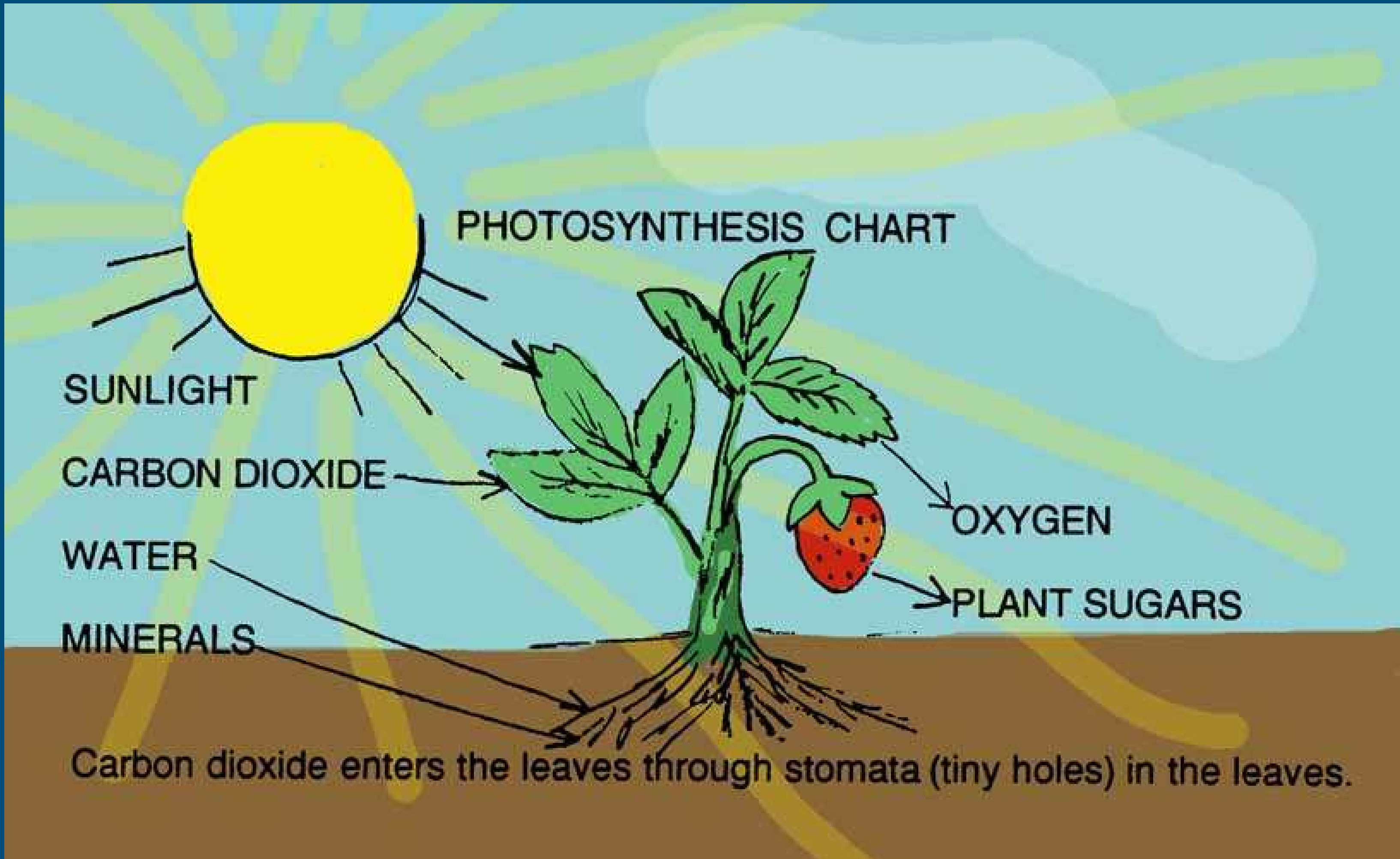
Goal of CO_2 supply

- To optimize the yield and benefit by CO_2 supply?
- Questions?
  - What is the CO_2 requirement?
  - What factors will influence these requiremnets?
  - What is the relation CO_2 supply and yield?
  - Under what conditions?

CO_2 use

- Depends on:
  - Crop conditions:
    - Leaf Area Index (surface leaf/m2)
    - Light level
    - Other growing conditions (temperature, humidity, etc.)
  - CO_2 concentration
  - Ventilation

Photosynthesis



Photosynthesis

Ingredients			*Product*	
Sunlight +				
H_2O +	CO_2 +	Nutrients →	"CH_2O" +	O_2
Water	Carbon dioxide	Nitrate NO_3 Phosphate PO_4 Iron Silica …	"Organic matter"	Oxygen

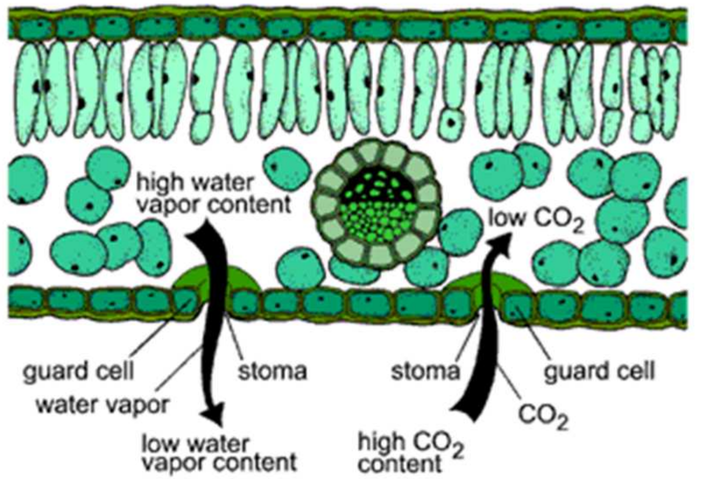
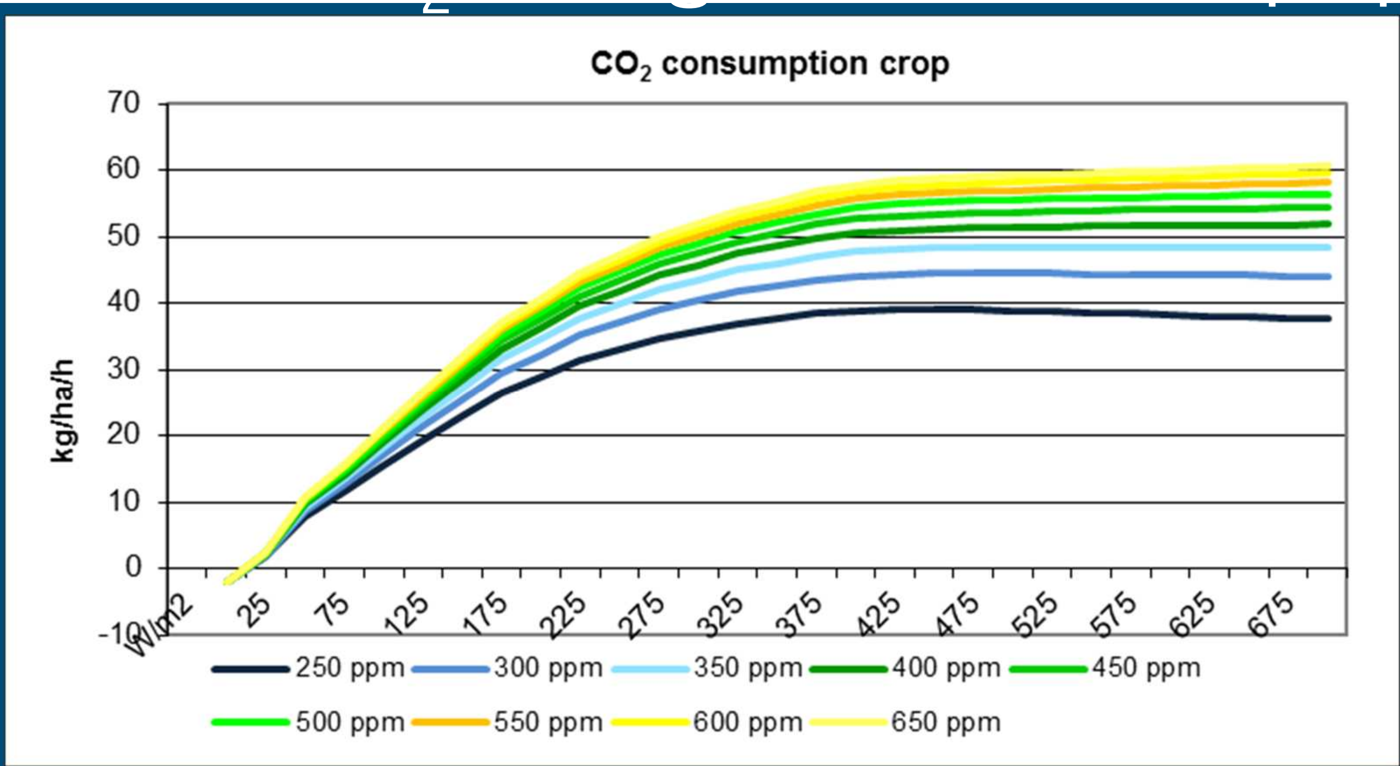


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

Relation CO_2 and light level and crop uptake



- More light → more CO_2 uptake
- Higher CO_2 level → more CO_2 uptake
- Limited grow of CO_2 uptake

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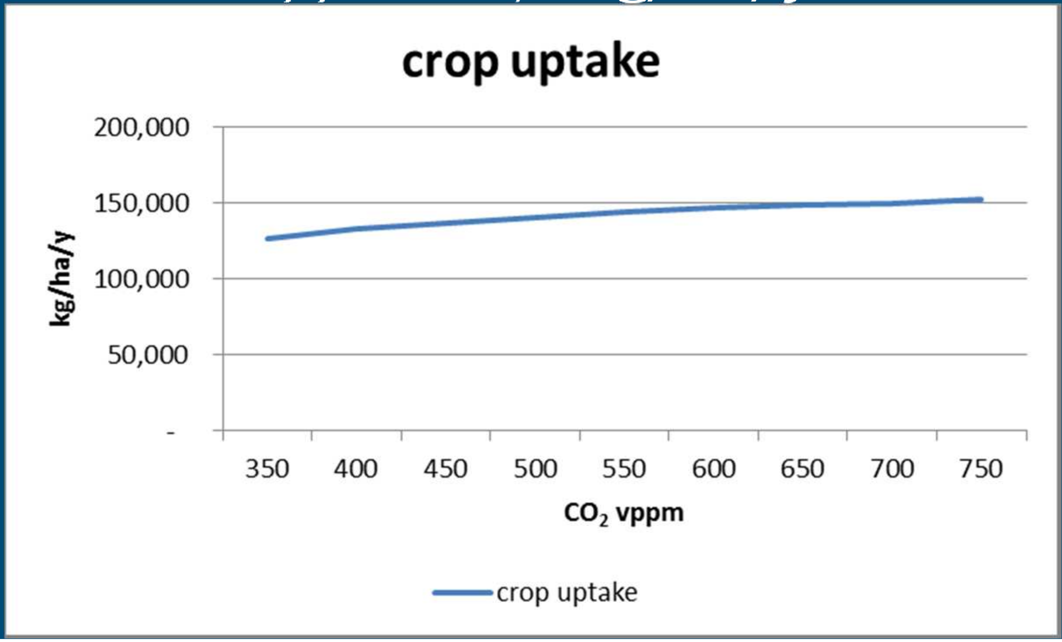
CO_2 consumption crop

- Yearly crop consumption:
  - 350 ppm: 12,7 kg/m^2/year
  - 450 ppm: 14,0 kg/m^2/year
  - 750 ppm: 15,3 kg/m^2/year



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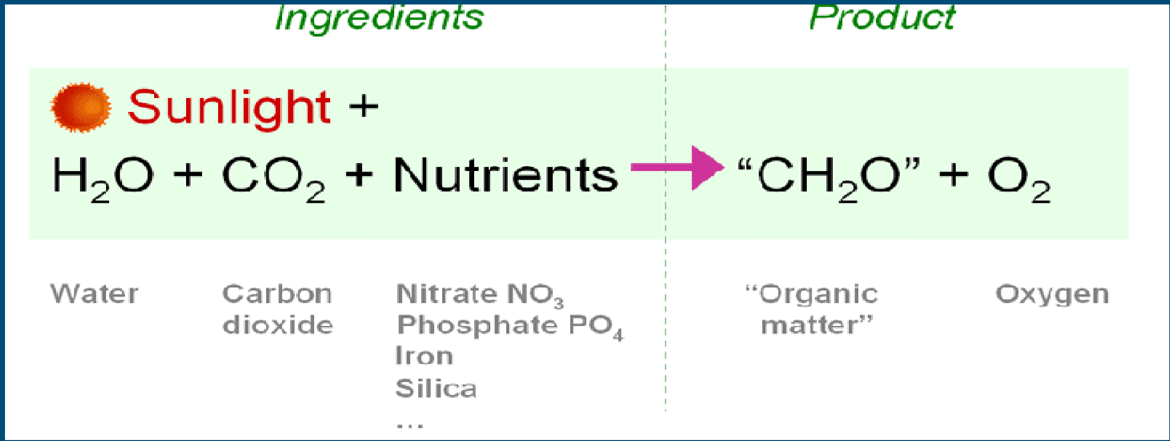
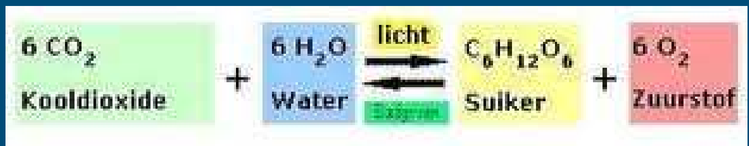
Yield in relation with CO_2 uptake: Photosynthesis





- Mass balance:
  - $6CO_2 = 6*12+12*16 = 264$
  - $C_6H_{12}O_6 = 6*12+12*1+6*16 = 180$
  - 1 kg CO_2 uptake → 180/264 = 0,68 kg dry matter

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Yield in relation with CO_2 uptake

- 1 kg CO_2 uptake → 0,68 kg dry matter
- Extra yield (Y_e) depends on:
  - Dry matter concentration (D_c) (3 – 6%)
  - Dry matter distribution rate (Dr_f) to fruits (60 and 75%)
- Formula:
  - $Y_e = 100/D_c * Dr_f * 0,68$ (kg Yield / kg CO_2 uptake)
- Example:
  - $Y_e = 100/5,8 * 60\% * 0,68 = 7$ (kg Yield / kg CO_2 uptake)

Yield in relation with CO_2 uptake

- Fruit production 1 kg CO_2 uptake:
  - Tomato 6 kg
  - Sweet pepper 4 kg
  - Cucumber 11 kg
  - Egg plant 5 kg

CO_2 use the Dutch greenhouse horticulture

- 10.300 ha
  - Total 5-6.000.000 Ton CO_2 /year = 50-60 kg/m^2/y
  - Will grow → 10.000.000 Ton CO_2 /jaar = 100 kg/m^2/y
- Internal sources:
  - Natural gasboiler CO_2 = 40 – 45 kg/m^2/y
  - Natural gas CHP CO_2 = 40 – 75 kg/m^2/y

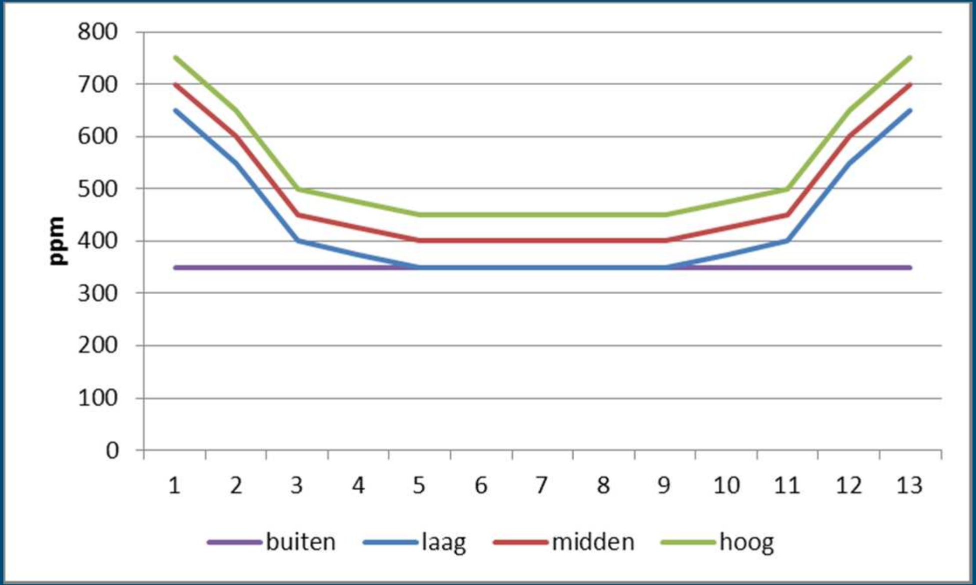
Costs CO_2

- Natural gasprice € 0,27/m^3
  - Burning 1 m^3 natural gas → 1.8 kg CO_2
- Gasboiler
  - In case all heath is used € 0.00 / kg CO_2
  - No heath use = € 0.15 / kg CO_2
- CHP
  - extra CO_2 by using CHP
    - 1 m3 natural gas → 35 -40 % electricty and 50 – 55 % heath
    - ~ double input ngas for same heath demand,
    - costs CO_2 depend on income out of electricity and price natural gas

CO_2 use the Netherlands

- External sources:
- RoCa3: CO_2 and heath from power plant by pipe
  - 5-7% in combustion gases
  - 23 kg/m^2/y
  - 68 kg/ha/h (50 – 100)
- OCAP: CO_2 from petrochemical industry by pipe
  - Pure CO_2
  - 39 kg/m^2/y
  - 116 kg/ha/h (100 – 300)
- Linde gas, Airliquide etc: liquide CO_2 by truck
  - 10 – 20 kg/m^2/y

Dutch CO_2 use:concentration + ventilation



- 3 CO_2 cases:
  - Supply avaibele CO_2 from boiler or CHP used for heating plus in summertime keep :

1. open air CO_2 level = Low (laag)
2. open air CO_2 level + 50 ppm = Middel (midden)
3. open air CO_2 level +100 ppm = High (hoog)

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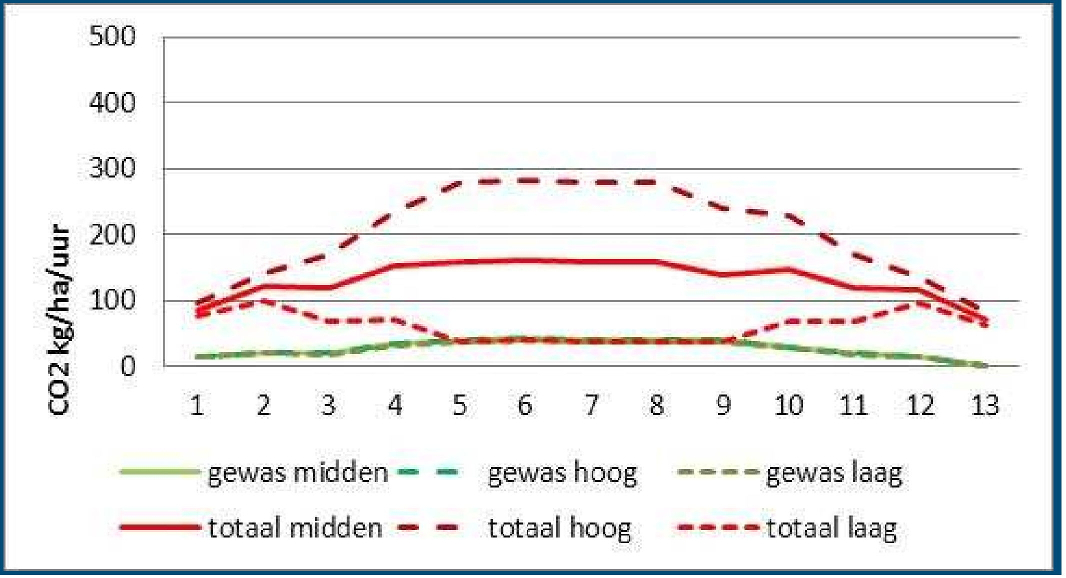
Dutch CO_2 use: concentration + ventilation

- CO_2 use crop and ventilation losses kg/m²/year

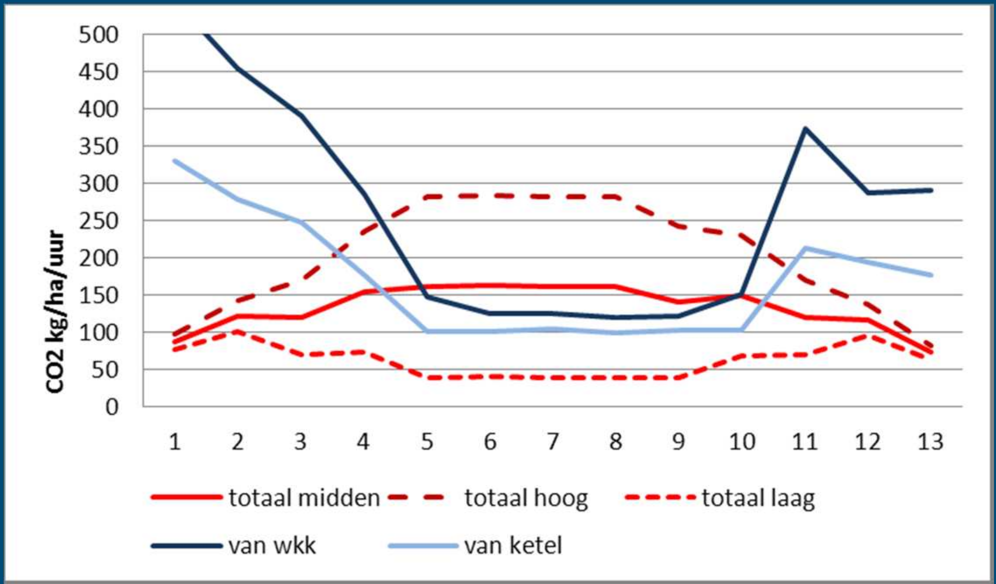
CO_2 kg/m²/year	crop	ventilation	total
Low (laag):	13.0	13.0	25.6
Middel (midden):	13.5	48.0	61.5
High (hoog):	13.8	83.3	97.1

→ Reduce ventilation



CO_2 use and supply in the Netherlands

- CO_2 from CHP or gasboiler
  - No heath waste



Ventilation losses

- Ventilation losses CO_2 = L (kg CO_2/ha/h)
  Depends on:
  - CO_2 level in greenhouse = C_{gh} (ml/m^3 = vppm)
  - CO_2 level in open air = C_{air} (ml/m^3 = vppm)
  - Ventilation exchange volume = VV (m^3/m^2/h)
  - Density CO_2 = D (kg/m3) 1.97 by 0 °C
  - 1.87 by 15 °C
  - 1.78 by 20 °C

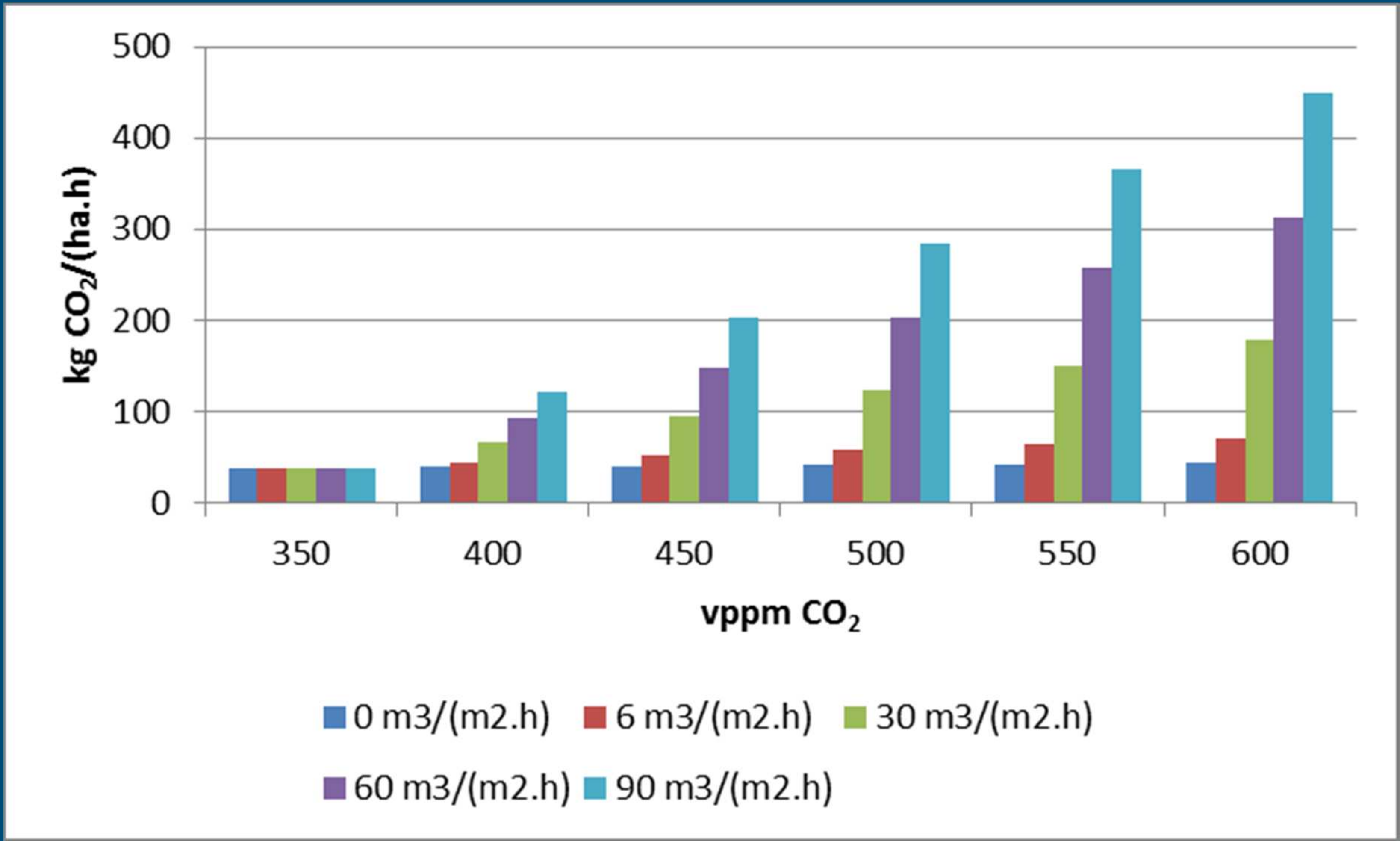
  $L = (C_{gh} - C_{air}) * 0.000001 * VV * 10000 * D$

  $= (C_{gh} - C_{air}) * 0.01 * VV * 1.8$

Ventilation losses

- Ventilation losses CO_2 = L (kg CO_2/ha/h)
  - $L = (C_{gh} - C_{air}) * 0.01 * W * 1.8$
  - L = (400 - 350) * 0.01 * 6 * 1.8 = 5.4
  - L = (450 - 350) * 0.01 * 6 * 1.8 = 10.8
  - L = (400 - 350) * 0.01 * 60 * 1.8 = 54
  - L = (450 - 350) * 0.01 * 60 * 1.8 = 108
- CO_2 efficiency (use plant/input)
  - Decrease by increasing ventilation

CO_2 supply and ventilation



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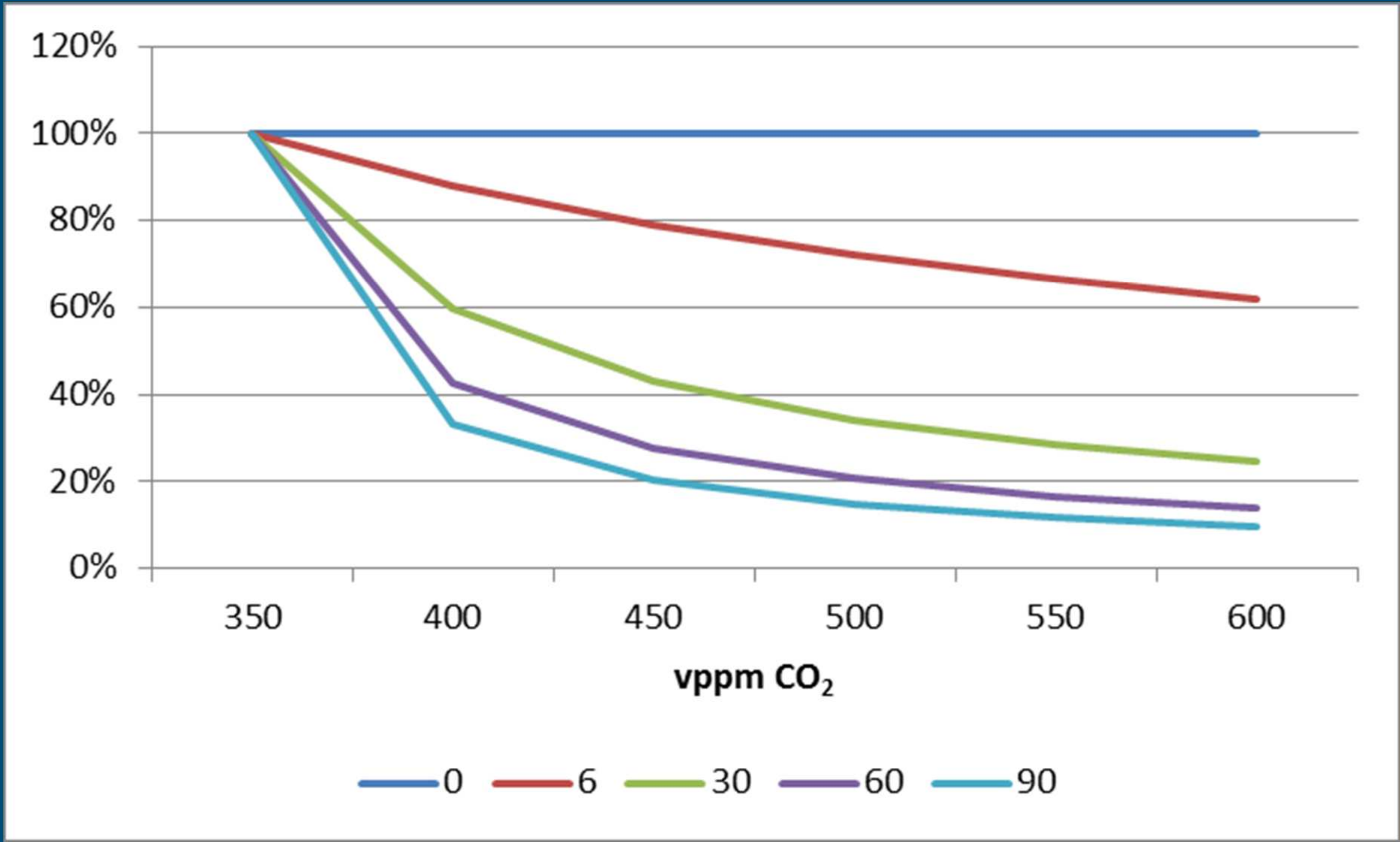
CO_2 efficiency (use plant/input)



Ventilation

- Ventilation depends on:
  - Window opening
  - Wind speed

- Ventilation necessary
  - In case of high radiation → temperature to high
  - Artificial lighting → temperature and humidity to high
  - In case of high humidity > 80 – 85 %

Economics:

- Crop uptake (kg/(ha.h)

	350 ppm	400 ppm	450 ppm
150 W/m_2	27.1	28.4	29.4
200 W/m_2	34.6	36.3	37.6
250 W/m_2	39.8	41.8	43.4
300 W/m_2	43.4	45.8	47.6

- Ventilation losses (kg/

	350 ppm	400 ppm	450 ppm
6 $m^3/m^2/h$	0	5.4	10.8
30 $m^3/m^2/h$	0	27.0	54.0
60 $m^3/m^2/h$	0	54.0	108.0
90 $m^3/m^2/h$	0	81.0	162.0

Economics

- Costs:
- (Crop uptake + Ventilation losses) * CO_2 price

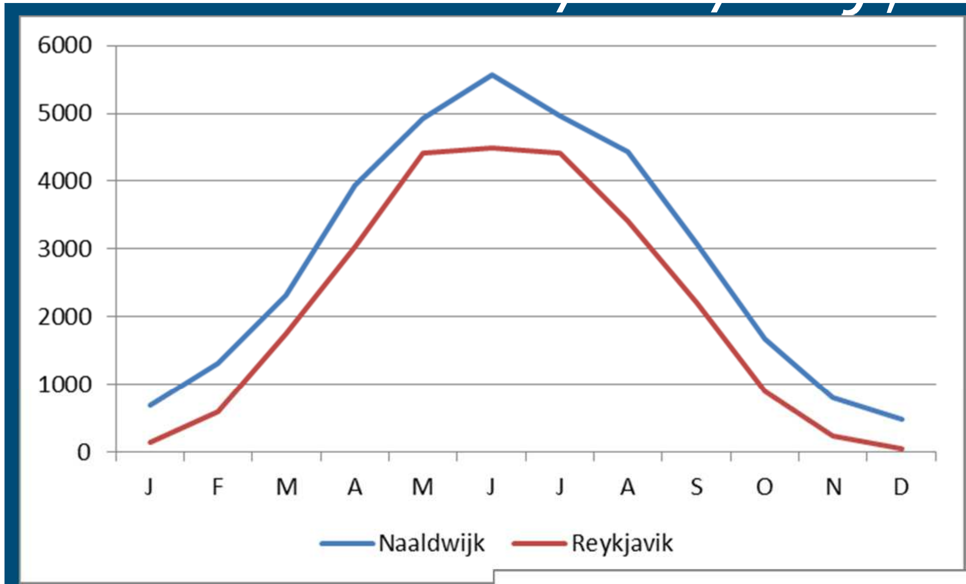
- Turn over:
  - $(100/D_c) * (Dr_f) * 0{,}68 *$ kg CO_2 uptake * product price

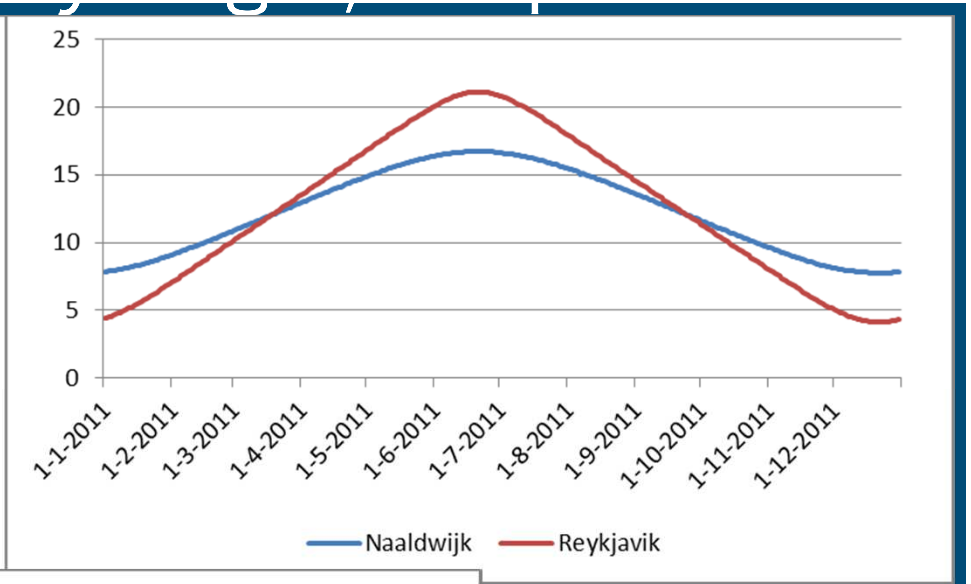
Economics

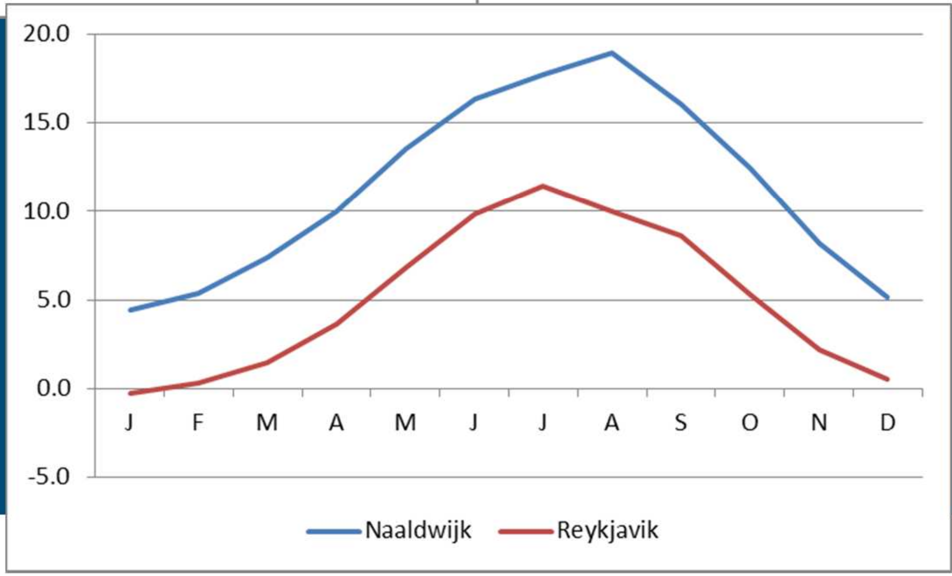
- Example:
- 300 W/m² 350 ppm → 450 ppm:
- Turn over:
  - → 4,2 kg extra CO_2 uptake /ha/h
  - → 0.68 * 4.2 = 2,85 kg extra dry matter
  - → 2,85 kg * 100/6 * 60% = 28.6 kg product /ha/h
- Costs
  - (4.2 kg CO_2 + ventilation losses) * CO_2 price

  - To get benefit reduce the ventilation
  - Balance between CO_2 and ventilation

Radiation Wh/m2/day, day lenght, temperature







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CO_2 uptake and humidity control

- high humidity in greenhouse:
  - Stoma will close
  - Lower CO_2 uptake
  - Assimilation will decrease
  - High risk diseases

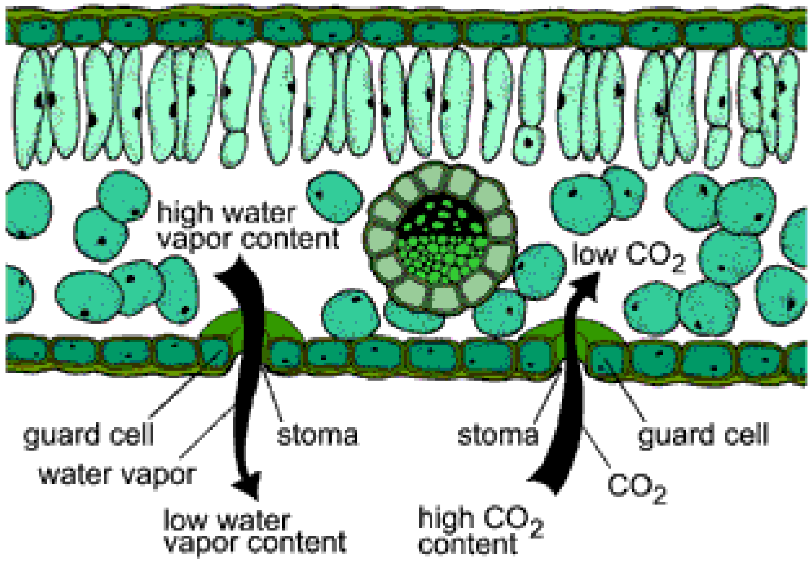


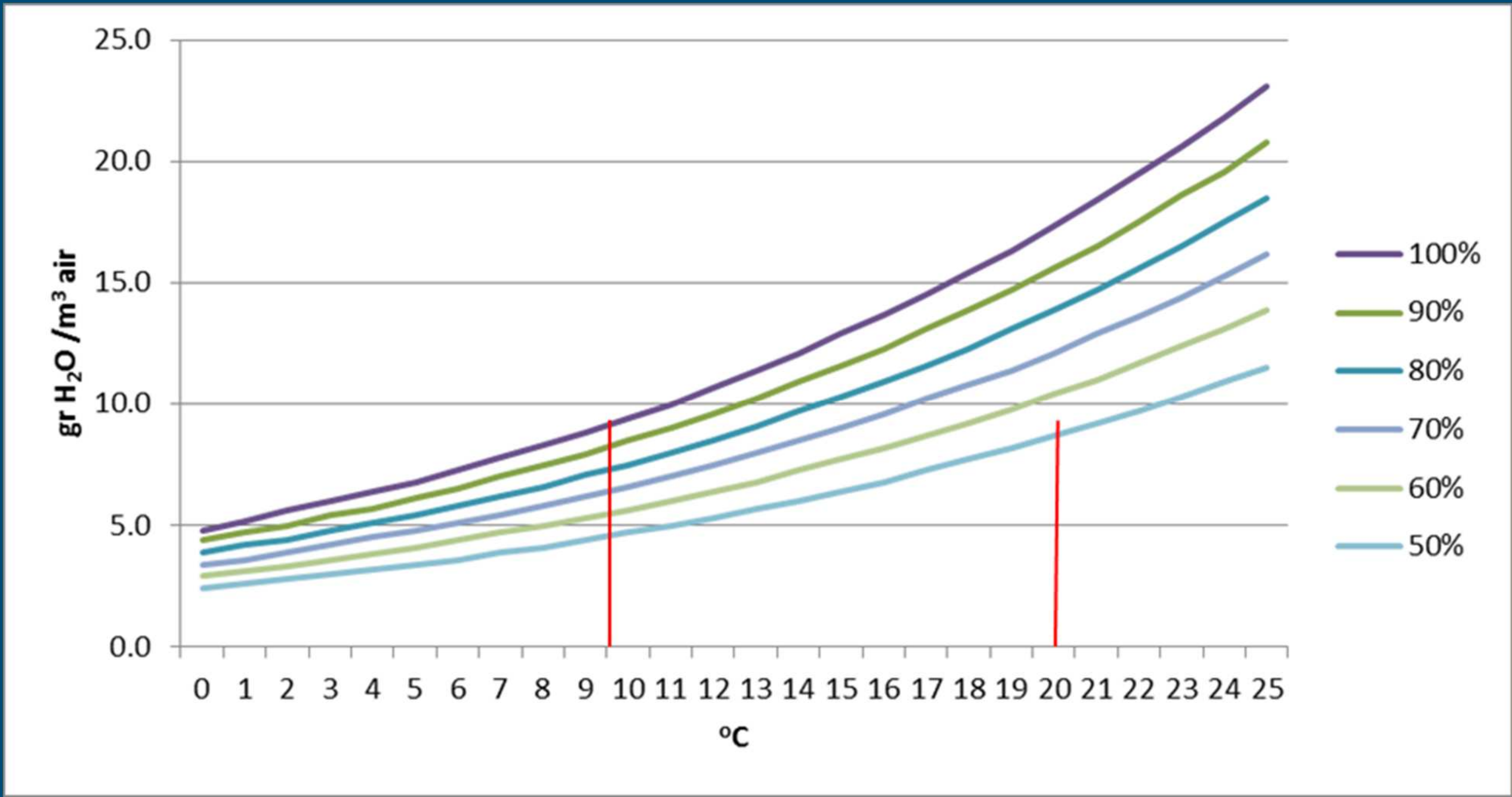
Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

Humidity control by controlled ventilation

- Artificial light
  - → crop temperature increase
  - → transpiration increase
  - → humidity increase

- Controlled ventilation
  - Colder outside air intake → RH will decrease
  - Less CO_2 losses → higher CO_2 efficiency

Humidity control by controlled ventilation



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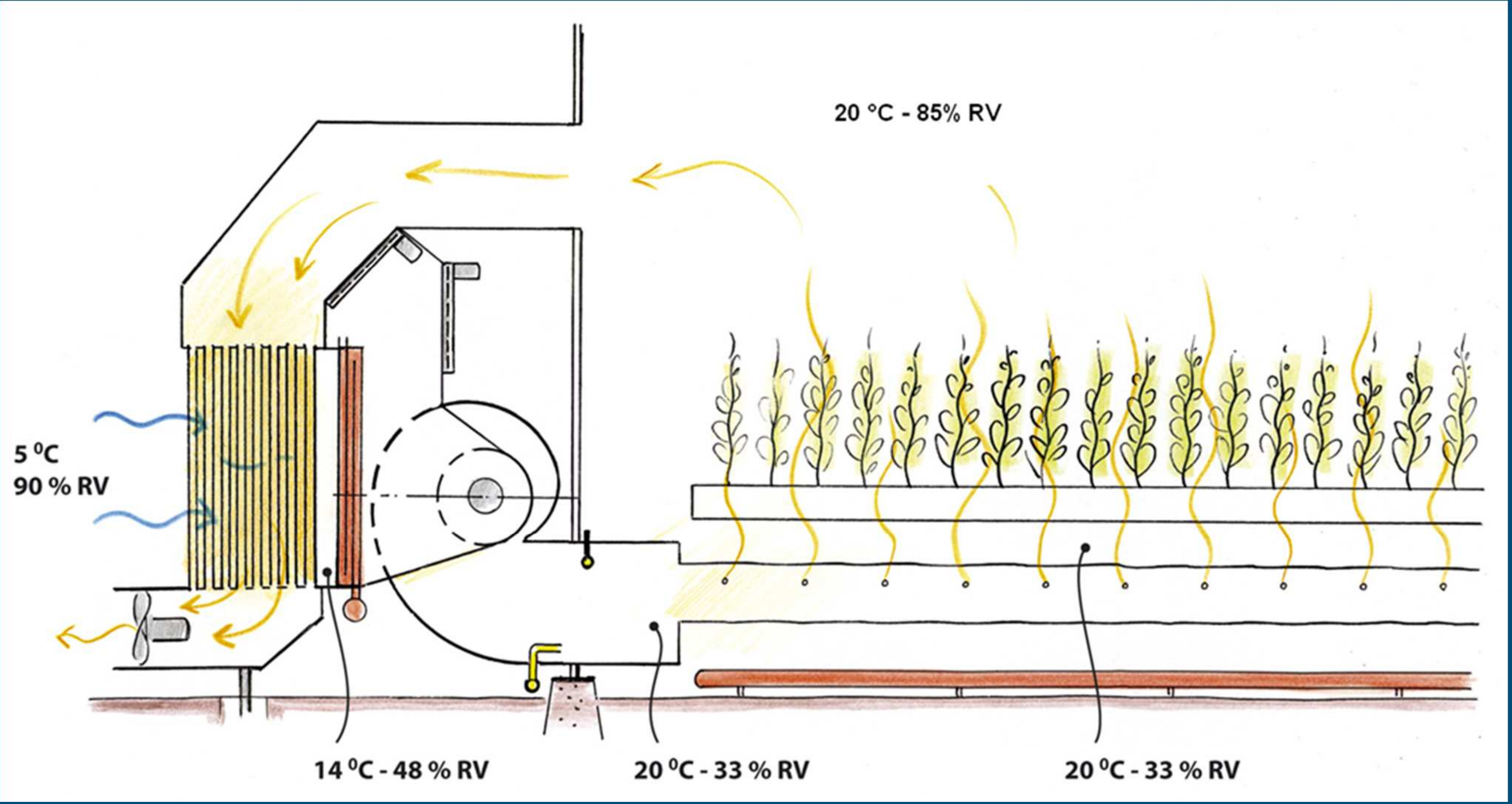
Controlled ventilation



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Air intake and ventilation tubes

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Results controlled ventilation

- Energy saving up to 40 %
- Higher CO_2 level in greenhouse with lower CO_2 use
- In tomato crop 2 kg/m2/y extra production
- Less diseases

Questions?

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Knowledge

- Literature:
  - Effects of CO_2 concentration on photosynthesis, transpiration and production of greenhouse fruit vegetable crops. E.M. Nederhoff
  - CO_2 dosering in de biologische glastuinbouw, P.C.M. Vermeulen
  - CO_2 in de glastuinbouw, Dr. Ir. G.A. van den Berg
  - www.glastuinbouw.wur.nl
  - www.kasalsenergiebron.nl
  - www.energiek2020.nl
- Financers:

Ministerie van Economische Zaken, Landbouw en Innovatie

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