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Technical Note

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Memorandum of Understanding 19071/05/NL/CP

MELiSSA Food Characterization: phase 1

Technical note 98.4.22

Preliminary trade-off of crop cultivars: Test performances for Bench Test 2

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List of Abbreviations

BT1 / BT2:	Bench Test 1 / Bench Test 2
DI:	Deionised
DM:	Dry Matter
DW:	Dry Weight
EC:	Electrical Conductivity
FID:	Flame Ionization Detector
FW:	Fresh weight
GC:	Gas Chromatograph
HZPC:	Consultant for hydroponic potato growth
IPL:	Institut Paul Lambein
IRGA:	Infra Red Gas Analyser
LA:	Leaf area
LC-MS/MS:	Liquid chromatography-mass spectrometry
NCER:	Net Carbon Exchange Rate
NFT:	Nutrient Film Technique
OD:	Optical Density
RH:	Relative Humidity

SEC-1 /SEC-2:	Sealed Environment Chambers
T:	Temperature
TDF:	Total Dietary Fibre
TGA:	Total glycoalcaloids
TN:	Technical Note
UBern:	University of Bern
UCL:	Université Catholique de Louvain
UGent:	Ghent University
UNapoli:	University of Naples
UoGuelph:	University of Guelph
USDA:	United States Department of Agriculture

1 Introduction

This second issue of TN 98.4.2 (TN 98.4.22) summarizes the results as obtained with the plant bench test measuring plan as defined in TN 98.4.12. Timing of the measurements and layout of the cultivars in the bench test setup are included for each setup at the start of the respective sections of the document.

This document presents final data for the last 2 cultivars of durum wheat (as planned in TN 98.4.12) (UoGuelph) and final plant growth data and nutritional analysis of the harvest for the same 4 cultivars as grown in bench test 1 (as planned in TN 98.4.12) (bread wheat at UBern, potato at UGent and UCL).
The soybean UNapoli bench tests2 includes 4 cultivars, another cultivar was chosen to replace the cultivar that didn't germinate under the planned conditions of the bench tests.

Durum wheat culture in a sealed growth environment was characterised by harvests with yields well above recorded field data, with a slightly longer culture period.

In bench test 2, bread wheat culture displayed normal growth and ear formation. Development and especially kernel ripening took longer than expected.
Potato culture started from in vitro plants had sufficient tuberisation induction, plant death was observed but depending on the setup (UGent or UCL), cultivars were affected to a different degree, and at a rather late stage Plant pathogen presence was confirmed in the nutrient solution, which are typical for non-optimally growing plants (opportunistic infections).

Soybean culture resulted in rapid pod formation

The measurement data as reported on a monthly basis in progress files is compiled on a companion CD. Depending on the respective setup hardware, time-lapse logging data is included.

2 Bread wheat (UBern)

2.1 Experimental Layout

2.1.1 Measuring Plan

Tab. 1 UBern - Timing of the measurements

Measurements	**Timing**
T, Relative humidity	Automatic
Chamber CO_2	Once a week
Air temperature at gully level	Weekly min and max
Plant development	Once a week
Temperature of the nutrient solution	Once a week
EC Electrical conductance	Once a week (twice if necessary at full vegetative development stage)
pH	Once a week (twice if necessary at full vegetative development stage)
Flow rate	At start, after flow adjustment, at harvest
Nutrient solution (nutrient content)	Every 4 weeks, before and after exchange of the solution
Biomass	After the harvest
Kernels nutrient content	After the harvest

Plant development

Assessment for one representative plant per Rockwool block of 15 plants (a-d: 4 blocks per gully)

1. height
2. number of tillers
3. number of leaves on the main shoot
4. number of ears
5. number of grains per ear
6. leaf senescence during grain ripening

Recording of time-points of initiation for each the representative plant

- stem elongation
- ear emergence
- anthesis
- ear yellowing

Nutrient solution analysis

K, Ca, Mg, N, P, Fe, Zn, Cu, Mn, Ni,

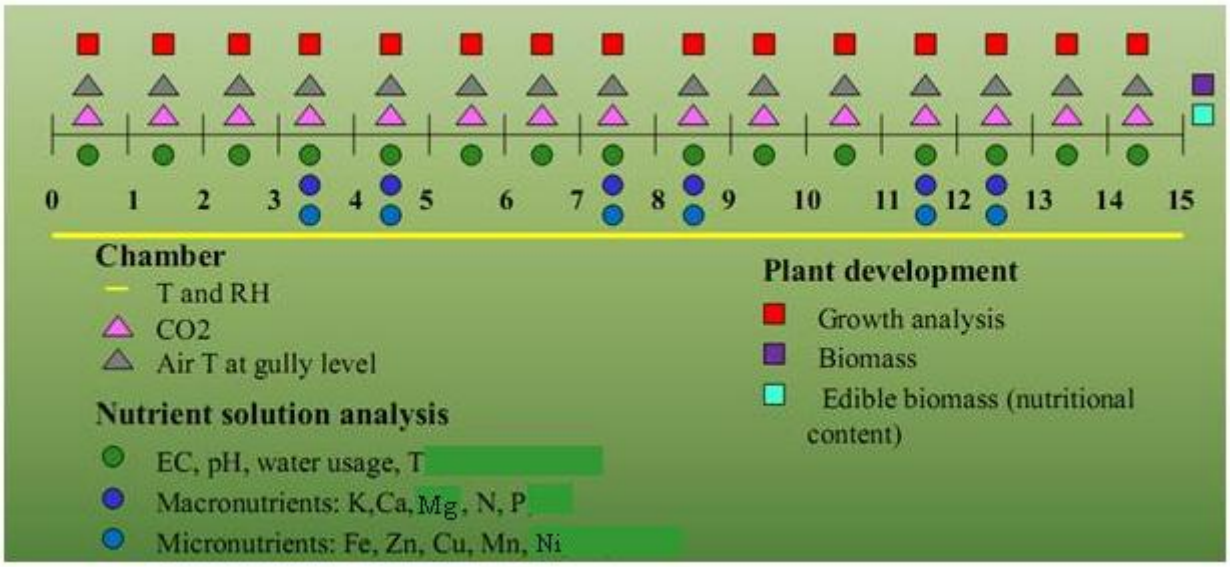


Fig. 1 UBern - Measurement plan

2.1.2 Setup

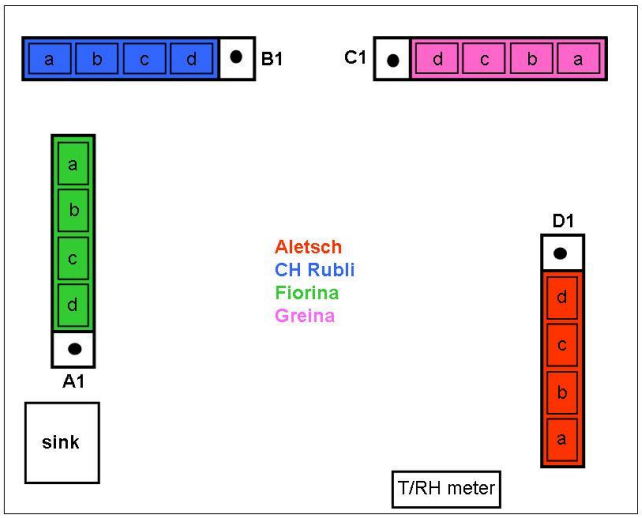


Fig. 2 UBern - Chamber Setup

Plant density was 60 plants per gully of 1m x 19cm width.
Shelf width is 60cm, 1 gully per shelf makes 60 plants / 0.6 m^2.
Corresponds to 100 plants / m^2.

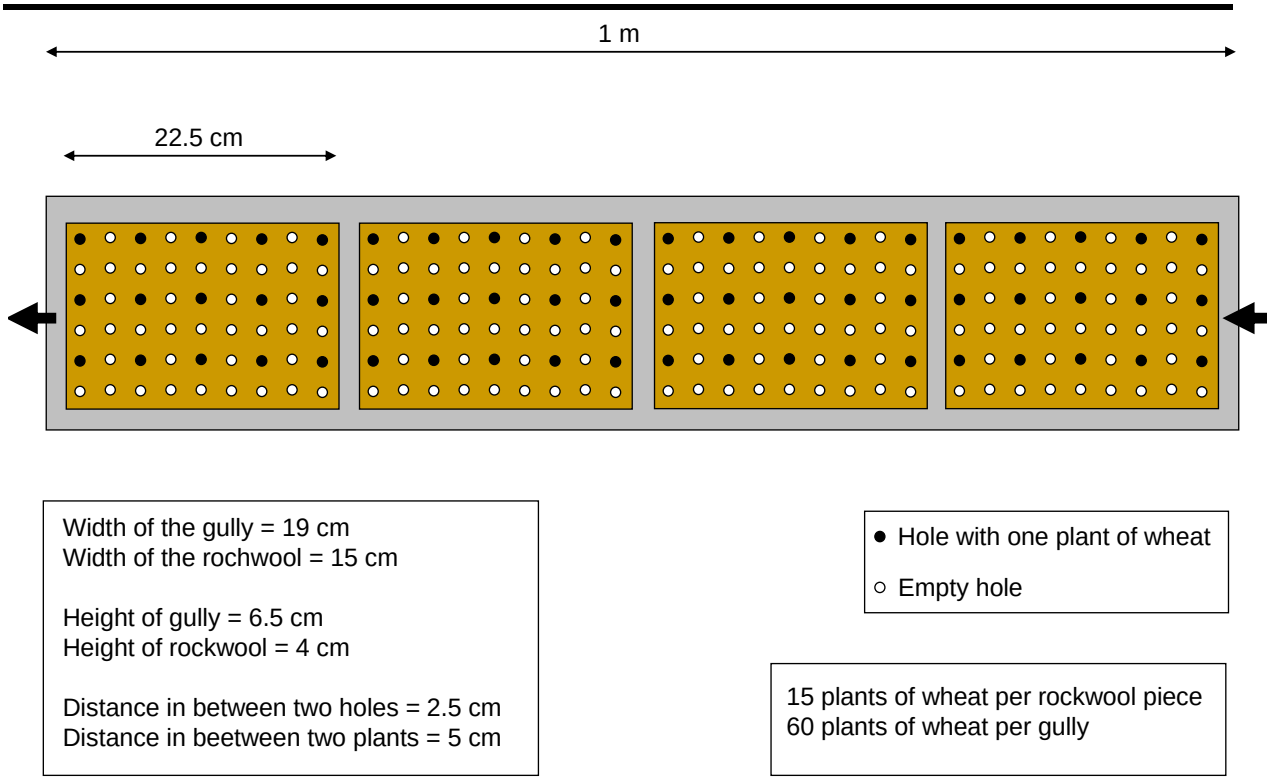


Fig. 3 UBern - Scheme of the gully and the Rockwool

2.2 Growth environment follow-up

2.2.1 Settings

Tab. 2 UBern - Settings

Photoperiod	14h 8:00 – 22:00
Light intensity	200- 450µmol/m²/s
Room temperature	22°C (day), 18°C (night)

2.2.2 Chamber T/RH evolution

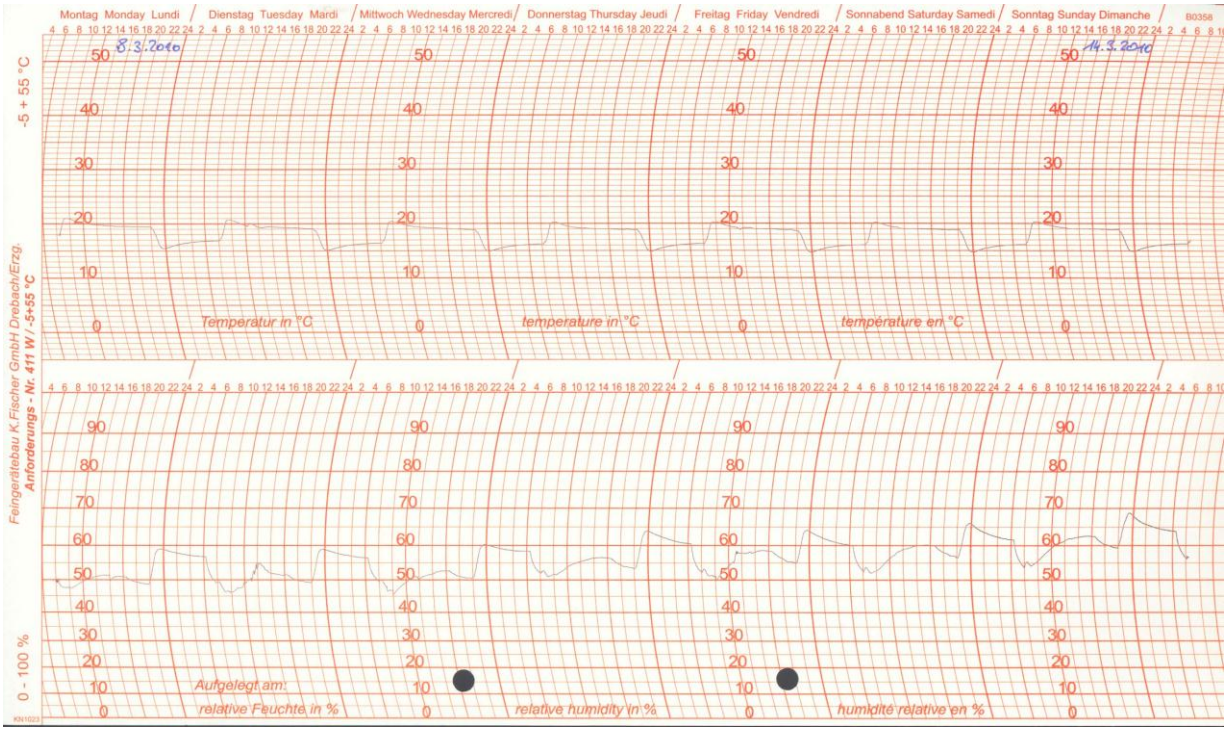


Fig. 4 UBern - Chamber T / RH 8.03.2010 – 14.03.2010

Humidity and T were measured at the location indicated (Fig. 2) the hygrometer was positioned at the same height as the gullies.
The temperature was stable at 20+-1 degree during the day, with a night T at 16+-1degree
Humidity increased during the night, and decreased during the day. The building central air renewal system operates from 06:30 till 22:00.
Humidity was overall higher as the plants developed (Fig. 4 / Fig. 5).
Extra dehumidification was installed to avoid exceeding chamber safety settings.
Tab. 3 shows temperature distribution in the room, according to the setup of thermometers in Fig. 6. Temperature was within 2.5 degrees as a function of space and time.

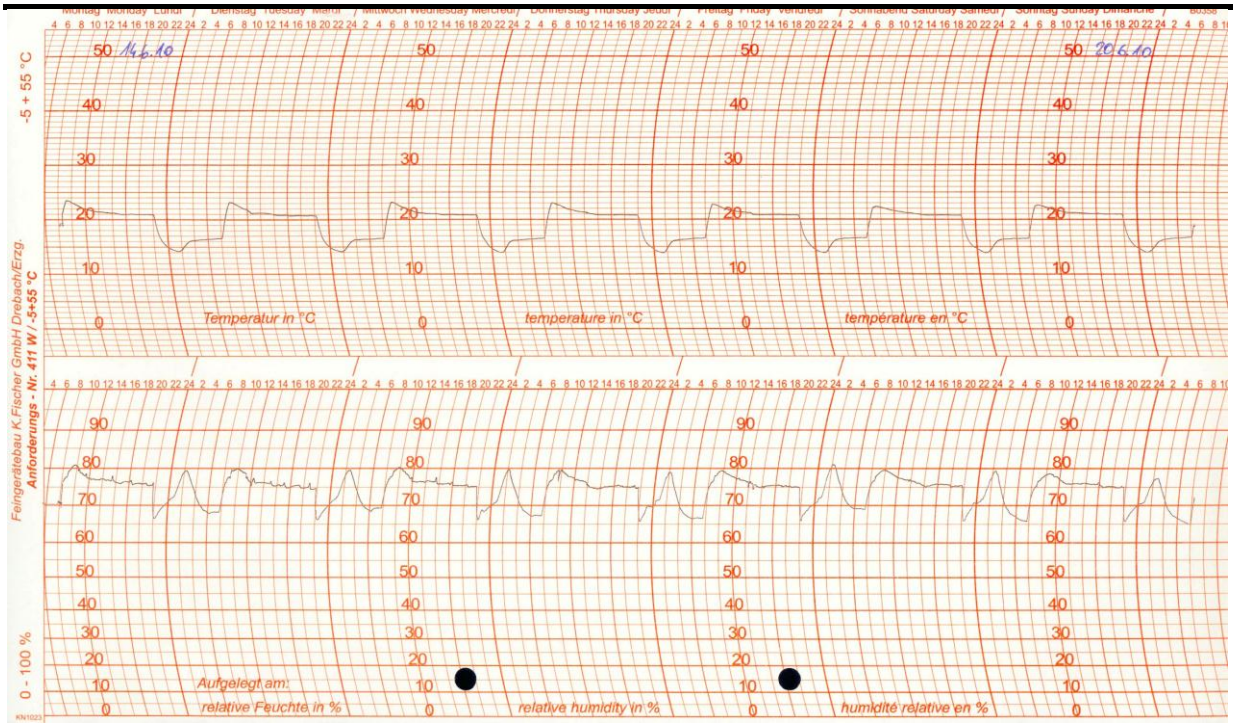


Fig. 5 UBern - Chamber T / RH 14.6.2010 – 20.6.2010

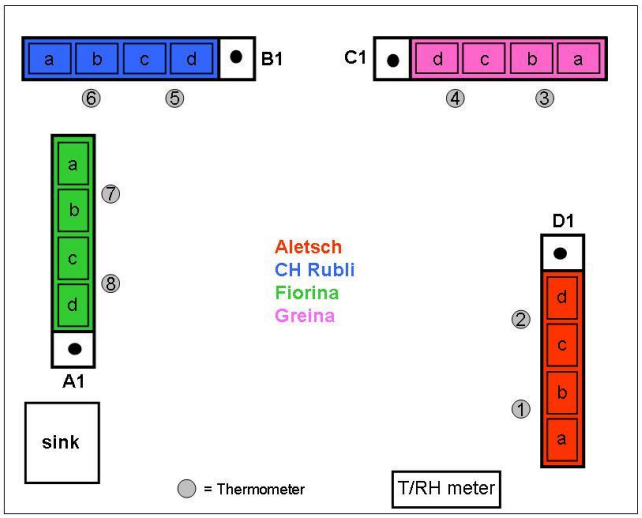


Fig. 6 UBern - Thermometer placement

Tab. 3 UBern - Temperature at gully level March

Date	Time	Therm. 1	Therm. 2	Therm. 3	Therm. 4	Therm. 5	Therm. 6	Therm. 7	Therm. 8
02.03.2010	11:00	22	22	23.5	22	22	22.5	23	23
09.03.2010	11:00	22	22	23	22.5	21.5	22	22.5	22.5
16.03.2010	11:20	22	22	23	22	21	22	22.5	22.5
23.03.2010	10:45	21	21.5	23	22.5	21.5	21.5	22.5	22
30.03.2010	10:40	21	21.5	23	22	21.5	21.5	22	21
Date	Time	Therm. 1	Therm. 2	Therm. 3	Therm. 4	Therm. 5	Therm. 6	Therm. 7	Therm. 8
02.03.2010	11:00	22	22	23.5	22	22	22.5	23	23
09.03.2010	11:00	22	22	23	22.5	21.5	22	22.5	22.5
16.03.2010	11:20	22	22	23	22	21	22	22.5	22.5
23.03.2010	10:45	21	21.5	23	22.5	21.5	21.5	22.5	22
30.03.2010	10:40	21	21.5	23	22	21.5	21.5	22	21
Date	Time	Therm. 1	Therm. 2	Therm. 3	Therm. 4	Therm. 5	Therm. 6	Therm. 7	Therm. 8
02.03.2010	11:00	22	22	23.5	22	22	22.5	23	23
09.03.2010	11:00	22	22	23	22.5	21.5	22	22.5	22.5
16.03.2010	11:20	22	22	23	22	21	22	22.5	22.5
23.03.2010	10:45	21	21.5	23	22.5	21.5	21.5	22.5	22
30.03.2010	10:40	21	21.5	23	22	21.5	21.5	22	21

Tab. 4 UBern - Temperature at gully level June

Date	Time	Therm. 1	Therm. 2	Therm. 3	Therm. 4	Therm. 5	Therm. 6	Therm. 7	Therm. 8
01.06.2010	10:35	22	23	24	23	22	22.5	22.5	22
09.06.2010	10:55	22	23	23.5	23	22.5	23	23	22
15.06.2010	10:55	22.5	23	24	23.5	23	23	23	22.5
22.06.2010	10:45	22	23	24	23.5	23	23	23	22.5
29.06.2010	11:15	22	22.5	24	23.5	23	22.5	23	22

Tab. 5 UBern - Night T / max. day T

Date		Therm. 1	Therm. 2	Therm. 3	Therm. 4	Therm. 5	Therm. 6	Therm. 7	Therm. 8
02.03.2010	T max	23.5	23.5	24	23	23	23.5	24	23.5
	T min	16	16	16	16	16	15	16	17
09.03.2010	T max	23	23	24	23.5	22	23	23.5	23
	T min	16.5	16	16.5	16	16	16.5	16	17
16.03.2010	T max	23	23	24.5	24	22.5	24	23.5	23
	T min	16	16	16	16	16	16	16	17
23.03.2010	T max	22.5	23	24	23.5	23.5	24	23	23
	T min	16	16	16	16	16	16	15.5	16

30.03.2010	T max	23.5	22.5	24	23	23.5	23.5	23	22.5
	T min	15	15	15	15.5	15.5	15	15	16
Date		**Therm. 1**	**Therm. 2**	**Therm. 3**	**Therm. 4**	**Therm. 5**	**Therm. 6**	**Therm. 7**	**Therm. 8**
02.03.2010	T max	23.5	23.5	24	23	23	23.5	24	23.5
	T min	16	16	16	16	16	15	16	17
09.03.2010	T max	23	23	24	23.5	22	23	23.5	23
	T min	16.5	16	16.5	16	16	16.5	16	17
16.03.2010	T max	23	23	24.5	24	22.5	24	23.5	23
	T min	16	16	16	16	16	16	16	17
23.03.2010	T max	22.5	23	24	23.5	23.5	24	23	23
	T min	16	16	16	16	16	16	15.5	16
30.03.2010	T max	23.5	22.5	24	23	23.5	23.5	23	22.5
	T min	15	15	15	15.5	15.5	15	15	16

2.2.3 Chamber CO_2 level

An IRGA system was used to monitor chamber CO_2 level. Ambient air is supplied to the chamber.

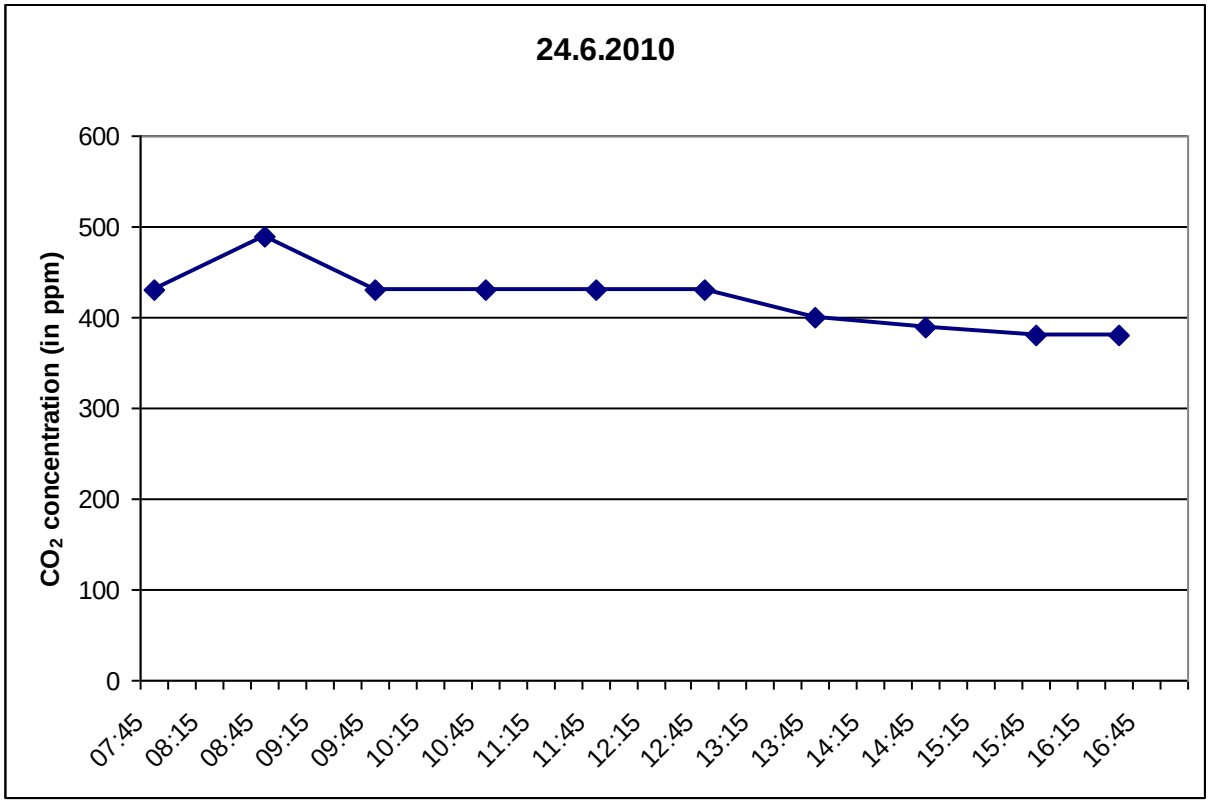


Fig. 7 UBern - Chamber CO_2 level

CO_2 concentration rises during the night, when the conditioned outside air supply system to the chamber is not active (22h-6:30h), and decreases to ambient levels and below during the day, as measured in the middle of the room.

2.2.4 Nutrient Solution Environment

Tab. 6 UBern - Nutrient solution environment

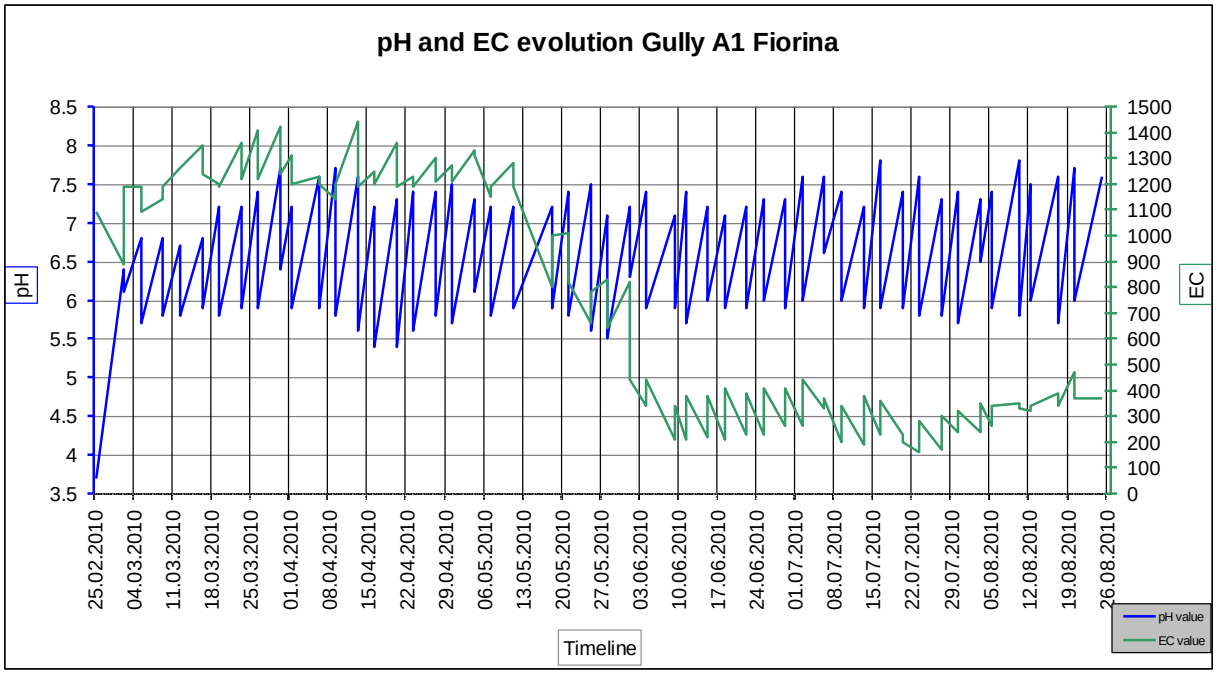
Change of nutrient solution	once per month
NFT layer thickness	approximately 0.5 cm
NFT nutrient solution flow	2 l/min Initial setting
Gully inclination	1%

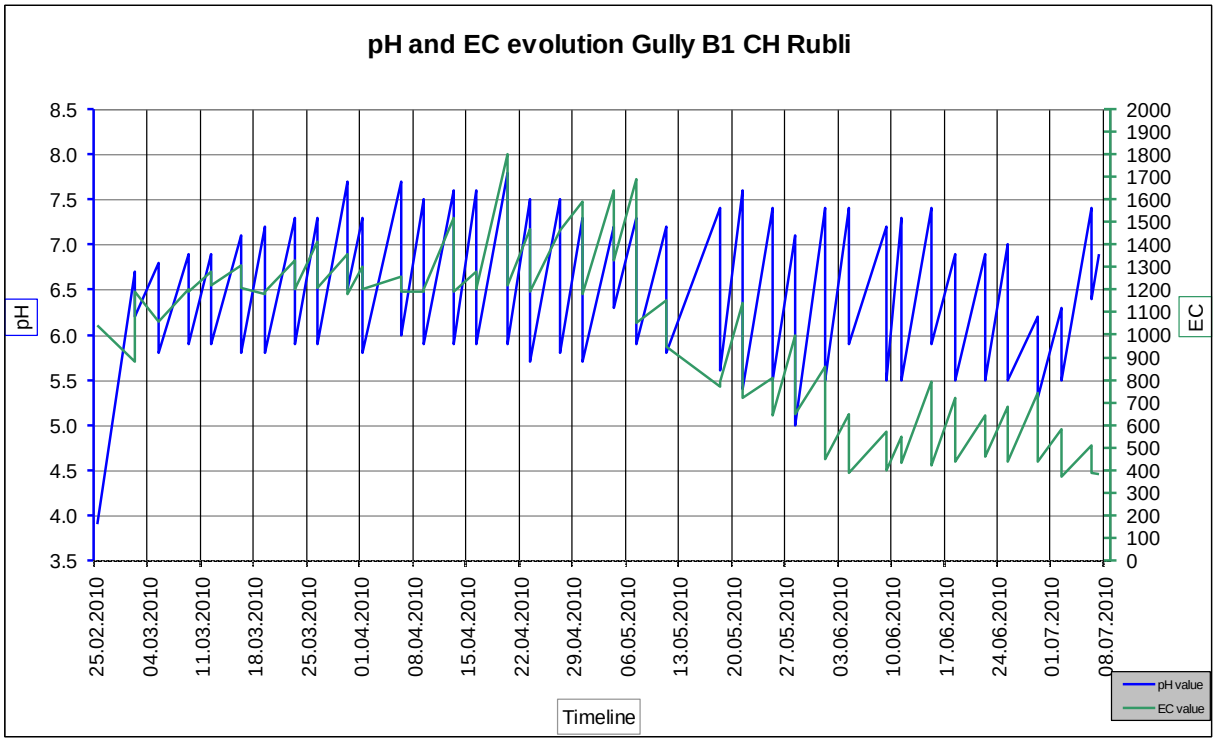
Tab. 7 UBern - NFT nutrient solution flow adjustments

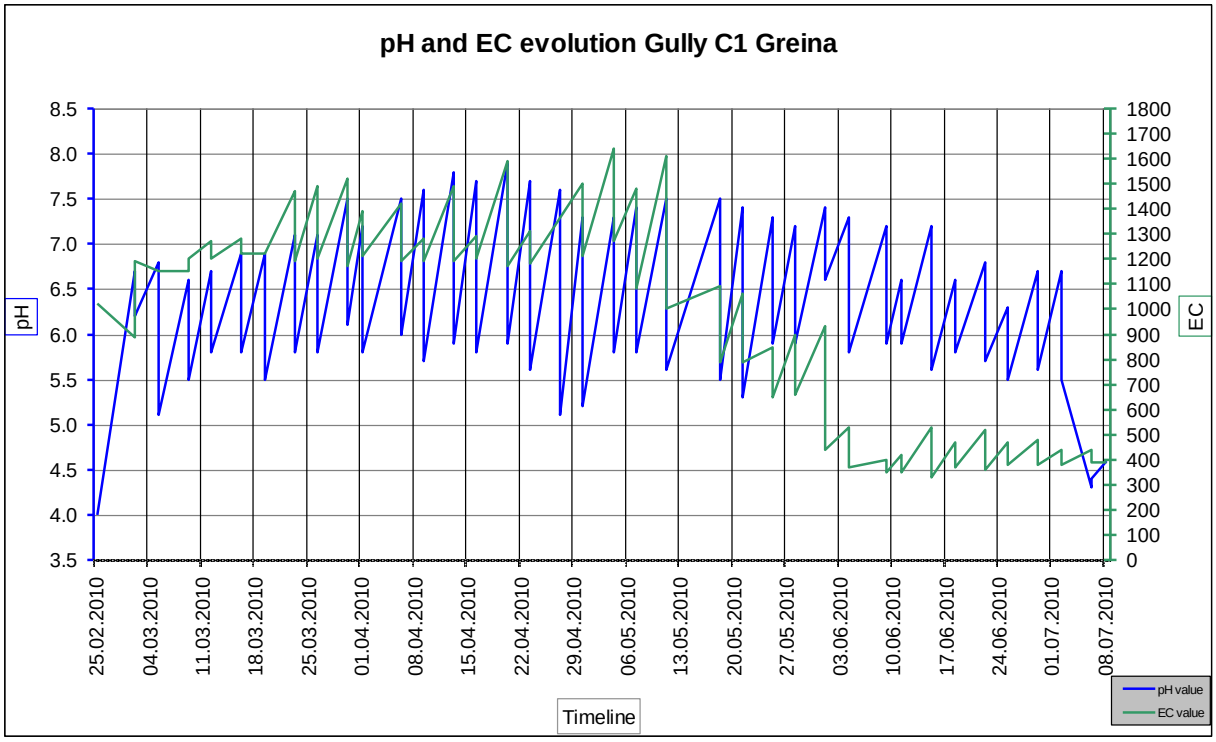
	Fiorina Gully A1	**CH Rubli Gully B1**	**Greina Gully C1**	**Aletsch Gully D1**
23.02.2010	2 L/min	2 L/min	2 L/min	2 L/min
Before 30.03.2010	2.8 L/min	2 L/min	1.8 L/min	4 L/min
After 30.3.2010	2 L/min	2.8 L/min	2 L/min	3.6 L/min
Before 04.05.2010	0.5 L/min	0.3 L/min	1 L/min	1.4 L/min
After 04.05.2010	2 L/min	2 L/min	1.7 L/min	1.3 L/min
Before 01.06.2010	0.7 L/min	0.2 L/min	1.5 L/min	200 L/min
After 01.06.2010	2 L/min	1 L/min	1.7 L/min	1.3 L/min
Before 06.07.2010	0.26 L/min			0.6 L/min
After 06.07.2010	1.7 L/min			1.3 L/min
Harvest 07.07.2010		0.2 L/min		
Harvest 08.07.2010			0.7 L/min	
Before 03.08.2010	0.5 L/min			
After 03.08.2010	1.1 L/min			
Harvest 04.08.2010				0.2 L/min
Harvest 25.08.2010	0.5 L/min			

2.2.5 pH and EC evolution

The pH rise of the nutrient solutions was compensated by acid additions (HNO_3 at beginning and H_2SO_4 after the flowering of the ears). pH fluctuated between 5.5 and 7.5 between successive reset time points.
EC of the nutrient solution was reset to 1200µS/cm with stock solution and distilled water, the EC of the nutrient solution was step-wise decreased after flowering to reach an EC of 400 µS/cm.
Nutrient solution changes 30 March (all gullies), 4 May (all gullies), 1 June (all gullies), 6 July (gullies A1 and D1) and 3 August (gully A1).







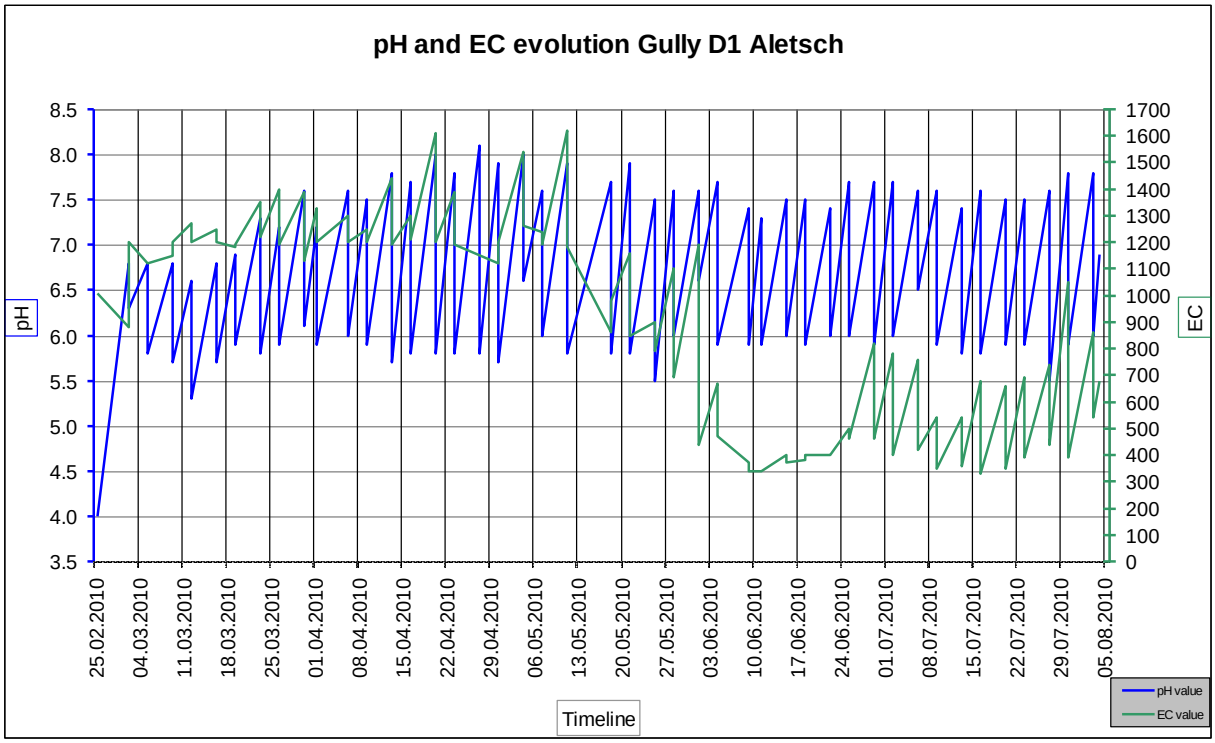


Fig. 8 UBern - pH / EC (µS/cm) evolution per gully/cultivar

2.2.6 Plant water usage

The total amount of liquid added to the 4 individual gully systems during the complete crop developmental period is shown in Fig. 9.

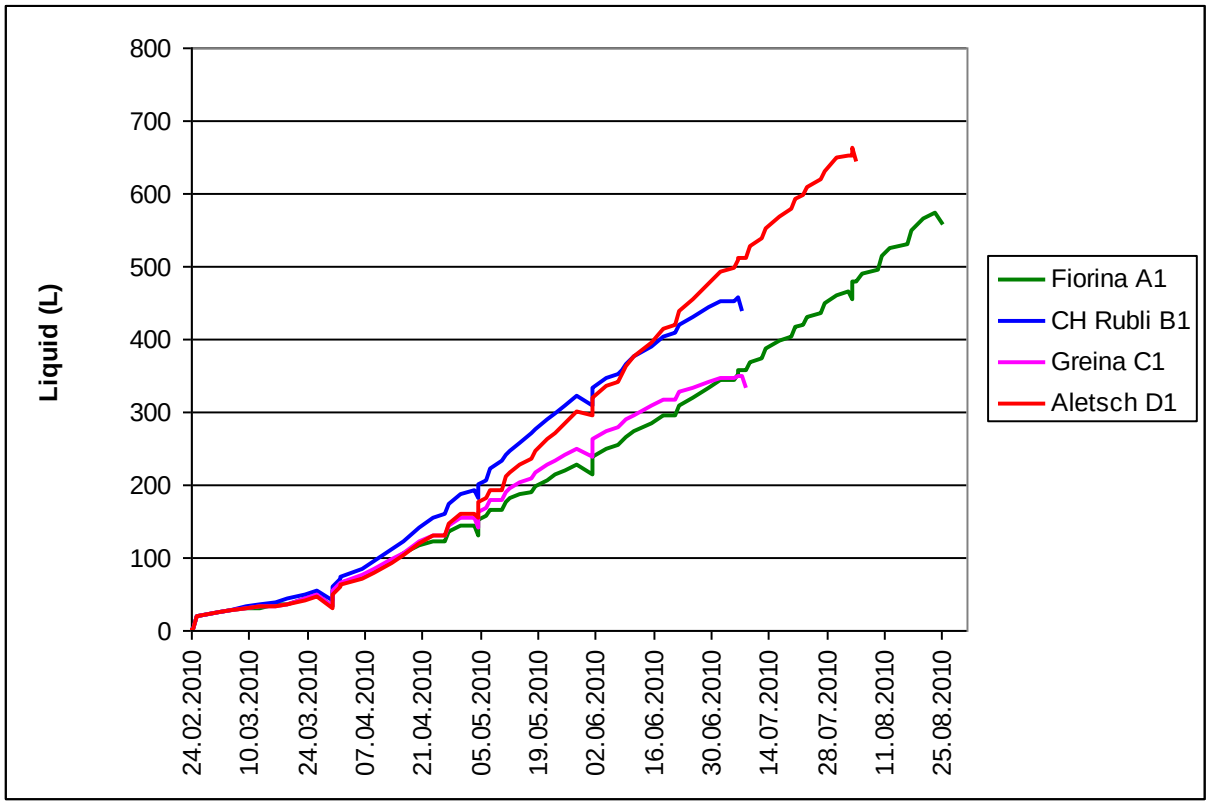


Fig. 9 UBern - Amount of liquid

Plant water usage was determined as starting nutrient solutions (20l) minus the amount left in the system at the time of solution change and harvest, plus the water added to adjust the liquid level, plus EC replenishment solution, plus the acid added to adjust pH.

2.2.7 Nutrient solution T

No nutrient solution cooling was foreseen, Fig. 10 shows temperature average of 25.5 degrees, chamber atmosphere T settings being 22 during the day and 18 degrees during the night.

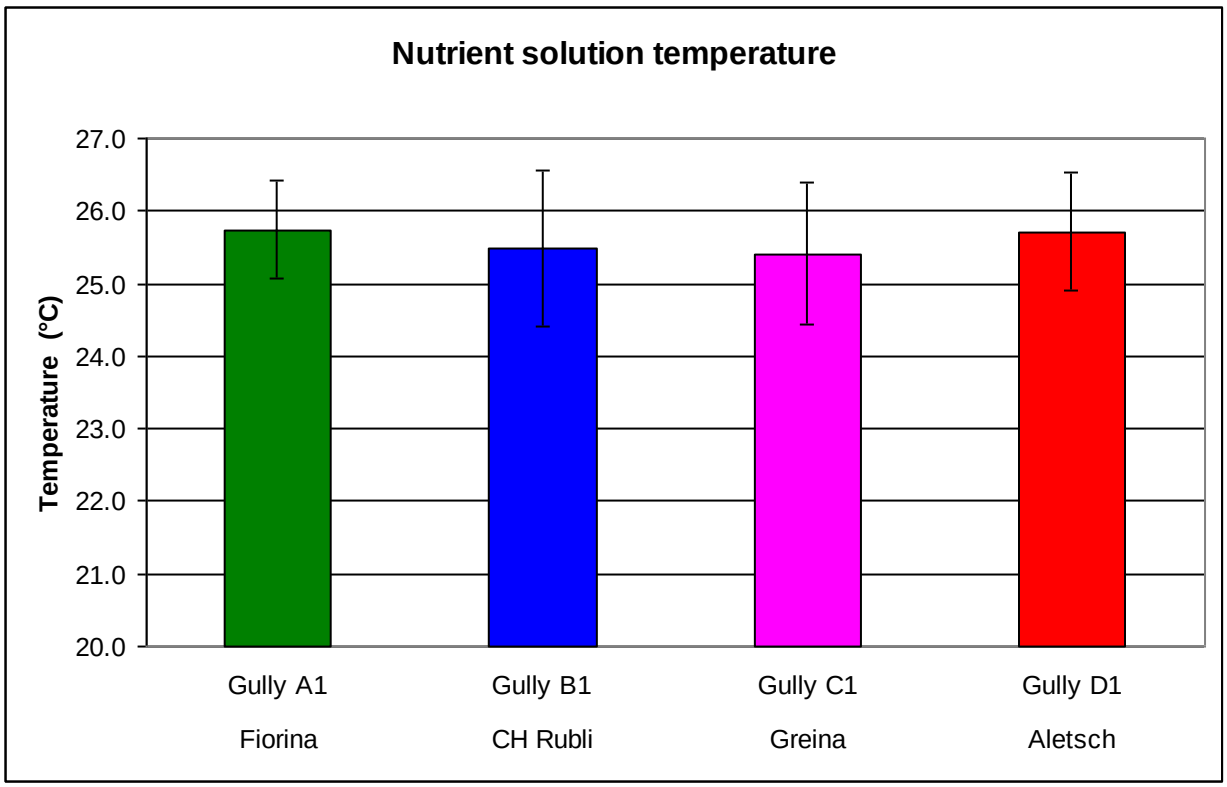
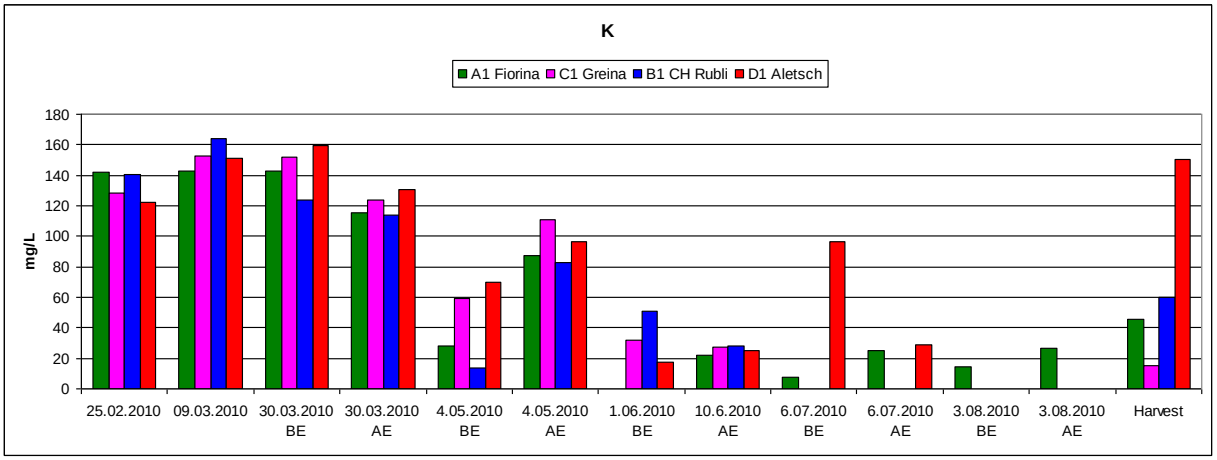
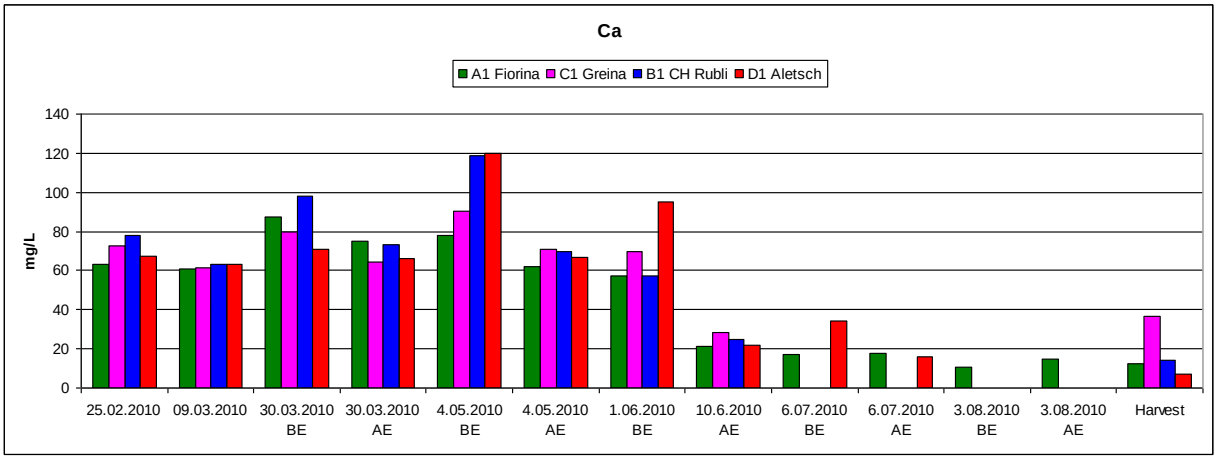
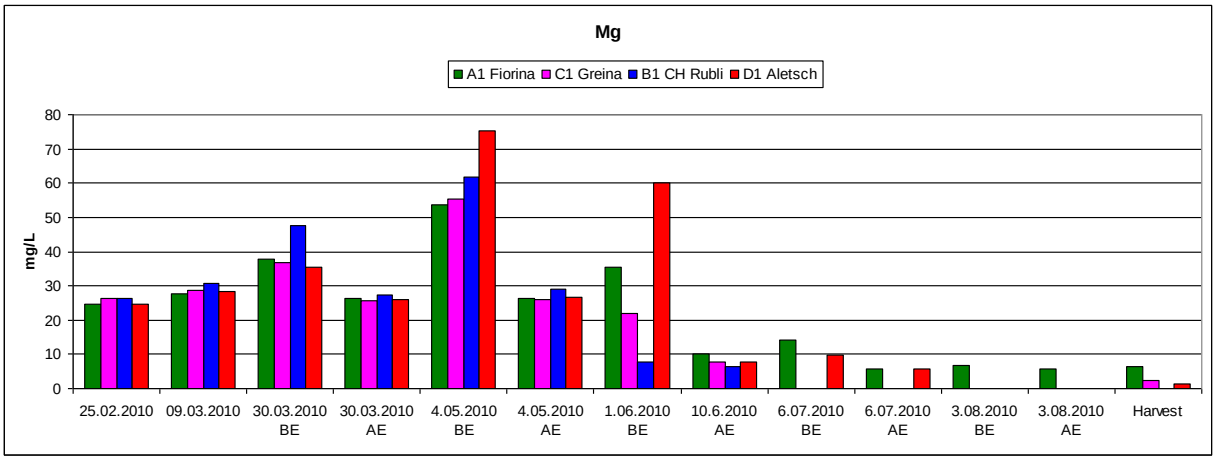


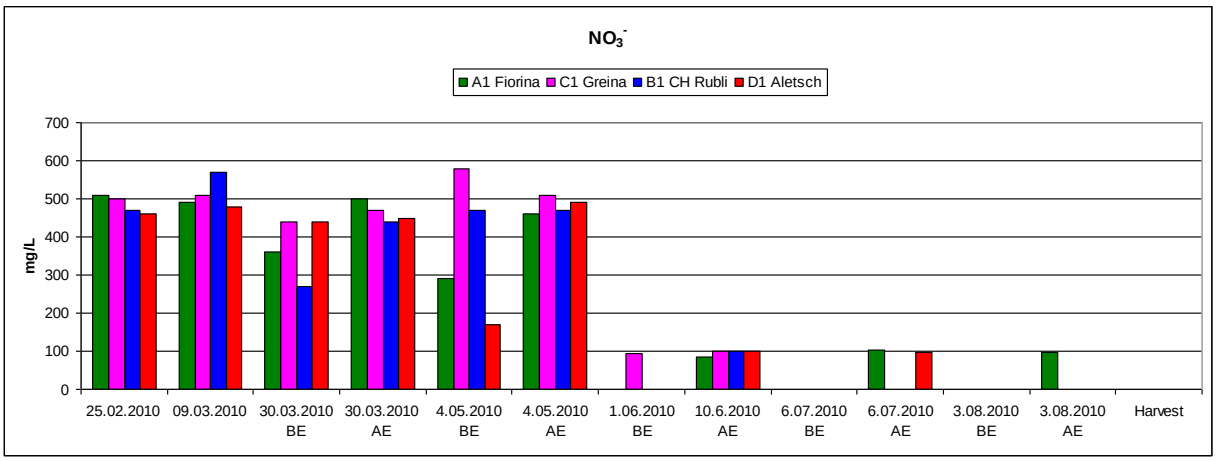
Fig. 10 UBern - Nutrient solution T 25.02.2010 – 25.8.2010

2.2.8 Nutrient solution analysis









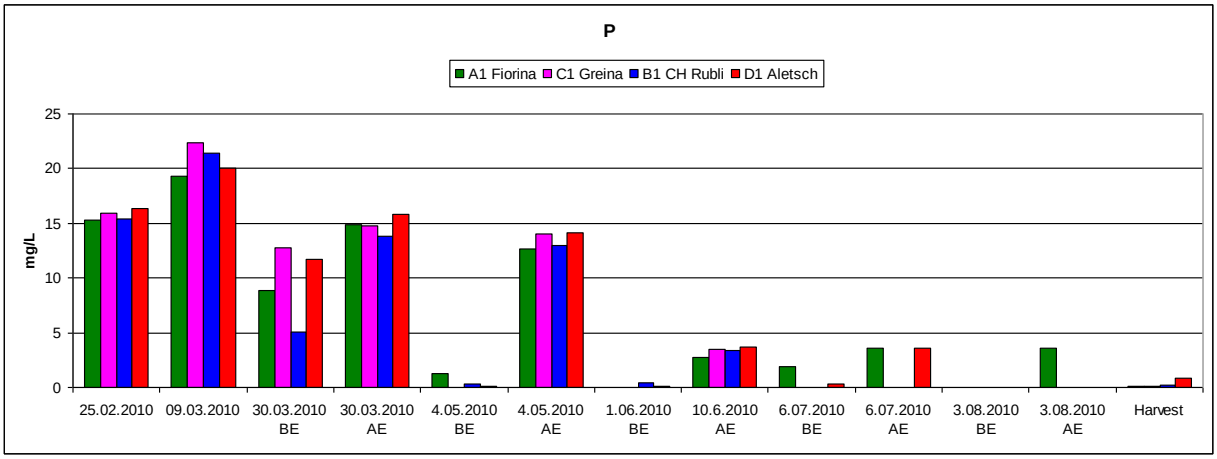
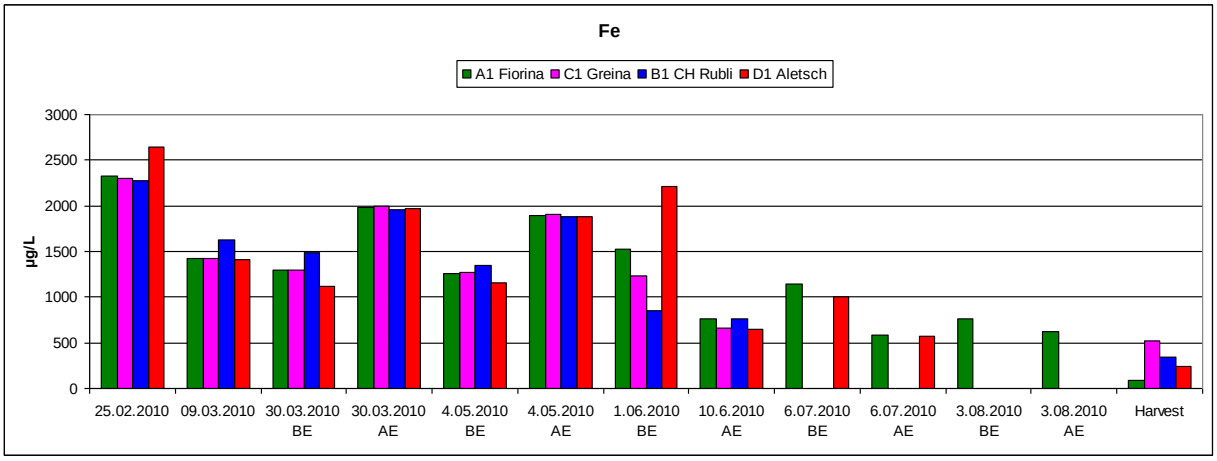
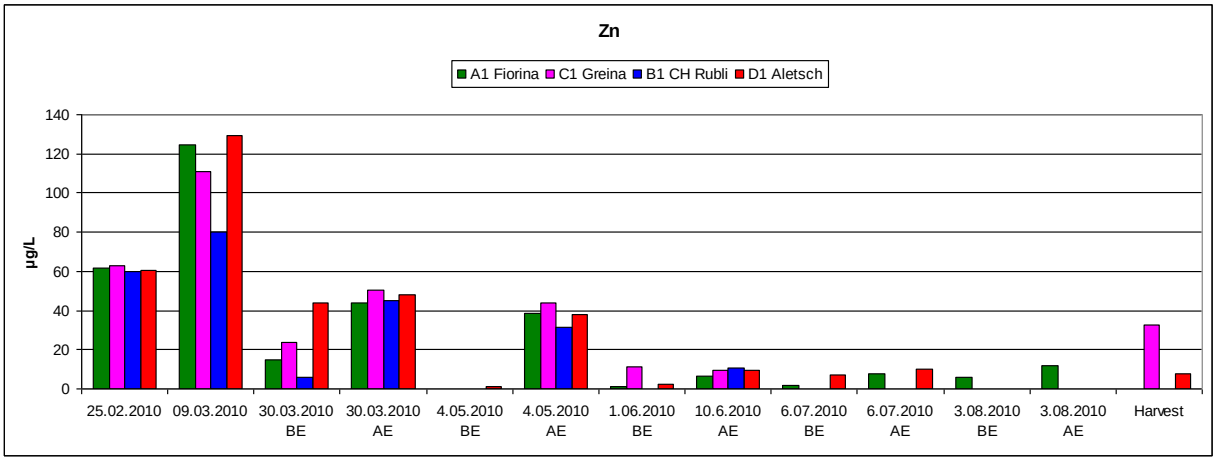
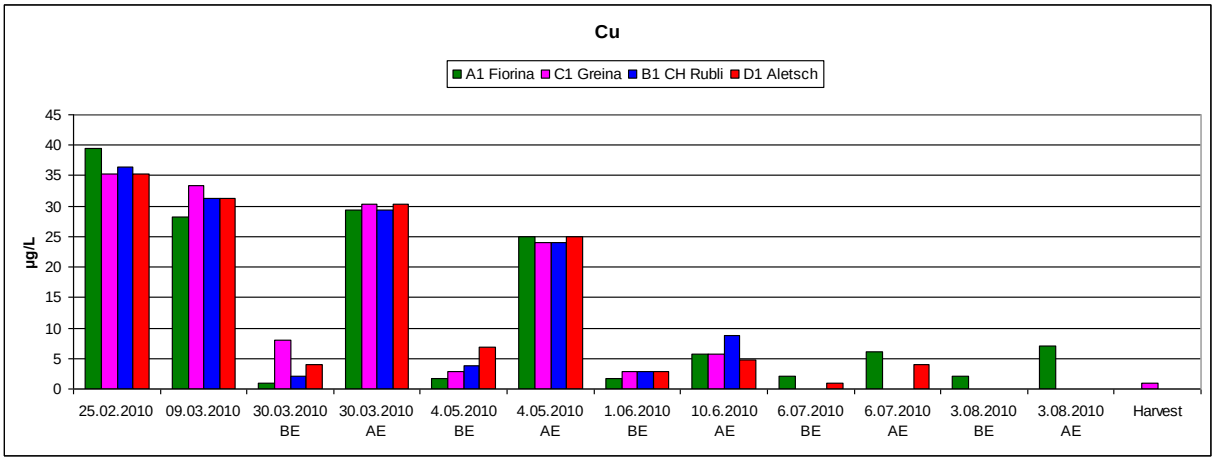
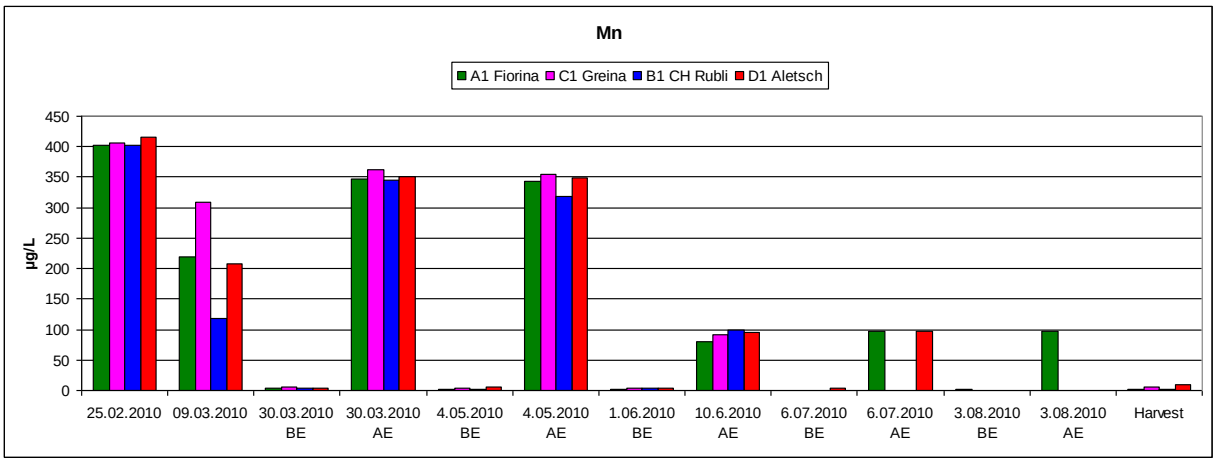


Fig. 11 UBern - Nutrient solution analysis for macro-nutrients K Ca Mg N P









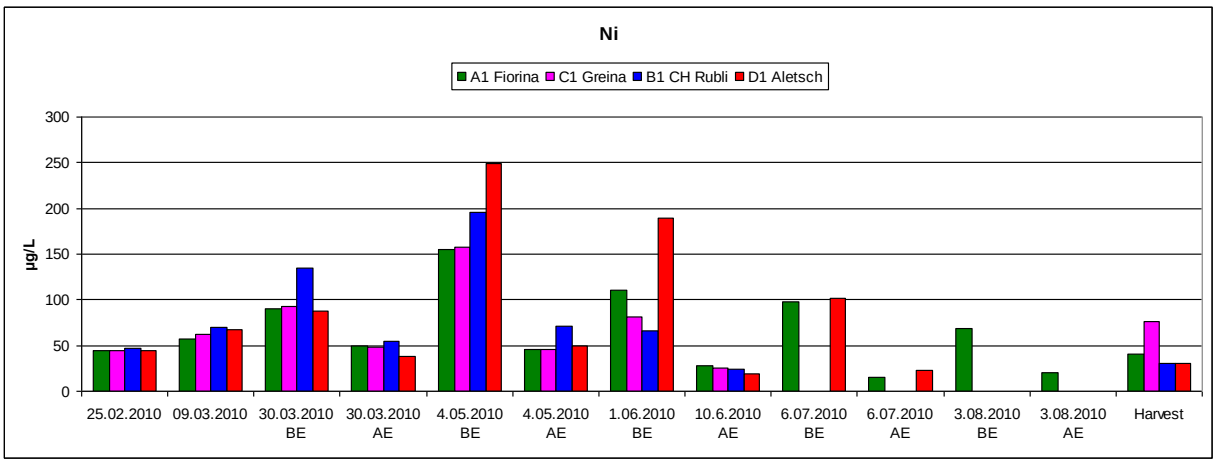


Fig. 12 UBern - Nutrient solution analysis for micro-nutrients Fe Zn Cu Mn Ni

2.3 Monitoring of plant development

The growth period varied from 135 to 184 days. This reflects the difference in maturation characteristics between the cultivars (see also Tab. 8).

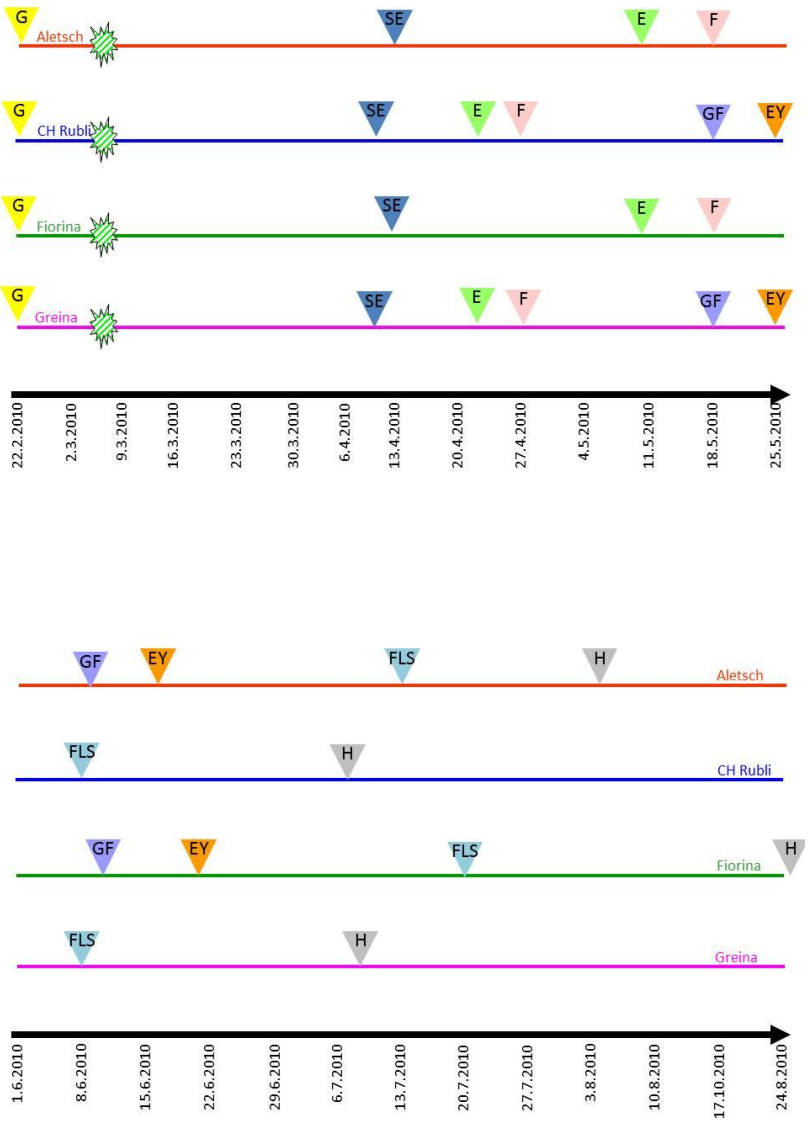


Fig. 13 UBern: Developmental stage of the 4 cultivars

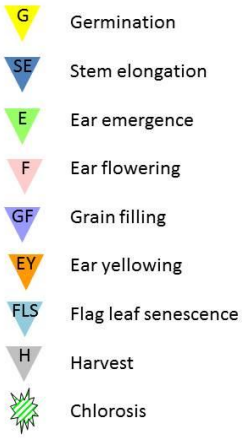


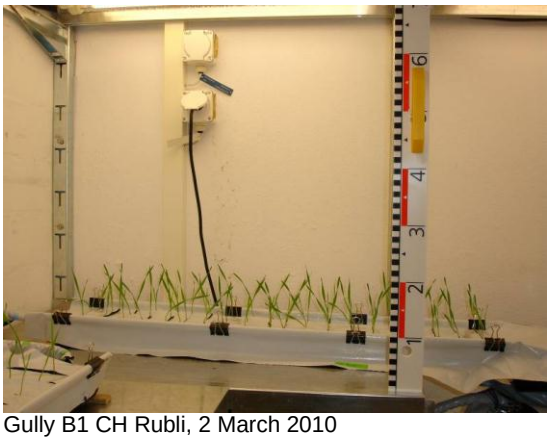
Fig. 14 UBern: Legend for the developmental stage

2.3.1 Photographic follow-up - monthly overview

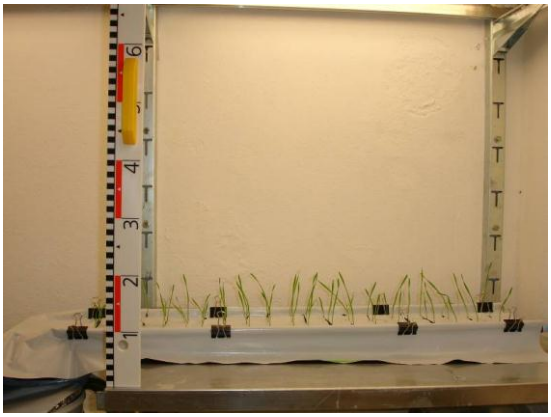
The development of the aerial part (shoot) is shown from the seedling stage to the final development with monthly intervals.
Additional information is available on the companion CD to this TN.
The experiment was started on February 22nd.

In the next section 2.3.2, the development of the wheat ears is shown on a monthly basis.

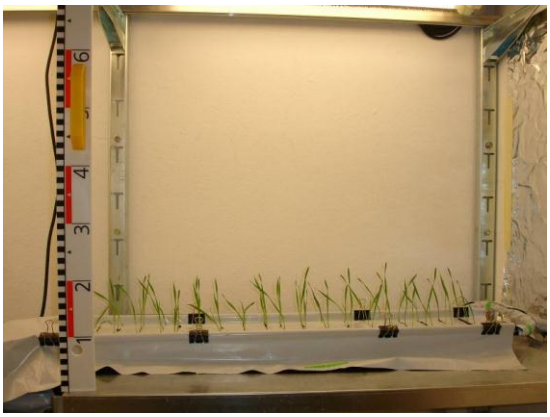
Gully A1 Fiorina, 2 March 2010



Gully B1 CH Rubli, 2 March 2010

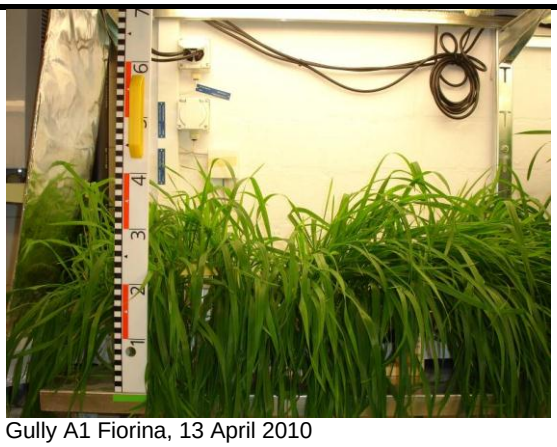


Gully C1 Greina, 2 March 2010



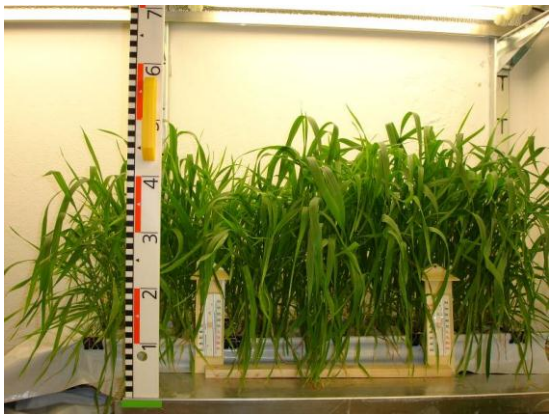
Gully D1 Aletsch, 2 March 2010

Fig. 15 UBern - Photographic follow up – 2 March 2010



Gully A1 Fiorina, 13 April 2010

Gully B1 CH Rubli, 13 April 2010

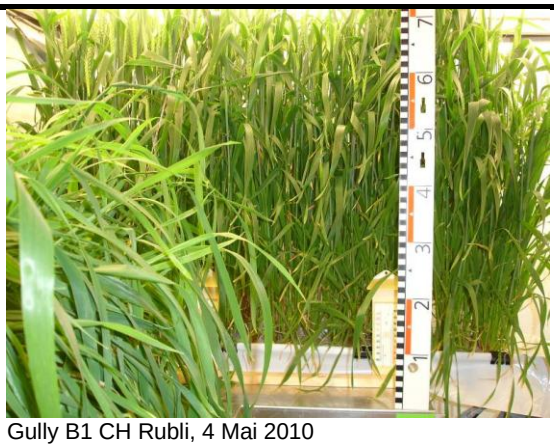


Gully C1 Greina, 13 April 2010

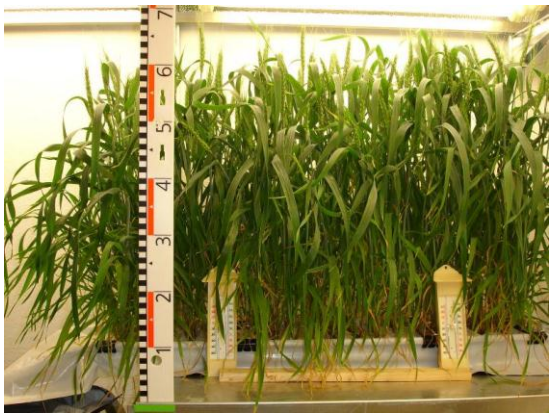
Gully D1 Aletsch, 13 April 2010

Fig. 16 UBern - Photographic follow up – 13 April 2010

Gully A1 Fiorina, 4 Mai 2010



Gully B1 CH Rubli, 4 Mai 2010

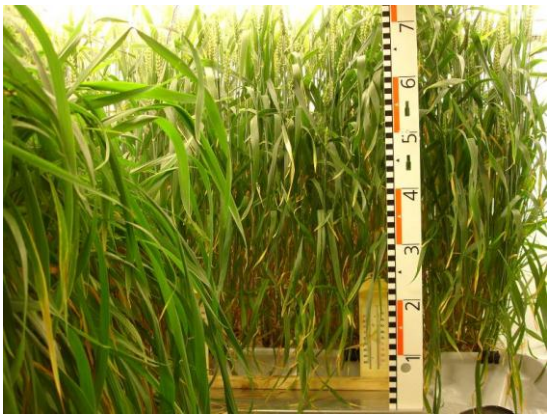


Gully C1 Greina, 4 Mai 2010

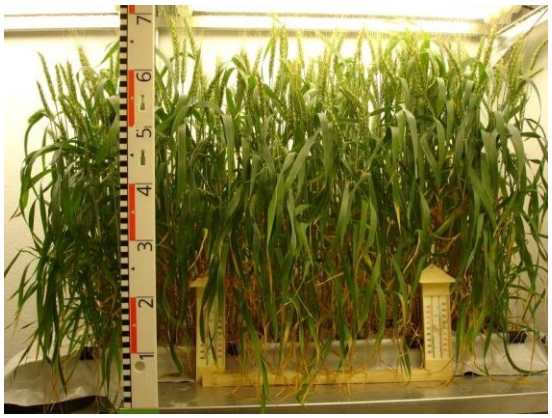
Gully D1 Aletsch, 4 Mai 2010

Fig. 17 UBern - Photographic follow up – 4 May 2010

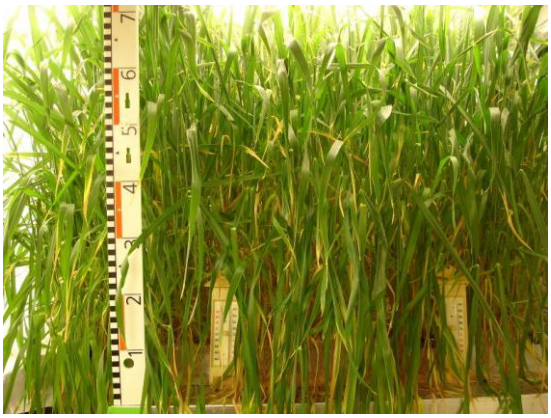
Gully A1 Fiorina, 1 June 2010



Gully B1 CH Rubli, 1 June 2010



Gully C1 Greina, 1 June 2010

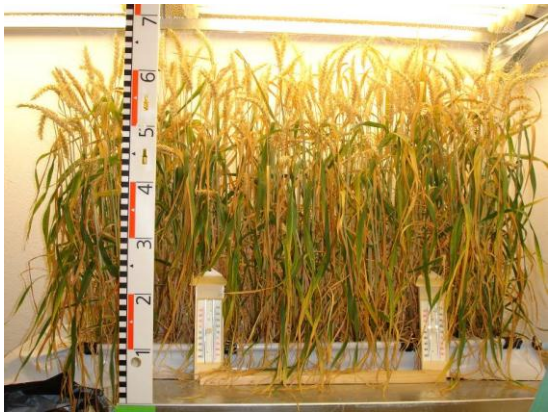


Gully D1 Aletsch, 1 June 2010

Fig. 18 UBern - Photographic follow up – 1 June 2010

Gully A1 Fiorina, 6 July 2010

Gully B1 CH Rubli, 6 July 2010



Gully C1 Greina, 6 July 2010

Gully D1 Aletsch, 6 July 2010

Fig. 19 UBern - Photographic follow up – 6 July 2010

Gully A1 Fiorina, 3 August 2010

Gully D1 Aletsch, 3 August 2010

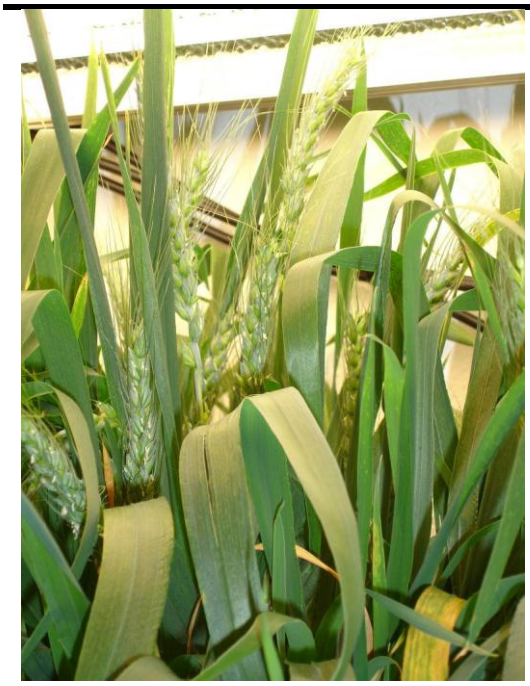
Gully A1 Fiorina, 25 August 2010

Fig. 20 UBern - Photographic follow up – 3 August 2010

2.3.2 Detailed photographic observations

Gully B1 CH Rubli, 27 April 2010

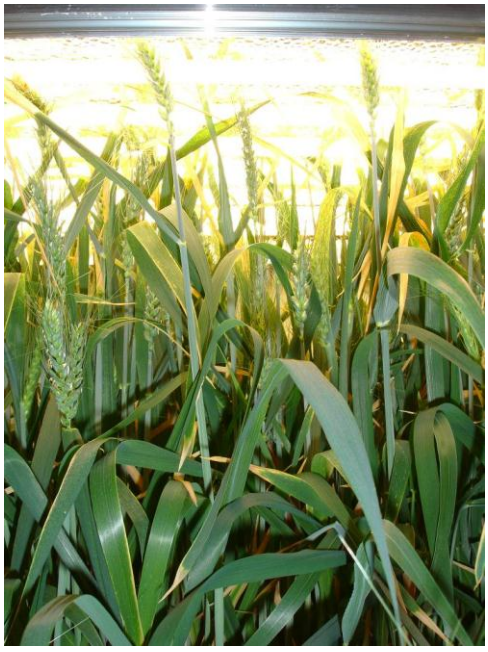
Gully C1 Greina, 27 April 2010



Gully A1 Fiorina, 15 June 2010

Gully B1 CH Rubli, 15 June 2010

Gully C1 Greina, 15 June 2010



Gully D1 Aletsch, 15 June 2010

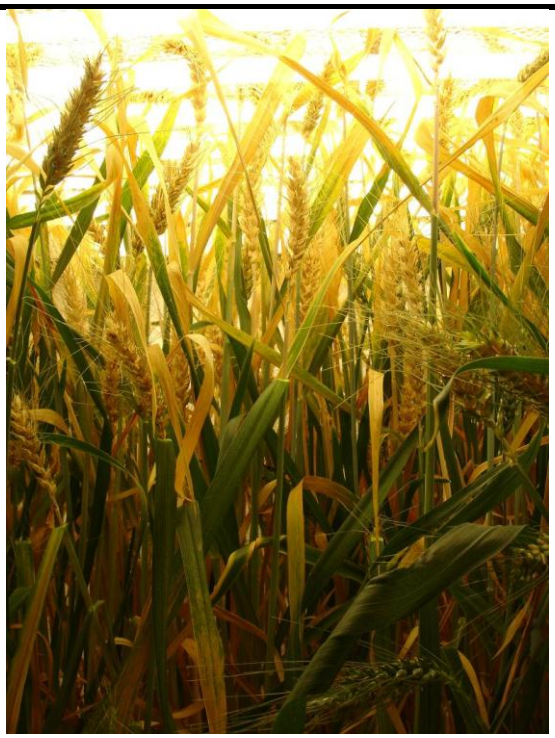
Gully A1 Fiorina, 6 July 2010

Gully B1 CH Rubli, 6 July 2010

Gully C1 Greina, 6 July 2010

Gully D1 Aletsch, 6 July 2010

Gully A1 Fiorina, 27 July 2010



Gully D1 Aletsch, 27 July 2010

Gully A1 Fiorina, 3 August 2010

Gully D1 Aletsch, 3 August 2010

Gully A1 Fiorina, 25 August 2010

Fig. 21 UBern - Ears of bread wheat

Fig. 22 UBern - BT2's Kernel compared to market samples

2.3.3 Growth assessment

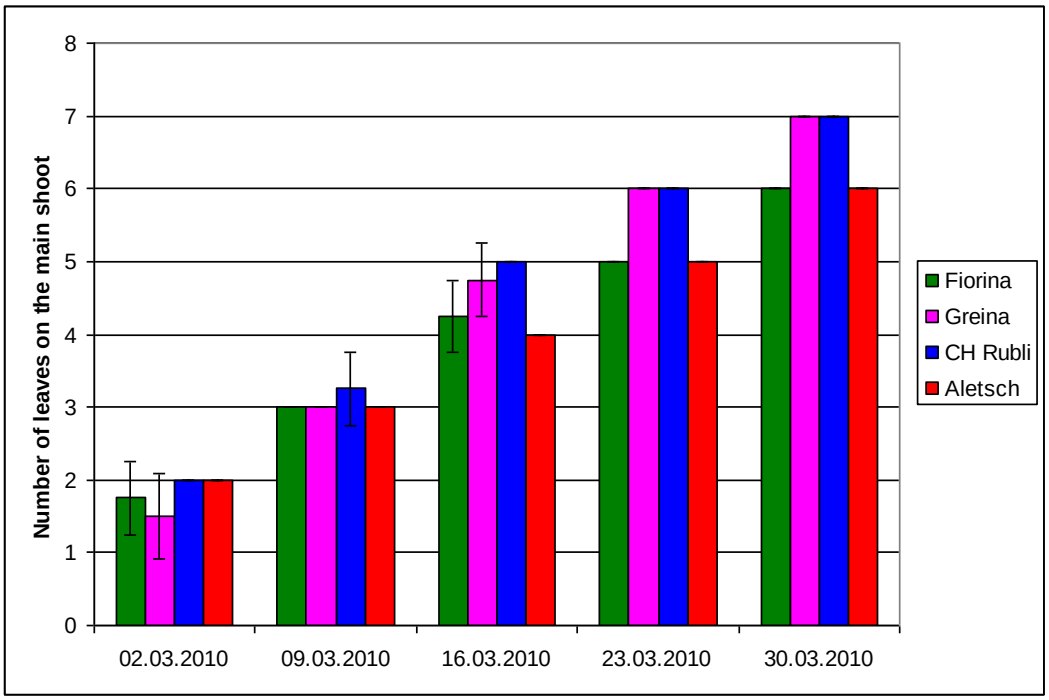


Fig. 23 UBern - Number of Leaves on the main shoot

Count was limited to the 7th leaf.

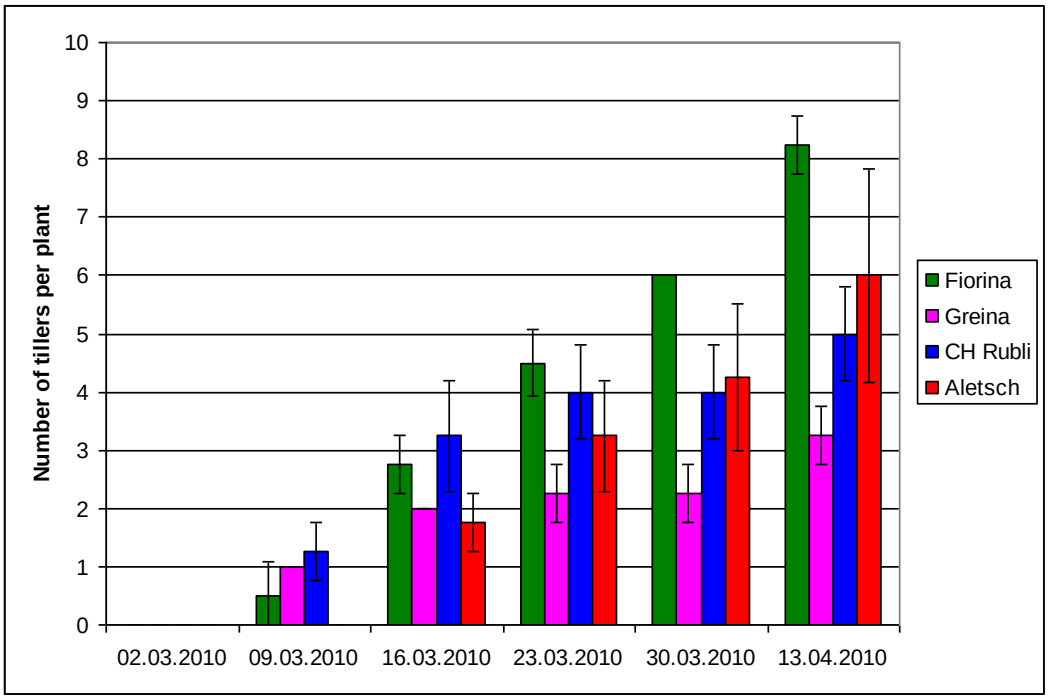


Fig. 24 UBern - Number of tillers per plant

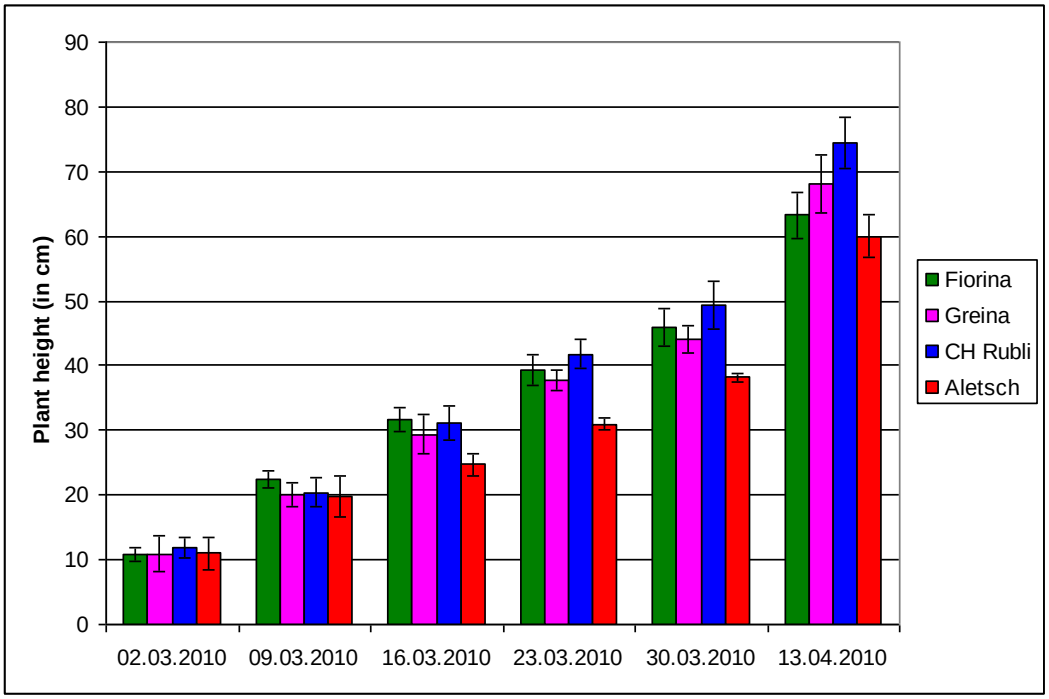


Fig. 25 UBern - Plant height

2.3.4 Gas exchange data

No plant level gas exchange measurements were carried out. See Fig. 7 and Fig. 9 on chamber level CO_2 and plant evaporation.

2.4 Harvest results

The yield expected in the field was reported to be good for CH Rubli and Fiorina, middle for Aletsch and middle to weak for Greina (see Table 2, TN98.3.1).

During BT2, the EC of the nutrient solution was step-wise decreased after flowering to reach an EC of 400 µS/cm. The aim of this change was to move towards a nutrient solution composition better adapted to the developmental stage of the plants, to shorten the maturation and to avoid the problem of leaves contamination with mould.

The maturation of Greina and CH Rubli was faster than in BT1 (one week earlier) and the maturation of the ear was quite homogenous for these two cultivars (most of the ears becoming yellow at the same time).

The maturation of Fiorina and Aletsch took a longer time, certainly related to the nutrient solution not being well adapted to the needs of these cultivars. The maturation of the ears was not homogenous (it took several days/weeks for the yellowing of the ears). After six months of growth, Fiorina was finally harvested without being completely mature.

The number of green ears (not mature) was high for Aletsch and Fiorina. CH Rubli also had some green ears, but for this cultivar, new ears appeared after the maturation of the previous ears. No green ears were found at the harvest of Greina.

Tab. 8 UBern - BT2 harvest and ripening

Cultivars	Gully	Germination	Harvest	Number of days	Ripeness	Number of days for ripeness
Fiorina	A1	22.02.2010	25.08.2010	184	not all ears mature at harvest	more than 184
CH Rubli	B1	22.02.2010	07.07.2010	135	07.07.2010	135
Greina	C1	22.02.2010	08.07.2010	136	08.07.2010	136
Aletsch	D1	22.02.2010	04.08.2010	163	04.08.2010	163

Tab. 9 UBern - BT2 harvest result summary

Cultivar	Gully	Rockwool piece	ears number			Dry weight (in g)		Fresh weight (in g)				Plants number	Average plant high (in cm)	Number of days for ripeness
			yellow ears	green ears	total ears	straw	roots	straw	yellow ears	green ears	total ears			
Fiorina	A1	a	36	63	99	135.50	32.77	454.01	47.50	79.95	127.45	15	75 - 80	more than 184
		b	79	39	118	185.93	35.20	648.66	143.40	54.58	197.98	15		
		c	57	13	70	117.95	18.73	320.68	83.48	19.15	102.63	15		
		d	31	36	67	130.01	19.43	410.94	40.52	56.52	97.04	15		
CH Rubli	B1	a	105	1	106	124.67	57.45	467.40	113.50	1.05	114.55	15	85 - 90	135
		b	72	3	75	83.25	23.66	298.71	66.15	2.13	68.28	15		
		c	71	6	77	74.53	16.66	276.51	52.17	4.05	56.22	15		
		d	128	3	131	142.09	30.02	497.46	122.13	2.16	124.29	15		
Greina	C1	a	67	0	67	72.38	33.35	236.80	110.50	0.00	110.50	15	70 - 75	136
		b	51	0	51	49.83	16.57	152.26	75.97	0.00	75.97	15		
		c	52	0	52	52.71	18.25	172.50	71.74	0.00	71.74	15		
		d	76	0	76	78.93	21.89	245.05	119.49	0.00	119.49	15		
Aletsch	D1	a	86	17	103	150.16	31.62	455.92	81.58	26.30	107.88	15	85 - 90	163
		b	80	8	88	117.80	22.36	348.29	79.18	8.81	87.99	15		
		c	71	7	78	104.22	24.00	303.47	61.95	6.72	68.67	15		
		d	118	32	150	214.10	44.44	660.03	153.40	52.95	206.35	15		

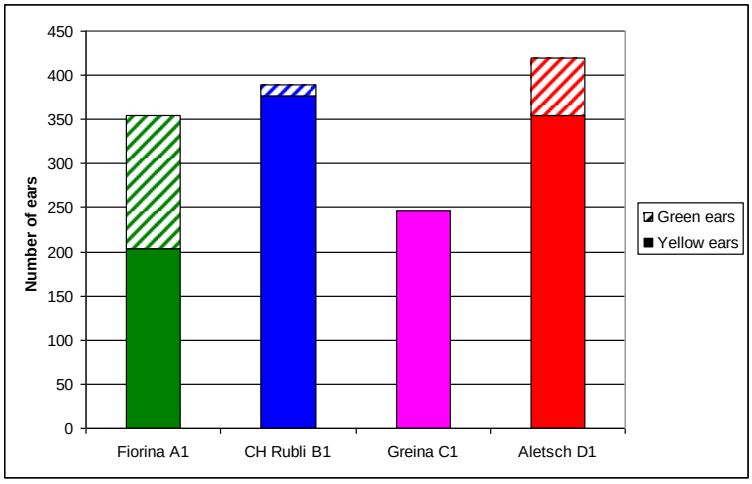


Fig. 26 UBern - BT2 yellow and green ears

Tab. 10 UBern: Fresh weight of kernels per gully

	Fresh weight of Kernels per gully (g)
Fiorina A1	276.72
CH Rubli B1	278.46
Greina C1	299.00
Aletsch D1	267.95

Tab. 11 UBern: yield/m2

		Fiorina	Aletsch	Greina	CH Rubli
Yield	in g/m^2	461.2	446.6	498.3	464.1

Tab. 12 UBern: Harvest index (with roots)

	DW Kernels in g	DW straw in g	DW roots in g	DW threshing debris in g	Harvest index for dry matter
Fiorina	276.72	569.39	106.13	141.32	0.25
CH Rubli	278.463	424.54	127.787	82.59	0.30
Greina	299.004	253.85	90.049	86.44	0.41
Aletsch	267.947	586.28	122.42	137.71	0.24

Tab. 13 UBern: Harvest index (without roots)

	DW Kernels in g	DW straw in g	DW threshing debris in g	Harvest index for dry matter
Fiorina	276.72	569.39	141.32	0.28
CH Rubli	278.463	424.54	82.59	0.35
Greina	299.004	253.85	86.44	0.47
Aletsch	267.947	586.28	137.71	0.27

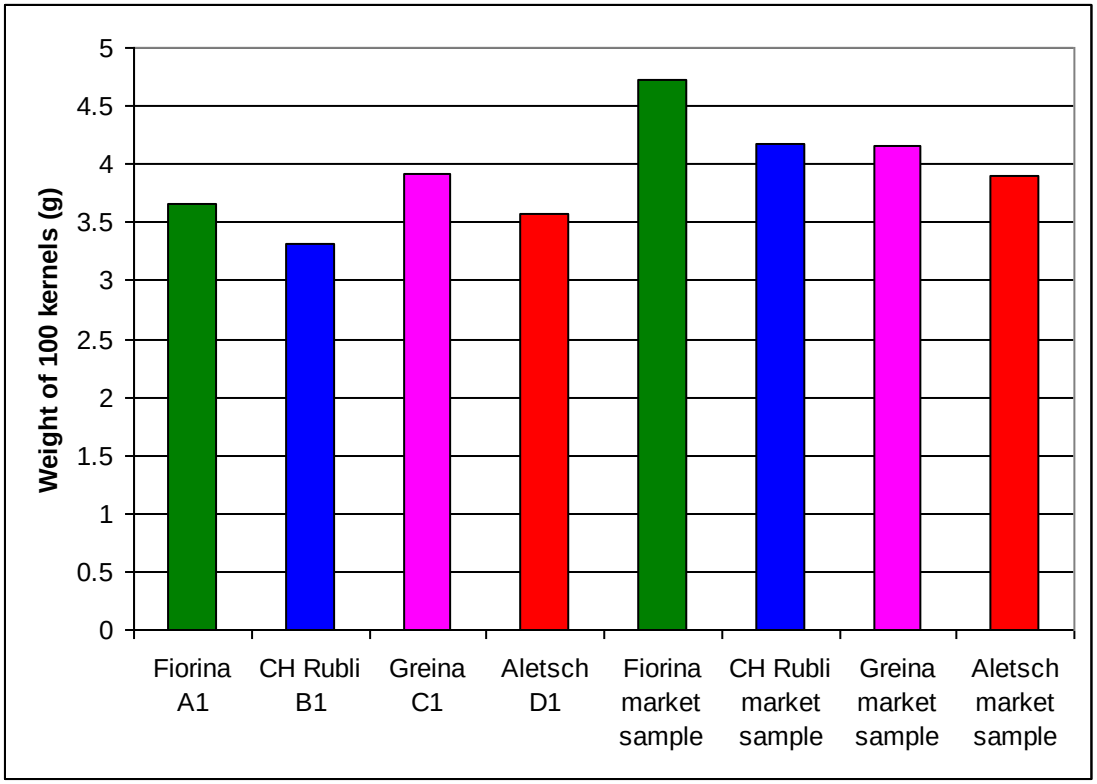


Fig. 27 UBern - Weight of 100 kernels

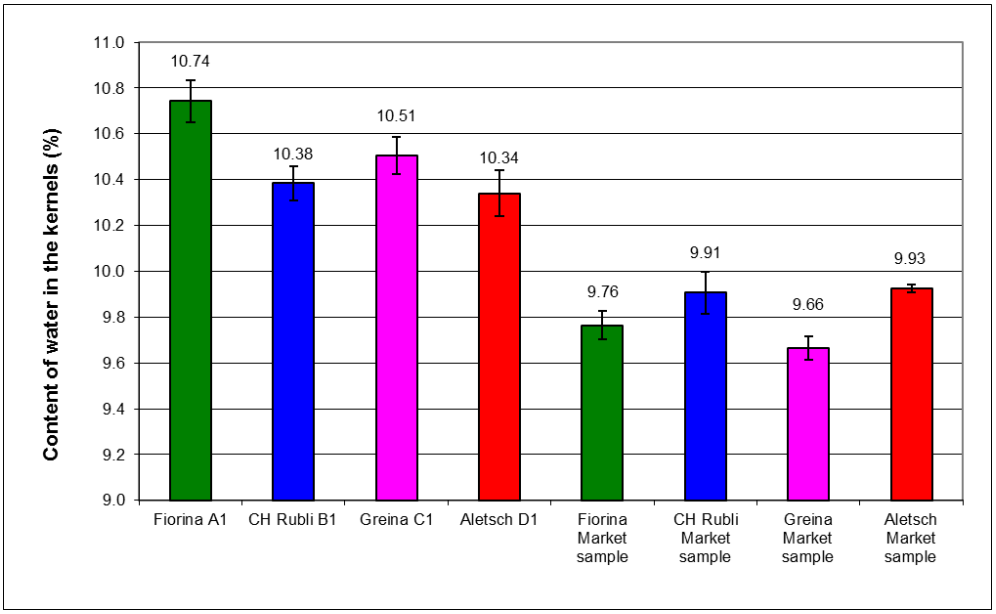
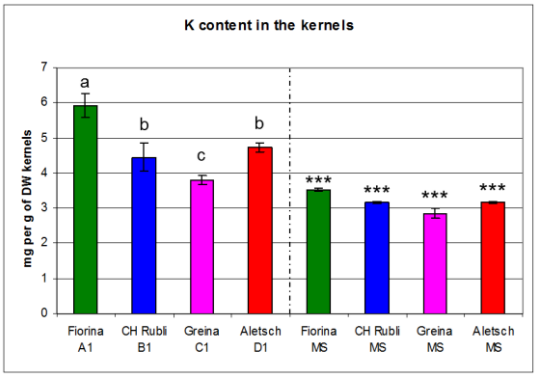
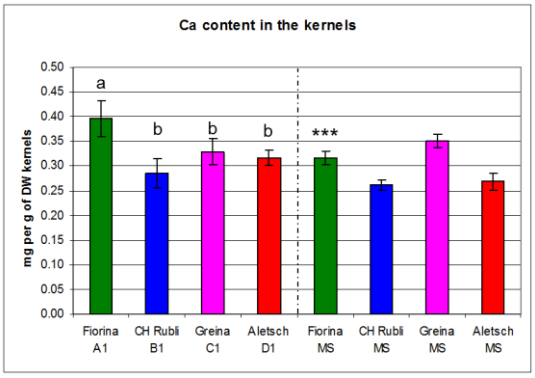


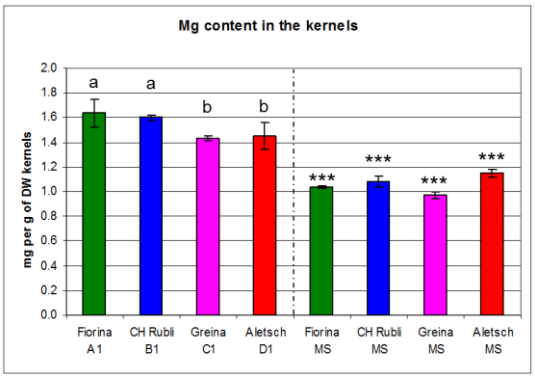
Fig. 28 UBern: Water content in the kernels

Tab. 14 UBern: Macro and micronutrient content in the kernels

			mg K per g DW	mg Ca per g DW	mg Mg per g DW	mg P per g DW	µg Fe per g DW	µg Zn per g DW	µg Cu per g DW	µg Mn per g DW	µg Ni per g DW
Fiorina	Gully A1	Rockwool a	6.11	0.41	1.61	5.72	45.40	51.73	11.95	37.94	1.06
Fiorina	Gully A1	Rockwool b	5.46	0.36	1.56	5.57	46.73	50.59	12.00	34.53	0.81
Fiorina	Gully A1	Rockwool c	5.93	0.37	1.58	5.83	43.91	50.17	11.52	32.68	1.21
Fiorina	Gully A1	Rockwool d	6.21	0.44	1.80	5.94	49.05	57.17	12.94	36.46	1.45
CH Rubli	Gully B1	Rockwool a	4.48	0.31	1.62	5.21	54.07	34.16	7.88	48.25	1.00
CH Rubli	Gully B1	Rockwool b	4.19	0.30	1.62	5.37	59.47	38.37	8.14	47.41	0.77
CH Rubli	Gully B1	Rockwool c	4.12	0.24	1.58	5.36	67.40	40.71	8.57	47.77	0.49
CH Rubli	Gully B1	Rockwool d	5.00	0.28	1.58	5.51	67.46	34.15	9.06	41.27	0.92
Greina	Gully C1	Rockwool a	3.95	0.36	1.42	4.90	47.48	53.45	5.72	38.83	0.89
Greina	Gully C1	Rockwool b	3.76	0.30	1.42	4.84	46.61	54.40	5.77	35.43	0.50
Greina	Gully C1	Rockwool c	3.67	0.32	1.44	4.95	47.42	50.42	5.98	36.64	0.78
Greina	Gully C1	Rockwool d	3.86	0.34	1.46	4.97	46.76	56.56	5.60	35.93	0.64
Aletsch	Gully D1	Rockwool a	4.67	0.32	1.30	5.69	54.79	58.00	9.11	36.40	0.69
Aletsch	Gully D1	Rockwool b	4.70	0.30	1.52	5.67	57.04	53.48	8.96	33.12	1.22
Aletsch	Gully D1	Rockwool c	4.91	0.34	1.53	5.88	61.46	55.88	9.41	34.91	1.28
Aletsch	Gully D1	Rockwool d	4.63	0.31	1.46	5.85	57.65	47.71	7.78	34.73	0.56
Fiorina	market samples	1	3.54	0.31	1.03	4.32	31.73	24.05	6.73	32.98	0.53
Fiorina	market samples	2	3.53	0.31	1.03	4.24	29.68	24.19	6.50	31.99	0.52
Fiorina	market samples	3	3.59	0.31	1.04	4.22	29.44	24.68	6.49	30.59	0.25
Fiorina	market samples	4	3.45	0.34	1.05	4.21	29.54	23.62	6.37	32.04	0.44
CH Rubli	market samples	1	3.17	0.25	1.12	4.06	37.02	35.98	4.11	43.52	0.28
CH Rubli	market samples	2	3.17	0.26	1.12	4.10	40.47	36.29	4.22	41.63	0.38
CH Rubli	market samples	3	3.14	0.28	1.04	4.14	40.11	37.30	4.09	43.50	0.17
CH Rubli	market samples	4	3.18	0.26	1.03	4.05	42.22	36.41	4.07	41.33	0.63
Greina	market samples	1	2.84	0.35	1.00	3.88	38.71	25.76	3.99	17.52	0.33
Greina	market samples	2	2.74	0.34	0.98	3.89	39.10	24.88	3.81	17.71	0.38
Greina	market samples	3	3.08	0.37	0.97	3.85	38.48	25.71	4.44	19.24	0.58
Greina	market samples	4	2.77	0.34	0.94	3.90	35.36	25.49	3.97	18.21	0.60
Aletsch	market samples	1	3.18	0.27	1.13	4.04	40.38	17.20	5.50	40.70	0.55
Aletsch	market samples	2	3.14	0.27	1.13	4.01	39.65	17.18	5.47	41.70	0.44
Aletsch	market samples	3	3.21	0.24	1.20	4.08	41.64	17.51	5.72	41.99	0.14
Aletsch	market samples	4	3.17	0.28	1.15	4.02	41.49	17.31	5.57	42.44	0.09







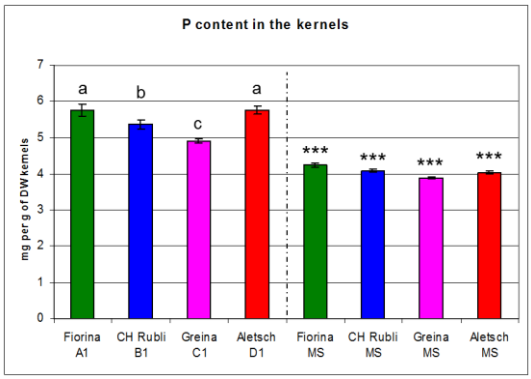


Fig. 29 UBern: K, Ca, Mg, P content in the kernels of BT2 and market samples (MS)

The content is in mg per g of dry weight of the kernels. Samples of BT2 are on the left and the market samples are on the right. Values are means + SD (n = 4). The different letters indicate the statistically significant differences in between the four cultivars of the bench test. The asterisks represent the statistically significant differences for the same cultivar in between BT2 and MS (: $P \leq 0.05$; ** : $P \leq 0.01$; *** : $P \leq 0.001$)*

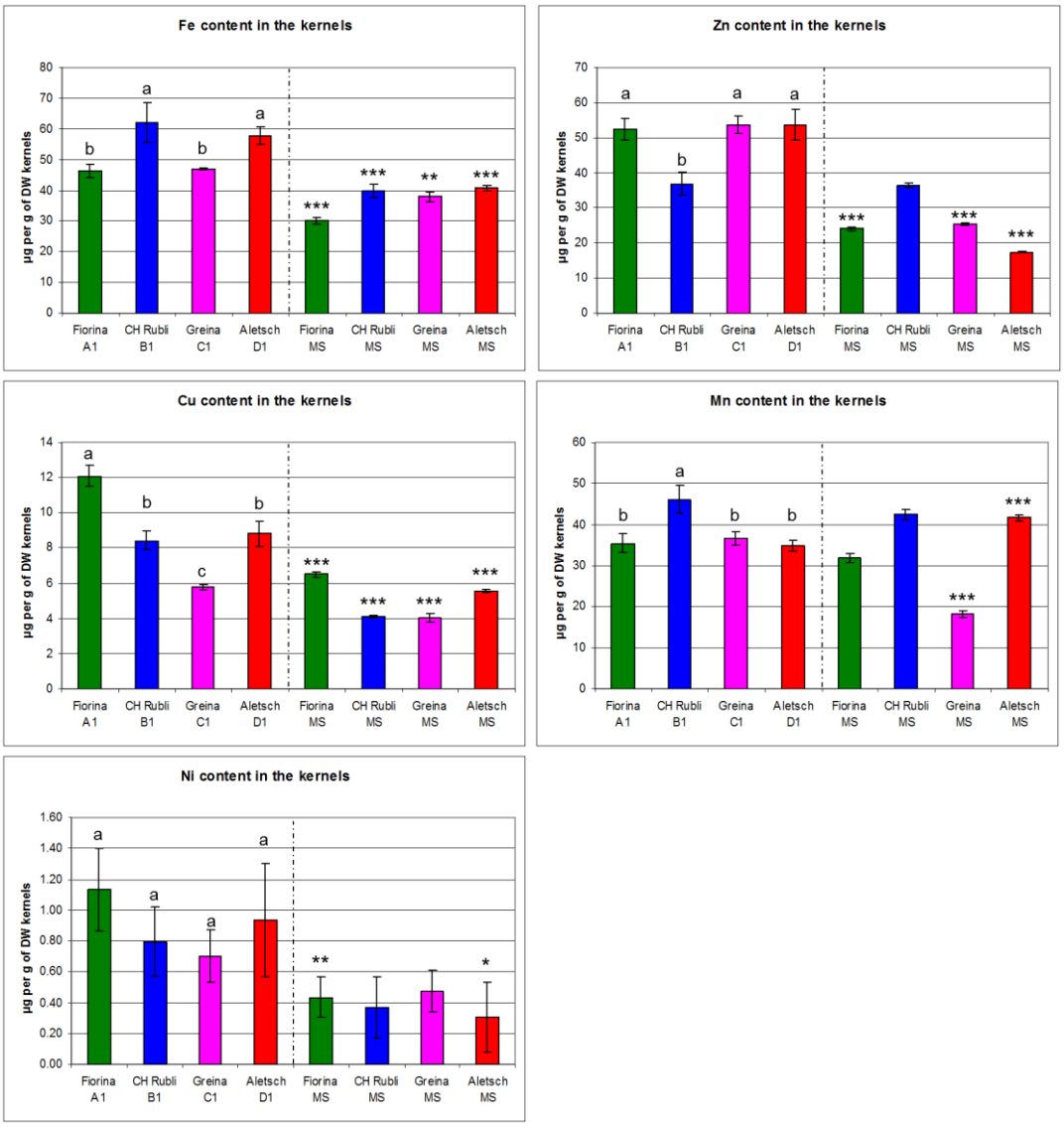


Fig. 30 UBern: Fe, Zn, Cu, Mn and Ni content in the kernels of BT2 and market samples (MS)

The content is in µg per g of dry weight of the kernels. Samples of BT2 are on the left and the market samples are on the right. Values are means + SD (n = 4). The different letters indicate

the statistically significant differences in between the four cultivars of the bench test. The asterisks represent the statistically significant differences for the same cultivar in between BT2 and MS (: P ≤ 0.05; ** : P ≤ 0.01; *** : P ≤ 0.001)*

3 Durum wheat (UoGuelph)

This document outlines the final test results for a single replicate of two cultivars of durum wheat (*Triticum turgidum* var durum*)* grown in the sealed environment chambers (SEC2) at the University of Guelph Controlled Environment Systems Research Facility. The cultivars selected for this phase of food characterization testing were Commander and Eurostar.

3.1 Experimental Layout

3.1.1 Measuring Plan

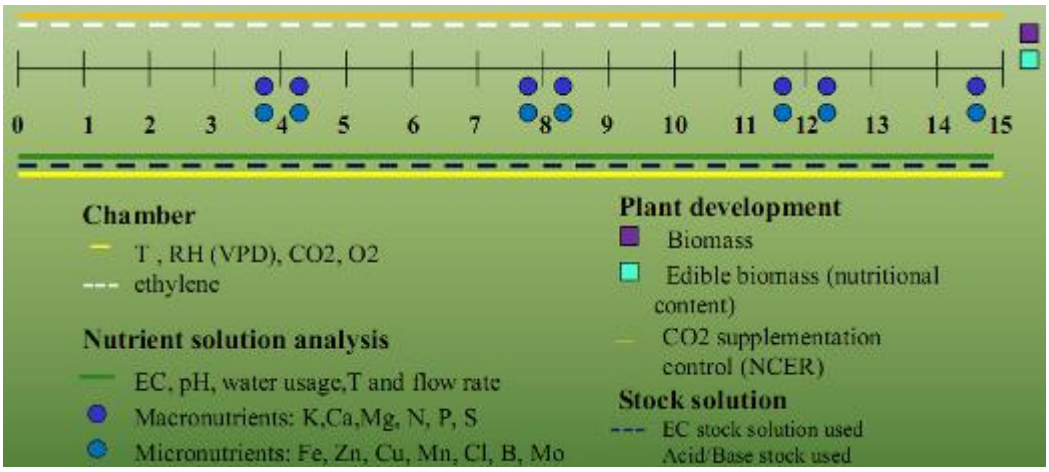


Fig. 31 UoGuelph - Measuring plan

3.1.2 Setup

3.1.2.1 Plant density

The plant growth area corresponds to 2.5m length (gully length 2.45m) x 2m width. Gully width is 0.17m. Crops of each gully have an area of 2.5x0.4m (1 m^2) to develop.
Planting density: 3 times 45 plants per gully = 135 plants, density = 135 plants / m2, 675 total.

3.1.2.2 Plant Cultural Conditions

Wheat was grown in 2.45 x 0.17 m stainless steel troughs in rockwool (Grodan AO 36/40 6/15W) using a recirculating nutrient film technique delivery system. Watering was enabled for 2 minutes out of every 10 minutes. There were 5 troughs per chamber with a growing area

of 5 m^2. Seeds were sown at a planting density of 135 seeds per trough split into three pads of 45 seeds (Fig. 32). A plastic black/white blackout cover with slits to accommodate the wheat was placed over the rockwool to minimize algae growth and reduce evaporation. A modified half-strength Hoagland's solution was used (Tab. 15). The rockwool was rinsed with deionized water prior to use to remove particulate material from the substrate.

Solution pH was automatically adjusted by the control system to 5.8 +/- 0.2 with additions of dilute acid (at 0.5 M HNO_3) or base (0.5M KOH). Solution electrical conductivity was monitored and automatically adjusted by the control system to 1.2 mS with the modified stock solution (Tab. 15). The nutrient solution was completely changed approximately every four weeks to reduce potential buildup of salts or other phytotoxic compounds.

3.1.2.3 Seed treatment

In order to avoid potential contamination problems, seeds were sterilized prior to seeding in the chamber by treating in 70% ethanol for 2 minutes followed by 20% commercial bleach for 20 minutes with gentle shaking and rinsed 3 times with sterile laboratory grade water.

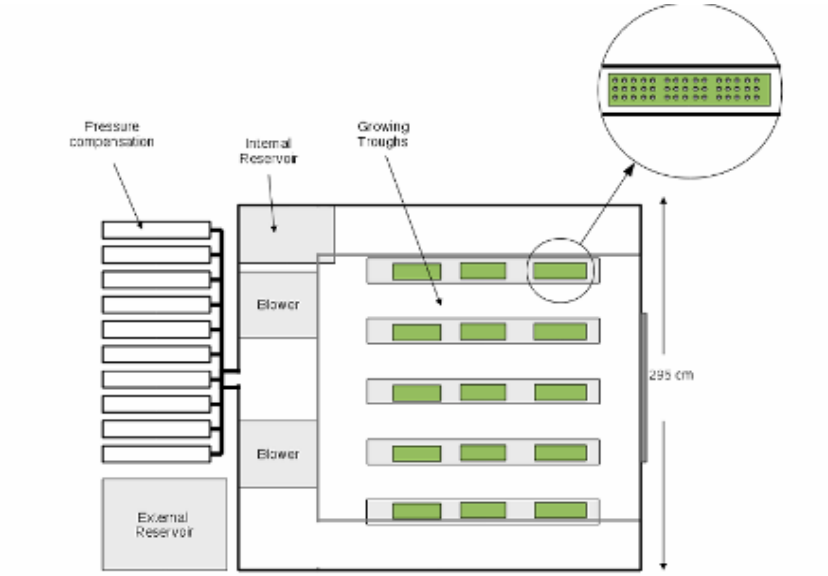


Fig. 32 UoGuelph: Setup of gullies and plant positioning within the growth chamber

3.1.2.4 Environmental parameters

In each chamber, lighting was provided by nine 600 Watt High Pressure Sodium (HPS) and six 400 Watt Metal Halide (MH) lamps cycled to provide a 16-h light/8-h dark photoperiod. Air temperature was isothermal at 23˚C (Mackowiak, Owens and Hinkle, 1989). CO_2 was maintained at concentration of 1200µmol mol^{-1} (partial pressure of 0.12 kPa), and relative humidity was set to 60% RH for the duration of crop growth. Twelve weeks after planting, the temperature was raised to 26˚C in order to accelerate seed filling, as recommended by Dr.

Mark Jordan during a follow-up visit to inspect the first crop at the UoG facility. Once the crop had reached physiological maturity, the demand humidity was set to 0% in order to accelerate the drying process.
The chambers were vented biweekly for a one hour period. This procedure was used to reduce ethylene and oxygen levels and to maintain hydroponic solution flow through removal of root material that has accumulated in the drainage system.

3.1.2.5 Ethylene analysis
Air samples from each chamber were taken, and a subsample was passed through the 1.0 mL sample loop of an SRI 8610C (SRI Instruments Inc., Menlo Park, California, USA) gas chromatograph (GC) equipped with a flame ionization detector (FID) and 30 metre 0.53mm ID SupelQ Plot capillary column (Supelco Inc). The GC was controlled by PeakSimple chromatography software (SRI Instruments Inc.). Calibration was carried out daily with a standard of known concentration. The detection limit for ethylene was 5 parts per billion (ppb) with a signal to noise ratio of 1 to 5.

3.2 Growth environment follow-up

3.2.1 Chamber T/RH

Profiles of chamber atmospheric temperature, humidity were recorded at six minute intervals for the duration of this experiment. Temperature control (Fig. 33, Fig. 34) was excellent throughout the experiment. Temperature was kept at an isothermal 23˚C during the majority of growth, but was raised to 26˚C after approximately 12 weeks in order to improve seed filling as recommended by durum wheat expert Dr. Mark Jordan.

Relative humidity was set to 60% until 15 weeks after planting, at which point it was set to 0% to facilitate crop drying prior to harvest. Humidity control was not as effective as desired and improvement requires the replacement of the current control system which is outdated and cannot be modified to improve response.

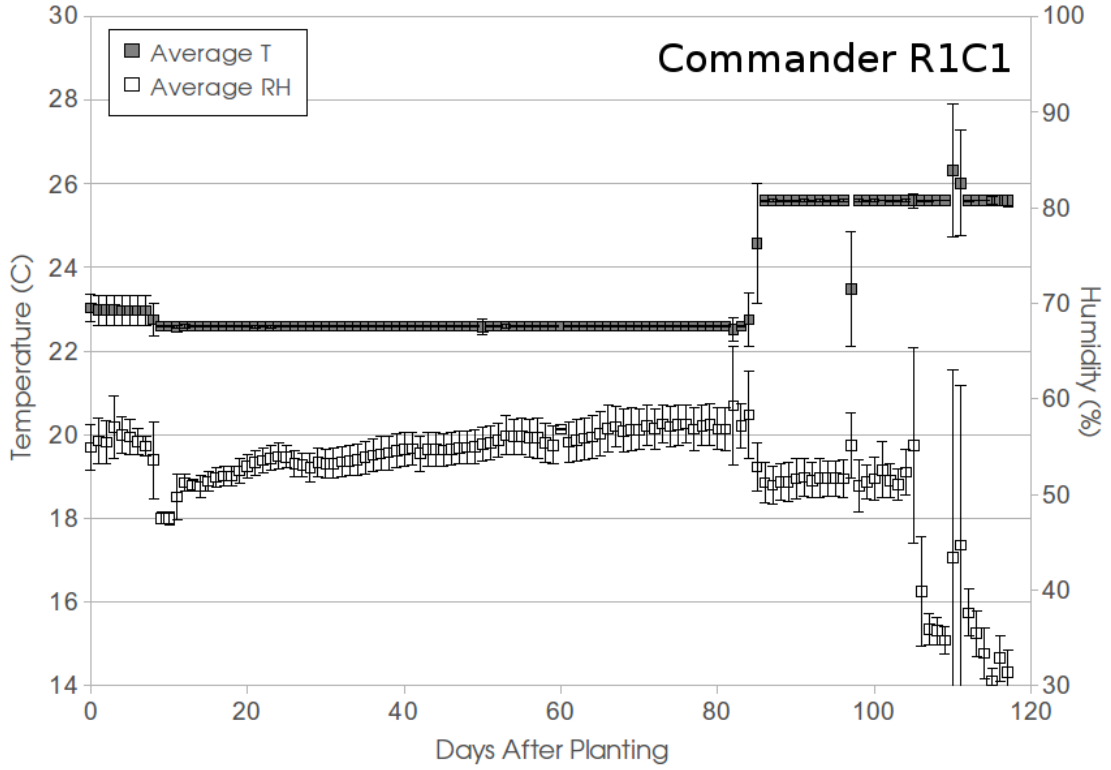


Fig. 33 UoGuelph : Temperature and humidity control during Commander durum wheat production in SEC2 chamber 1

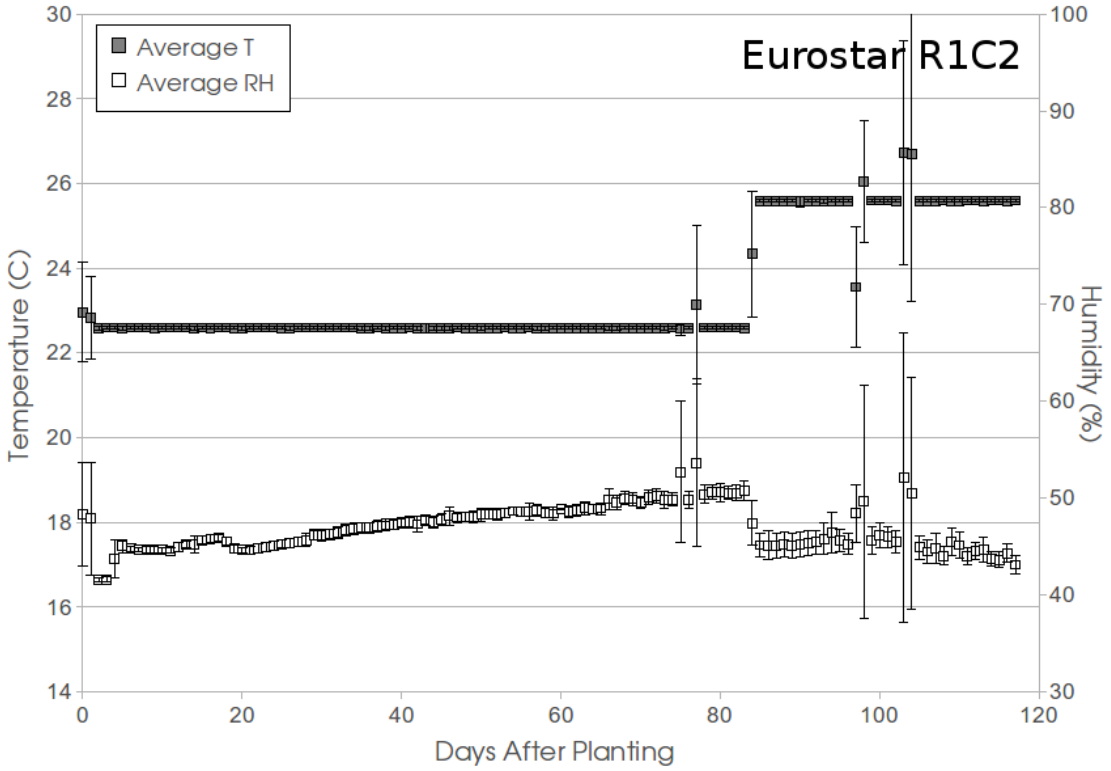


Fig. 34 UoGuelph: Temperature and humidity control during Eurostar durum wheat production in SEC2 chamber 2

3.2.2 Chamber NCER

NCER and transpiration followed typical profiles found in plant growth and development (Fig. 35, Fig. 36). Both cultivars had similar peak productivity, however Commander productivity dropped off rapidly at approximately 80 days whereas Eurostar productivity dropped at a slower rate. As this is during the seed filling stage, the higher NCER observed at the later growth stage in Eurostar may be the reason for higher overall kernel yields.

A significant reduction in NCER was observed in both cultivars immediately after the first solution change and was similar to the pattern observed in earlier experiments with Avonlea and Strongfield however the definitive reason for this is currently unknown. As the same event occurred in both chambers at chronologically different times, the observed reduction is likely directly related to the nutrient solution change. Similar reductions in NCER have been observed in soybean during growing solution changes in our laboratory in other chambers as well. The current hypothesis is that the rapid change from a differentially depleted solution to a full strength feed solution results in osmotic shock in the root zone. Increased productivity

should be realized by reducing or eliminating this reaction to nutrient solution change and remedies should be investigated in future trials.

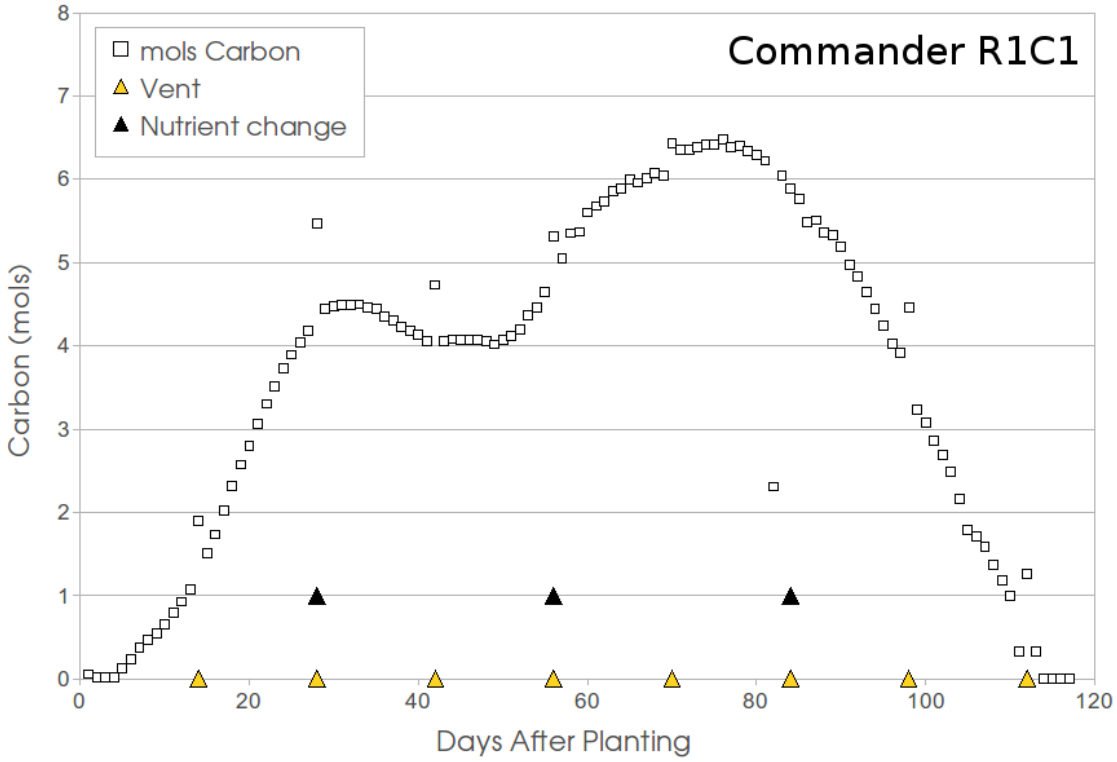


Fig. 35 UoGuelph: Daily carbon assimilation (NCER) in Commander durum wheat growth and development

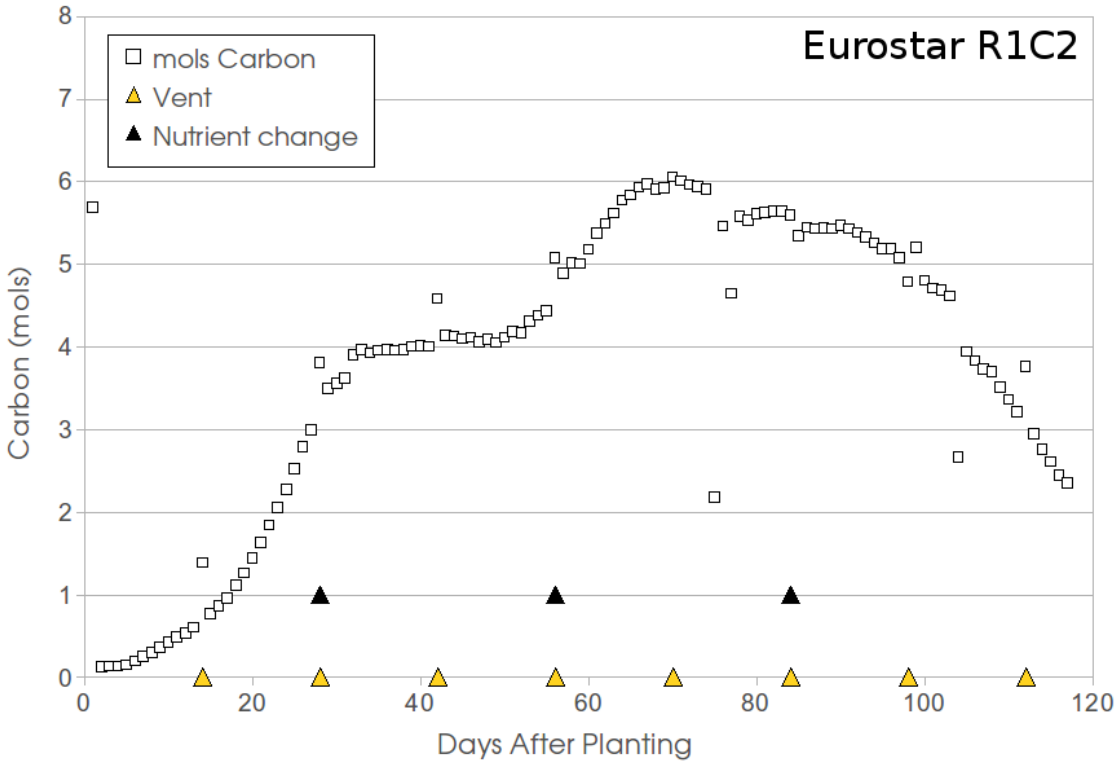


Fig. 36 UoGuelph: Daily carbon assimilation (NCER) in Eurostar durum wheat growth and development

3.2.3 Evapotranspiration

Commander and Eurostar evapotranspiration peaked at approximately 60 and 120 liters per day (Fig. 37, Fig. 38). Unlike NCER, the first nutrient solution change had a less noticeable effect on water production, however following total productivity, the cultivars with the highest yield also produced the most water. In both cases, the highest rates of evapotranspiration were observed in chamber 2 (Eurostar), indicating a possible chamber effect. Recent evidence has shown that chamber 2 has a higher air velocity than chamber 1. Increased air velocity and subsequent improvements in gas exchange would likely be the cause of the differences in observed evapotranspiration, however additional studies on air velocity and plant productivity should be performed to confirm this hypothesis.

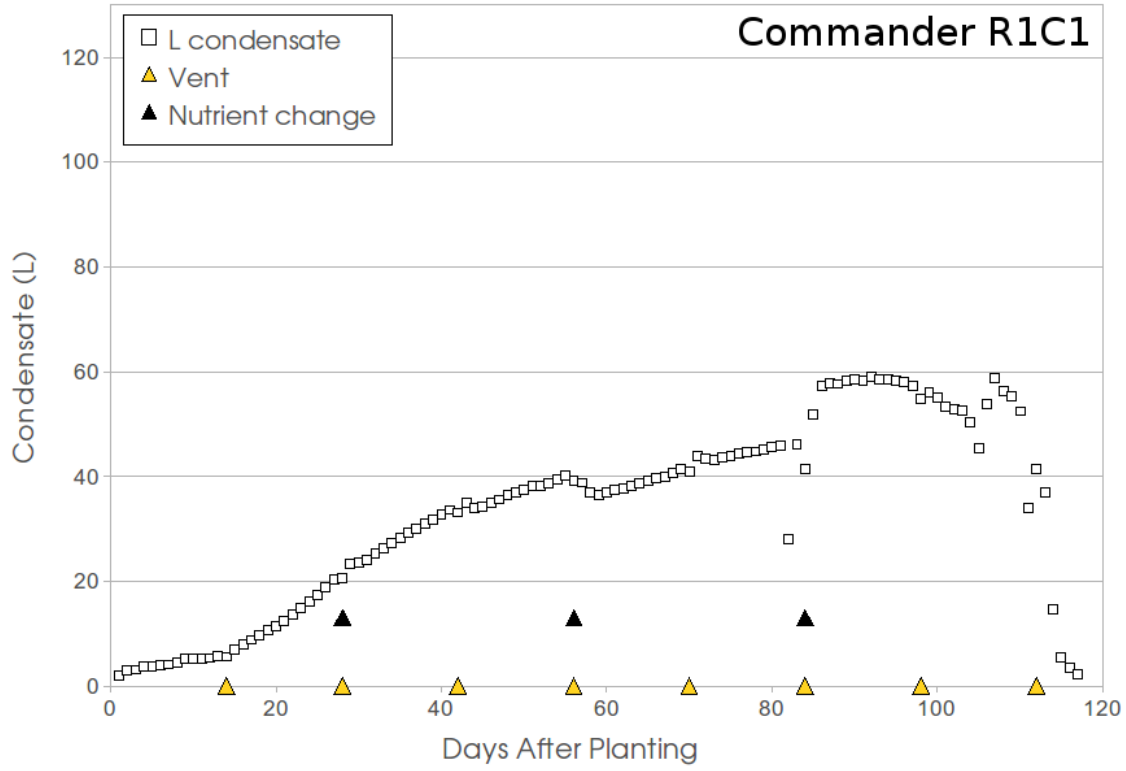


Fig. 37 Water accumulation from evapotranspiration in the durum wheat cultivar Commander

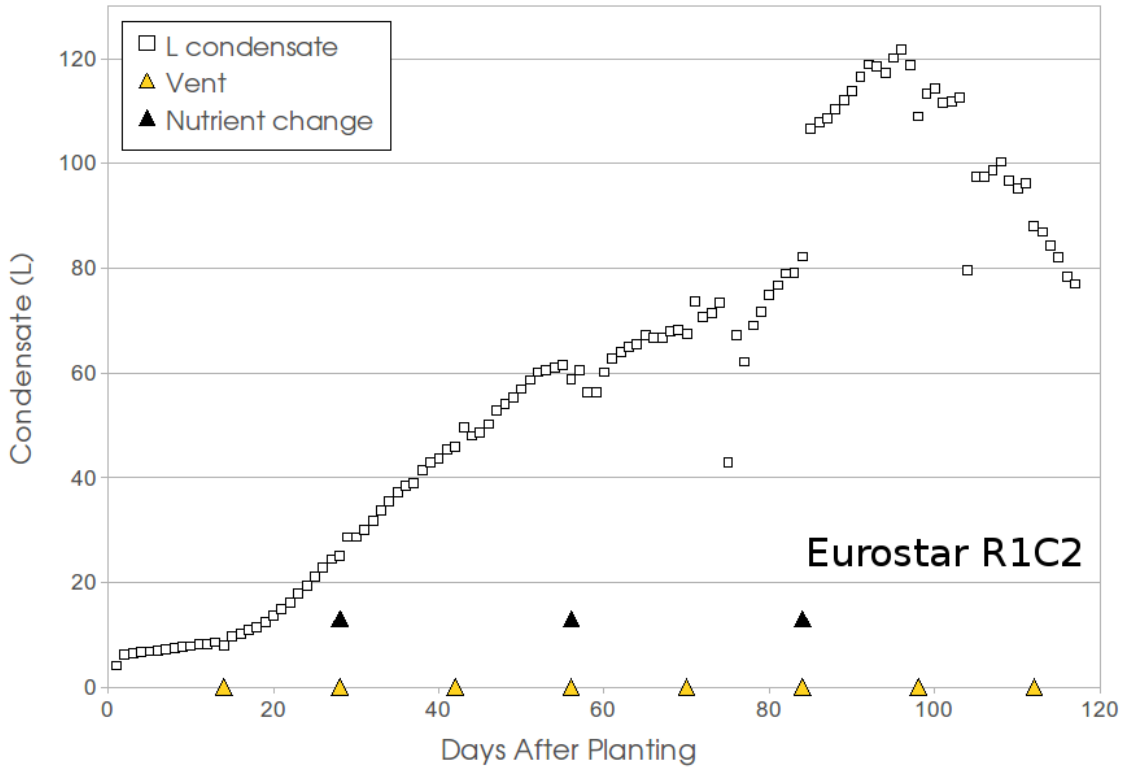


Fig. 38 Water accumulation from evapotranspiration in the durum wheat cultivar Eurostar

3.2.4 Ethylene production

Air samples were monitored for ethylene by GC analysis every standard working day. A sample of air was withdrawn through the atmosphere sampling ports and injected into an SRI GC. Ethylene was sampled starting the first day after closure and continued until harvest. The highest level of ethylene was observed in the Commander cultivar with a level of 49 ppb (Fig. 39). while Eurostar had a maximal observed ethylene concentrations 41 ppb (Fig. 40). Biweekly venting was performed in these trials in an effort to mitigate potential ethylene effects on crop productivity. As results were similar to those observed in the previous trials with Avonlea and Strongfield, ethylene is not likely a problem at the levels observed thus far.

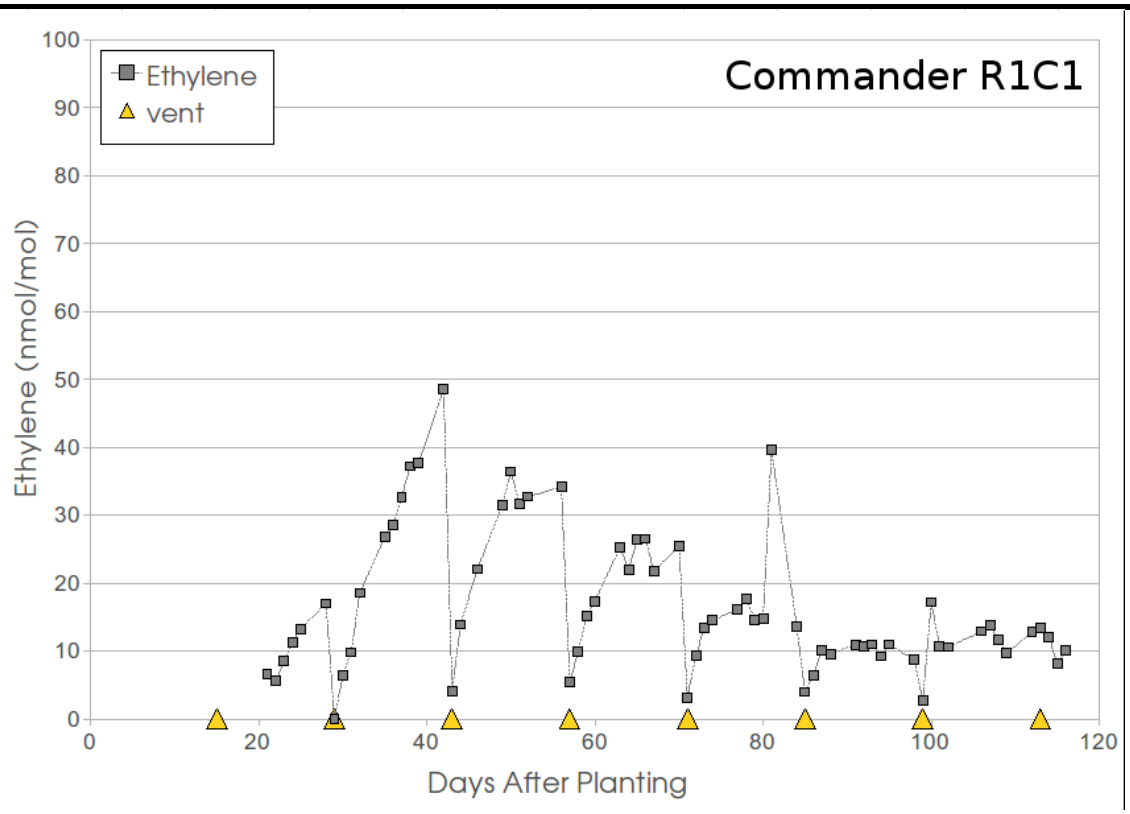


Fig. 39 UoGuelph: Ethylene evolution during durum wheat (cv Commander) crop growth and development in a sealed environment chamber (SEC2-1)

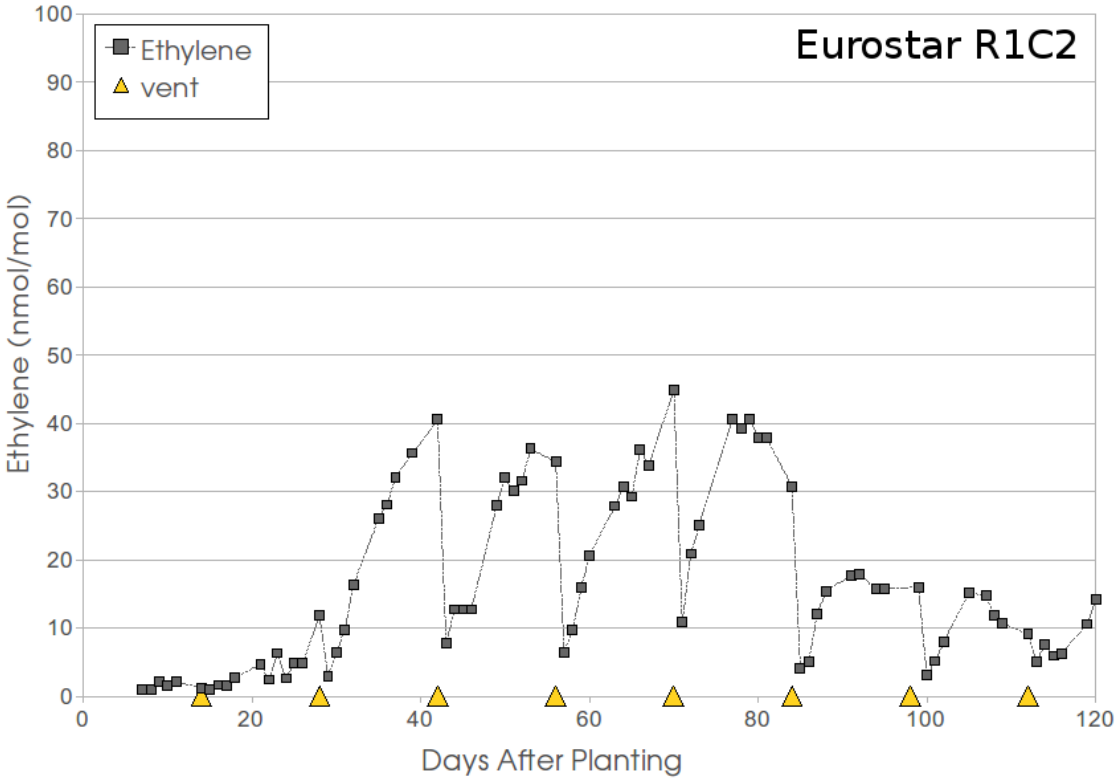


Fig. 40 UoGuelph: Ethylene evolution during durum wheat (cv Eurostar) crop growth and development in a sealed environment chamber (SEC2-2)

3.2.5 Oxygen production

Because of high oxygen concentrations observed in earlier experiments, these tests with Commander and Eurostar were vented on a biweekly basis. With venting, oxygen reached maximum concentrations of 25.5 and 23.5 percent in Commander and Eurostar respectively (Fig. 41; Fig. 42).

Oxygen was one of the considerations for adopting biweekly venting. In crops grown under ambient concentrations of carbon dioxide, high oxygen reduces the efficiency of photosynthesis by competing with CO_2 for the acceptor 1,5-bisphosphate (Warburg effect). However, these studies used enriched carbon dioxide levels (0.12 kPa) which can suppress photorespiration even at the high partial pressures of oxygen observed in these experiments (Maleszewski et al., 1988; Drake et al., 1996).

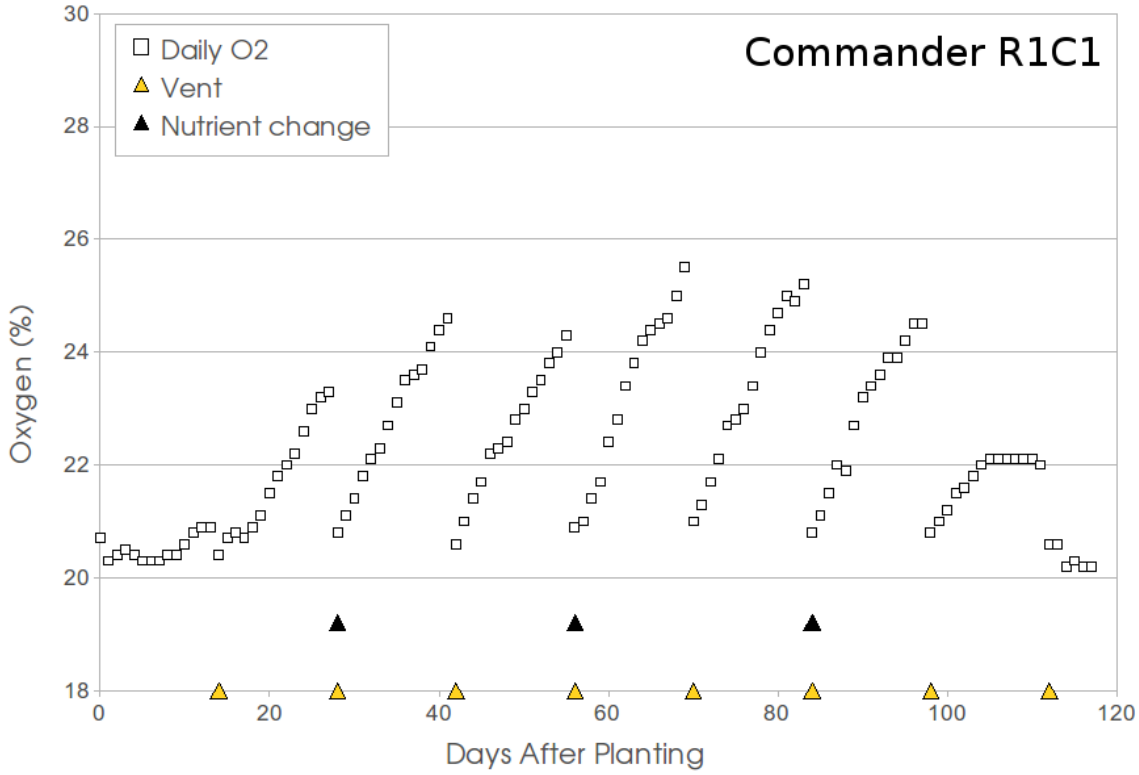


Fig. 41 UoGuelph: Daily oxygen levels in durum wheat cultivar Commander

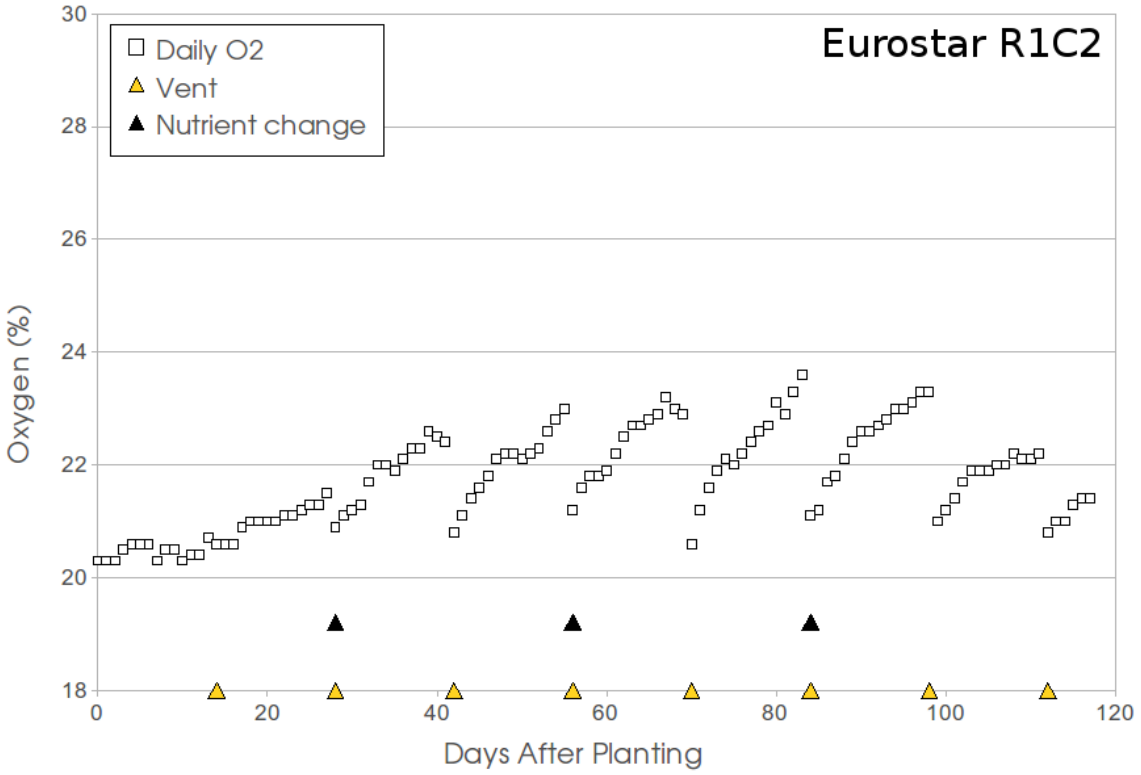


Fig. 42 UoGuelph: Daily oxygen levels in durum wheat cultivar Eurostar

3.2.6 Nutrient Solution Environment

NFT flow was intermittent with a 2min pump on, 8min pump off cycle. The period was adjusted to 3min on / 7min off to increase nutrient availability when the plants were 1 month old, and returned to 2min on / 8min off at the 2 month time point.

Samples of nutrient solution were analyzed by an external laboratory.

MACROS

Formula	F.W.	g/L	Stock Concentration	For 150L start up (1/2 HOAG)	For 10L Replenishment Container
1. Fe-EDTA Solution FeCl3 * 6H2O	270.3g	2.42	8.96mM	840ml	150ml
EDTA	292.2g	2.49	8.52mM		
2. KH2PO4	136.09g	136.09	1M	75ml	100ml
3. KNO3	101.1 g	101.1	1M	375ml	460ml
4. MgSO4 * 7H2O	246.48g	246.48	1M	150ml	100ml
5. Mixed Micros *(See Part 1 and Part 2 Below)*		see below	Varies	150ml	130ml
6. Ca(NO3)2 * 4H2O	236.1 g	236.1	1M	375ml "	120ml
7. WATER				148.035L	8.94L

1. Mix each individual macro above in separate labeled carboys found in the Harvest Lab
2. Prepare the mixed Micros (#6) as shown below.
3. Add desired amount of Macro #1 - #6 to either 150 L or 10L replenish tanks - amounts specified for each listed in table above

MIXED MICROS (For #5 in Recipe Above)

PART 1 - Mix Each Micronutrient separately as shown below

Nutrient	F.W.	g/500 ml	Stock Concentration
H3BO3	61.83g	14.7	0.4560M
MnCl2 * 4H2O	197.9g	36.61	0.37M
ZnSO4 * 7H2O	287.54g	9.2	0.064M
CuSO4 * 5H2O	249.68g	6.50	0.052M
(NH4)6Mo7O24 * 2H2O	1235.86g	0.10	1.01mM

SEPARATE MICRONUTRIENT STOCK SOLUTIONS

Weigh out amts in highlighted column into individual 500 ml bottles and add 500 mL deionized water

PART 2 - Prepare Mixed Micro Solution by Combining MicroStocks in Part 1 into 8L Carboy

Nutrient	Separate Stock Concentration	mls for 8L carboy	Final Concentration
H3BO3	0.4560M	120	7.13mM
MnCl2 * 4H2O	0.37M	160	7.40mM
ZnSO4 * 7H2O	0.064M	120	0.96mM
CuSO4 * 5H2O	0.052M	80	0.52mM
(NH4)6Mo7O24 * 2H2O	1.01mM	80	0.01mM

Measure amts in highlighted column from the individual micro bottles above.

Mix all in a single 8 L Carboy

Bring to 8 L with 7440 mL of deionized water

Tab. 15 Nutrient solution recipe

3.2.7 pH and EC evolution

pH and EC were automatically measured and adjusted on a continuous basis by the control system (Fig. 43, Fig. 44). Sampling of hydroponics solution was performed at the beginning and end of each 4 week nutrient solution interval. Control was excellent with deviations from setpoint only during initial operation and equilibration and during solution changes. Results of nutrient solution analysis are presented in Tab. 16 and Tab. 17. Observed pH and EC levels deviated from the setpoints at the end of the experiment in both chambers and were direct results of the cessation of nutrient circulation to the plants.

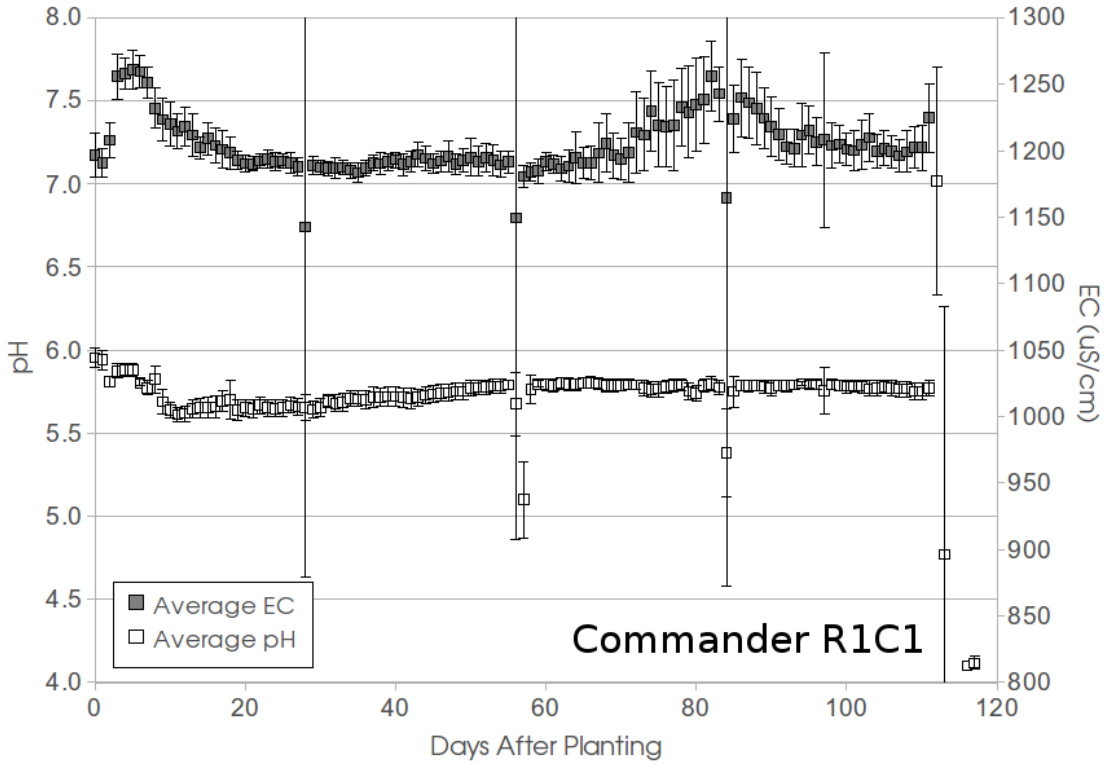


Fig. 43 UoGuelph: Electrical conductivity (EC) and pH control during growth and development of the durum wheat cultivar Commander grown in SEC2 chamber 1

Tab. 16 Results of nutrient solution analysis during growth and development of durum wheat cultivar Commander

Sample date	NO3-N ppm	P ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	S ppm	NH4-N ppm	Na ppm	Zn ppm	Mn ppm	Cu ppm	Fe ppm	B ppm	Mo ppm	Si ppm
start	132.00	16.44	128.87	120.64	24.35	4.00	102.21	<1.00	8.98	0.07	0.49	0.04	2.75	0.12	0.03	<0.10
end	110.00	<1.00	34.25	137.46	41.27	<1.00	162.56	1.67	<0.50	0.03	0.03	0.04	2.87	0.25	<0.01	<0.10
start	115.00	13.02	114.14	120.29	27.86	3.00	110.32	<1.00	4.81	0.03	0.24	0.08	2.74	0.18	<0.01	<0.10
end	95.00	<1.00	<1.00	154.39	62.17	<1.00	273.5	<1.00	<0.50	0.01	0.01	0.04	4.14	0.31	<0.01	<0.10
start	133.00	17.01	132.43	114.74	23.46	4.00	98.93	<1.00	7.06	0.01	0.42	0.04	2.72	0.12	0.01	<0.10
end	111.00	<1.00	27.43	141.33	60.62	<1.00	228.35	1.85	<0.50	0.01	0.01	0.02	3.54	0.22	<0.01	<0.10
start	131.00	17.83	131.25	116.86	24.01	4.00	101.99	<1.00	7.14	0.06	0.43	0.05	2.73	0.09	<0.01	<0.10
end	125.00	<1.00	143.49	94.87	32.92	<1.00	118.02	2.53	<0.50	0.01	0.02	0.03	1.9	0.1	0.01	<0.10

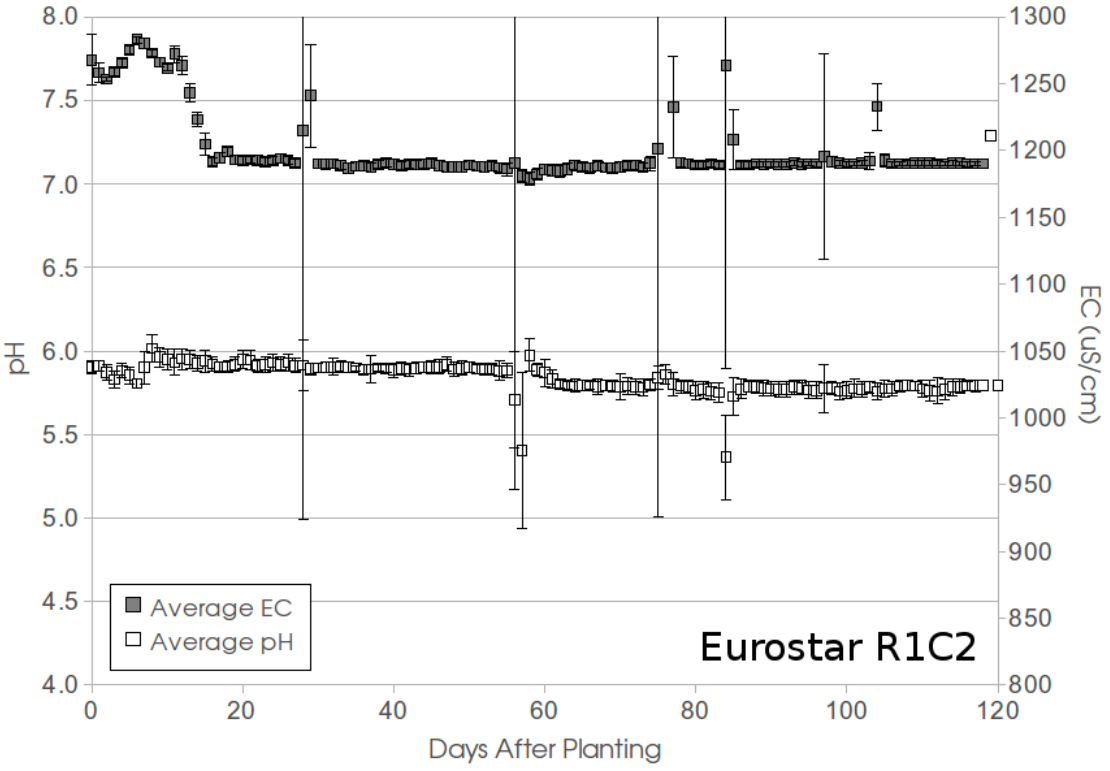


Fig. 44 UoGuelph: Electrical conductivity (EC) and pH control during growth and development of the durum wheat cultivar Eurostar grown in SEC2 chamber 2

Tab. 17 Results of nutrient solution analysis during growth and development of durum wheat cultivar Commander

Sample date	NO3-N ppm	P ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	S ppm	NH4-N ppm	Na ppm	Zn ppm	Mn ppm	Cu ppm	Fe ppm	B ppm	Mo ppm	Si ppm
start	132.00	15.93	128.54	117.47	24.24	4.00	103.02	<1.00	7.31	0.02	0.44	0.04	2.85	0.12	0.01	<0.10
end	108.00	2.16	59.57	119.1	30.73	2	124.29	1.27	<0.50	0.03	0.03	0.1	2.47	0.2	<0.01	<0.10
start	133.00	15.86	126.88	115.63	23.46	4.00	100.85	<1.00	7.09	0.01	0.43	0.04	2.81	0.12	<0.01	<0.10
end	92.00	<1.00	<1.00	148.27	49.71	<1.00	232.57	<1.00	<0.50	0.01	0.03	0.09	3.79	0.29	0.02	<0.10
start	128.00	16.8	130.29	113.84	23.18	4.00	97.81	<1.00	6.71	0.01	0.43	0.04	2.73	0.12	<0.01	<0.10
end	104.00	<1.00	5.94	130.77	59.08	<1.00	203.85	<1.00	<0.50	0.01	0.02	0.03	3.23	0.2	<0.01	<0.10
start	134.00	16.8	131.85	117.06	23.95	4.00	101.92	<1.00	6.59	0.06	0.43	0.04	2.67	0.09	<0.01	<0.10
end	113.00	<1.00	77.49	97.42	35.13	<1.00	108.54	3.09	<0.50	0.02	0.01	0.07	2.33	0.1	<0.01	<0.10

3.2.8 Nutrient solution T

A nutrient solution cooling system was used in this trial. Temperature was maintained at 21 C for the duration of the experiment with an excellent chiller.

3.3 Monitoring of plant development

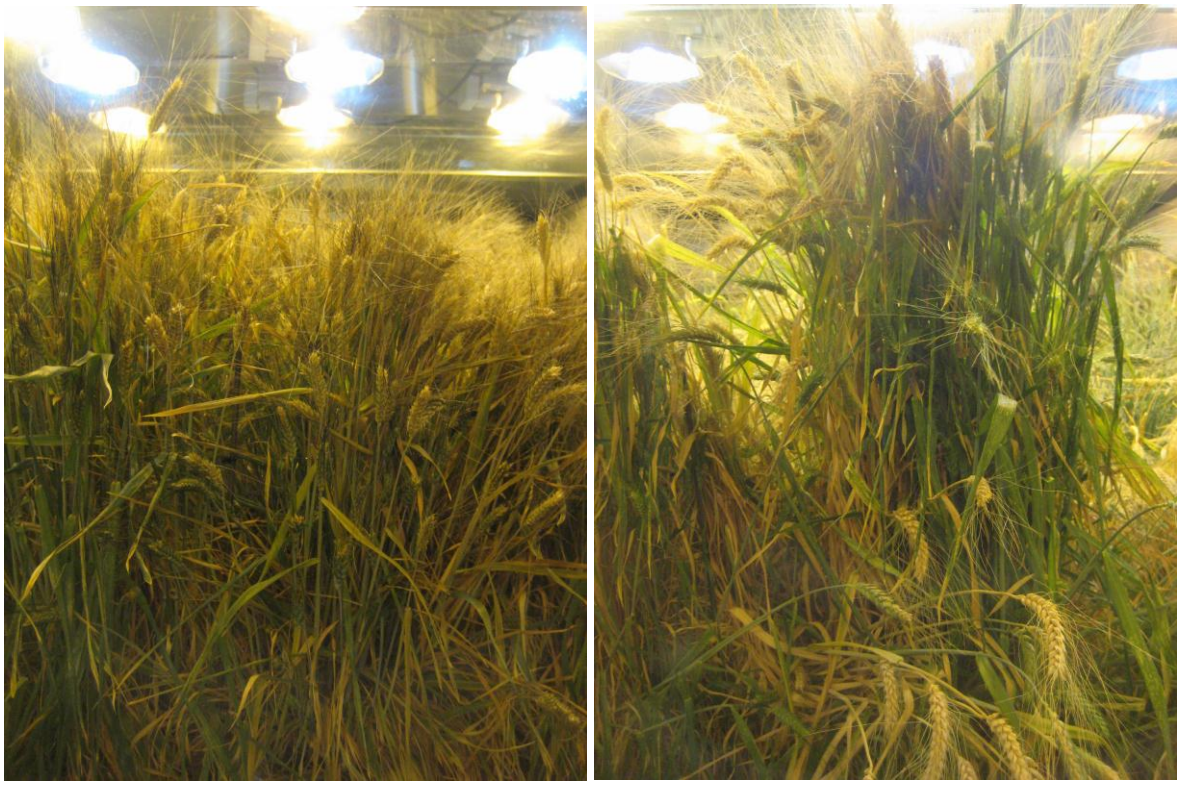
The 2 durum wheat cultivars were grown for nearly 4 months.
119 days for Commander.
126 days for Eurostar.

3.3.1 Photographic follow-up

Given the usage of a sealed chamber photographic follow-up wasn't possible.

Commander (left) and Eurostar (right) at 2 weeks after planting

Commander (left) and Eurostar (right) at 8 weeks after planting.



Commander (left) and Eurostar (right) at 16 weeks after planting.

3.3.2 Growth assessment

Given the usage of a sealed chamber, only carried out at harvest, see 3.4.

3.3.3 Gas exchange data

Carried out at chamber level, see 3.2.2, 3.2.4, 3.2.5

3.4 Harvest results

Results from all cultivars exceeded recorded field production yields by 14 and 41 percent in Commander and Eurostar (Clark et al., 2005, 2009), demonstrating that the sealed environments were suitable for durum wheat growth and development. In this trial, the least productive cultivar was Commander, with a kernel mass of 0.40 kg m^{-2} whereas Eurostar produced over 0.58 kg m^{-2}. Eurostar also had the highest harvest index at 0.22 compared to 0.17 with Commander. Comparative harvest indexes are not available for these cultivars as it is not a commonly reported parameter in documented cultivar descriptions. Possible chamber differences preclude drawing definitive conclusions on the most suitable cultivar for ALS use from this single replicate. To improve statistical reliability, crops should be grown in alternate chambers. Additional growth parameters are presented in Tab. 18.

Tab. 18 UoGuelph - Summary of durum wheat growth parameters.

Cultivar	Total DW (g)	Height (cm)	Roots (g)	Straw (g)	Kernels (g)	Number of Plants	100 kernel weight	kg/ha equivalent
Avonlea	12 054	86	1 291	8 630	2 133	469	4.17	4 266
Commander	11 912	73	1 465	6 803	2 009	457	4.64	4 019
Eurostar	13 474	85	1 244	7 835	2 912	438	3.02	5 824
Strongfield	13 531	84	1 435	8 325	3 771	466	4.57	7 542

Plant growth parameters measured at the end of the growth period were dry weight of roots, kernels, and straw. Data was collected on a per pad basis for the entire chamber. Results of fibre/lignin analysis are shown in Tab. 21 and Tab. 22. Proximate analysis are shown in Tab. 23 and Tab. 24.

Tab. 19 UoGuelph: results of dry mass analysis for durum wheat cultivar Commander

Trough number	Plot number	Heads number			Plant height avg (cm)	Dry Weight(g)					Total DW above ground	Cultivar % lodged	Number of Plants	Rockwool DW(g)
		Yellow heads	Green heads	Total # heads		Heads str. and seeds	Seeds only	Straw only	Roots with rockwool	Roots only				
1	1	371	75	446	72	243.6	109.8	556.1	259.9	122.4	799.7	50	30	137.5
1	2	261	7	268	82	243.6	158.3	471.7	82.3	82.3	715.3	50	29	135.4
1	3	293	3	296	74	287.1	188.0	409.3	80.9	80.9	696.4	90	30	132.8
Total		925	85	1010		774.3	456.1	1437.1	423.1	285.6	2211.4		89	405.7
2	4	260	35	295	78	261.1	146.3	463.3	248.6	118.5	724.4	50	31	130.1
2	5	247	127	374	76	327.8	202.3	529.6	242.9	113.9	857.4	90	28	129.0
2	6	223	125	348	81	323.4	215.6	452.8	233.7	97.4	776.2	50	21	136.3
Total		730	287	1017		912.3	564.2	1445.7	725.2	329.8	2358.0		80	395.4
3	7	203	98	301	72	146.1	66.1	317.6	197.7	69.4	463.7	50	29	128.3
3	8	295	102	397	74	269.7	143.0	448.7	230.0	103.3	718.4	52	31	126.7
3	9	186	133	319	78	294.2	188.6	484.0	243.3	105.7	778.2	52	27	137.6
Total		684	333	1017		710.0	397.7	1250.3	671.0	278.4	1960.3		87	392.6
4	10	360	47	407	69	192.3	70.4	426.7	239.1	105.4	619.0	50	32	133.7
4	11	267	79	346	72	243.9	140.8	407.8	225.7	94.5	651.7	70	31	131.2
4	12	247	70	317	74	209.8	122.3	486.2	207.0	81.2	696.0	90	32	125.8
Total		874	196	1070		646.0	333.5	1320.7	671.8	281.1	1966.7		95	390.7
5	13	493	60	553	65	188.6	40.2	458.1	232.2	115.4	646.7	85	40	116.8
5	14	357	67	424	65	224.5	106.6	458.1	216.9	100.1	682.6	70	37	116.8
5	15	191	74	265	65	187.5	111.0	433.4	196.0	74.5	620.9	50	29	121.5
Total		1041	201	1242		600.6	257.8	1349.6	645.1	290.0	1950.2		106	355.1
Total in CH-1		4254	1102	5356		3643.2	2009.3	6803.4	3404.4	1464.9	10446.6		457	1939.5

Tab. 20 UoGuelph: results of dry mass analysis for durum wheat cultivar Eurostar

Trough number	Plot number	Heads number			Plant height avg (cm)	Dry Weight(g)					Total DW above ground	Cultivar % lodged	Number of Plants	Rockwool DW(g)
		Yellow heads	Green heads	Total # heads		Heads str. and seeds	Seeds only	Straw only	Roots with rockwool	Roots only				
1	1	144	120	264	82	197.1	119.0	518.3	209.4	75.2	715.4	90	37	134.2
1	2	191	148	339	75	214.6	123.5	357.8	197.1	58.2	572.4	85	28	138.9
1	3	222	135	357	78	267.1	141.2	528.9	186.2	62.2	796.0	90	28	124.0
Total		557	403	960		678.8	383.7	1405.0	592.7	195.6	2083.8		93	397.1
2	4	171	57	228	86	134.0	79.9	367.1	194.5	52.0	501.1	90	24	142.5
2	5	380	170	550	90	497.4	315.1	652.3	257.1	108.8	1149.7	20	31	148.3
2	6	442	185	627	96	621.6	392.2	759.5	266.8	124.8	1381.1	95	30	142.0
Total		993	412	1405		1253.0	787.2	1778.9	718.4	285.6	3031.9		85	432.8
3	7	265	122	387	89	30.7	232.2	619.9	239.4	101.2	650.6	55	29	138.2
3	8	382	166	548	90	553.0	350.1	632.1	264.6	124.2	1185.1	80	23	140.4
3	9	78	24	102	84	76.9	47.6	263.4	172.8	35.8	340.3	90	30	137.0
Total		725	312	1037		660.6	629.9	1515.4	676.8	261.2	2176.0		82	415.6
4	10	243	101	344	91	285.6	181.4	430.0	239.9	100.0	715.6	50	33	139.9
4	11	522	214	736	91	793.1	512.6	868.9	312.1	164.0	1662.0	90	29	148.1
4	12	200	79	279	87	271.1	167.1	577.3	200.4	52.7	848.4	90	30	147.7
Total		965	394	1359		1349.8	861.1	1876.2	752.4	316.7	3226.0		92	435.7
5	13	160	117	277	78	117.6	66.7	400.1	197.7	57.8	517.7	70	30	139.9
5	14	229	180	409	71	170.6	91.3	469.1	216.2	75.4	639.7	90	28	140.8
5	15	142	146	288	86	165.6	91.7	390.0	196.7	51.3	555.6	90	28	145.4
Total		531	443	974		453.8	249.7	1259.2	610.6	184.5	1713.0		86	426.1
Total in CH-2		3771	1964	5735		4396.0	2911.6	7834.7	3350.9	1243.6	12230.7		438	2107.3

Tab. 21 UoGuelph: results of triplicate fibre/lignin analysis in durum wheat cultivar Commander

Sample number	Material	Cultivar	NDF %	ADF %	Lignin %
1	mix seeds	Commander	26.19	5.37	0.59
2	mix seeds	Commander	23.99	4.96	0.61
3	mix seeds	Commander	24.75	5.58	0.79
4	mix straw	Commander	53.03	34.41	5.18
5	mix straw	Commander	54.04	28.79	3.17
6	mix straw	Commander	54.45	29.76	3.08
7	mix roots	Commander	54.53	22.59	2.98
8	mix roots	Commander	50.51	21.51	3.17
9	mix roots	Commander	51.46	22.42	3.00

Tab. 22 UoGuelph: results of triplicate fibre/lignin analysis in durum wheat cultivar Eurostar

Sample number	Material	Cultivar	NDF %	ADF %	Lignin %
1	mix seeds	Eurostar	24.77	4.71	0.67
2	mix seeds	Eurostar	32.22	5.02	0.57
3	mix seeds	Eurostar	29.87	5.72	0.66
4	mix straw	Eurostar	49.70	29.92	4.35
5	mix straw	Eurostar	47.65	30.39	3.93
6	mix straw	Eurostar	48.59	29.30	3.41
7	mix roots	Eurostar	52.30	25.55	4.01
8	mix roots	Eurostar	53.16	26.10	4.33
9	mix roots	Eurostar	51.98	25.75	5.68

Tab. 23 Results of proximate analysis for durum wheat cultivar Commander

Sample number	Material	% Fat	% Protein	% Moisture	% Ash	% CHO
1	seeds	1.14	15.50	10.44	2.15	70.77
2	seeds	1.48	15.51	10.33	2.13	70.56
3	seeds	1.34	15.44	10.53	2.13	70.56
Average		**1.32**	**15.48**	**10.43**	**2.14**	**70.63**

Tab. 24 Results of proximate analysis for durum wheat cultivar Eurostar

Sample number	Material	% Fat	% Protein	% Moisture	% Ash	% CHO
1	seeds	1.63	16.03	9.93	2.75	69.66
2	seeds	1.72	15.54	10.51	2.53	69.71
3	seeds	1.93	15.93	10.83	2.49	68.82
Average		**1.76**	**15.83**	**10.42**	**2.59**	**69.40**

Tab. 25 Results of tissue analysis for durum wheat cultivar Commander

Sample name	Material	Total C %	N %	P %	K %	Mg %	Ca %
1	seeds	41.50	2.63	0.45	0.52	0.14	0.05
2	straw	41.40	2.10	0.47	3.57	0.31	1.04
3	roots	36.00	5.62	0.6	6.91	0.17	0.55

Tab. 26 Results of tissue analysis for durum wheat cultivar Eurostar

Sample name	Material	Total C %	N %	P %	K %	Mg %	Ca %
1	seeds	41.50	2.45	0.47	0.47	0.15	0.06
2	straw	41.50	2.52	0.53	0.61	0.16	0.05
3	roots	38.70	2.55	0.64	4.66	0.26	0.78

3.5 Quality tests

During the quality analysis performed at the Cereal Research Centre, we were again fortunate to get results from field data for the same cultivars. The CHK 'Y' refers to data from field trials that was analyzed at the same time (Tab. 27). The protein levels were quite good.

						Semolina Testing									
ID	CHK	Protein (asis%)	Protein (DM%)	Gluten Index	Falling Number	Semolina Yield%	Semolina Ash %	Moisture	Protein (asis%)	Protein (14%)	Semolina Colour b*	Alveograph P	Alveograp h L	Alveograph W	Alveograph P/L
mean of checks		12.17	13.63	78	492	67.10	0.66	15.82	10.61	10.88	25.24	107	45	181	2.40
09 Morse	Y	13.87	15.51	43	521	65.7	0.64	16.14	11.75	12.04	23.79	87	44	135	1.97
09 Commander	Y	12.83	14.33	96	423	68.3	0.67	15.55	11.70	11.90	25.89	127	46	226	2.77
09 Eurostar	Y	9.81	11.05	94	532	67.3	0.68	15.76	8.40	8.70	26.04	108	44	181	2.45
ESA-Commande	N	14.26	15.53	73	438	61.6	0.77	16.32	12.39	12.72	25.78	112	66	260	1.71
ESA-Eurostar	N	14.62	15.73	93	203	58.7	1.00	15.97	12.30	12.61	25.81	128	66	305	1.94

Tab. 27 Results of analysis from the Cereal Research Centre

The protein content is quite good both in grain and semolina flour. The gluten index was low for Commander compared to this check but still within the normal range for the variety and would not impact quality. The Eurostar is still quite high, as expected being a high gluten cultivar.

Semolina yield was lower after milling likely due to a low test weight, but the remaining factors are good. In fact alveograph L, which is extensibility, is better than checks and alveograph W, which is a a measure of strength, is also a slightly higher.

The conclusion for the durum wheat quality results that there is less semolina than field grown durum, but it will make good pasta. This could possibly be corrected by growing Eurostar longer as there was some green seed in the harvest, indicating it was harvested early.

3.6 General conclusions

When the results of this and the previous trial with Strongfield and Avonlea are compared, results show higher yields in the Eurostar and Strongfield cultivars, however conclusions regarding the best candidate for closed environment production cannot be made on a single case study. Both of the highest yielding crops were grown in SEC2 chamber 2, indicating a possible chamber effect. The initial consideration for the discrepancy between the two chambers was the lower rate of leakage in chamber 1 when compared to chamber 2 (<1% vs. >5%), resulting in possible negative effects from higher concentrations of oxygen and ethylene. Biweekly venting was employed in an effort to mitigate this effect in the next trials, however the highest yield was still observed in chamber 2. One of the additional variables that differs between the two chambers is air velocity. Chamber 2 air speed is higher than that of chamber 1, which may allow improved gas exchange in the dense durum wheat canopy. Faster air velocity may also explain the large differences in evapotranspiration that was noted between the two chambers.

All cultivars demonstrated a marked decrease in NCER during the first nutrient solution change, demonstrating the usefulness of this measurement in advanced life support research. Study of the cause of this decrease, and methods for improved nutrient delivery should be a priority for future research to increase yields beyond those observed here.

In order to improve data capture and system control and allow for future sensor expansion, further testing on wheat cultivars requires modification of the SEC2 control system. The current system, based on MS-DOS was installed in 1995 and last updated in 1999, cannot be modified. Prior to any future plant trials, a new control system provided by Argus Control Systems will be installed and tested.

3.7 References

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4 Potato (UGent)

Potato in vitro plants were obtained from UGent consultant HZPC.
A similar type of gully-setup in a test-room was used in parallel (see TN 98.4.12, 4.3.12).

As for the first bench test a batch of in-vitro plants of the selected cultivars was distributed for culture at UGent and UCL.
The results from bench test 2 are reported in this document (this section for UGent, see 5 for UCL results).

The in-vitro plants obtained from HZPC were grown for 3 weeks in-vitro at HZPC, subsequently transported to UGent and UCL and elongated there in the in-vitro boxes for 1 more week (see TN 98.4.12). This elongation step should have been accomplished by transplanting the acclimated plants from vitro-boxes to NFT system for 4 to 5 days. Indeed, over 3 weeks of culture the agar medium doesn't provide optimal growth conditions anymore which can lead to weakened plants.

The in-vitro plants of the Innovator cultivar were clearly smaller compared to the other 3 cultivars (Annabelle, Bintje and Desiree). These 4 cultivars were chosen based on a preliminary listing derived in TN 98.3.1.

4.1 Experimental Layout

4.1.1 Measuring Plan

As an overview, the list of parameters to be measured from TN 98.4.11 is repeated below, and a measuring timeline plan is added.

Tab. 28 UGent - Parameters and frequency of logging

		Frequency logging	**Online/ Manual**
Fixed	**airflow**		
	Solution flow	Weakly check	Manual
Daily measurements	**Light quantity**	5 min	Online
	Air temperature	30sec and 5 min	Online
	Humidity	30sec and 5 min	Online
	CO_2 in air	5 min	Online
	O_2 in air	5 min	Online
	Ethylene	1 min	Online
	Oxygen in solution	weekly	Manual
	pH	5 min	Online

	EC	5 min	Online
	Solution temperature	5 min	Online
	Weight gully 4	1 h	Online
	EC stock solution used	weekly	Manual
	Water stock used	weekly	Manual
	Acid/Base stock used	weekly	Manual
	Video imaging	1 h	Online
Weekly measurements	**Plant height**		Manual
	Number of stolons		Manual
	Number of tubers		Manual
	Date of stolon appearance		Manual
	Date of tuber appearance		Manual
	Date of flowering		Manual
Week 3, 8 and harvest	**Complete nutrient solution composition control**		Manual
Harvest	**Foliage fresh weight**		Manual
	Stem fresh weight		Manual
	Root fresh weight		Manual
	Tuber fresh weight		Manual
	Foliage dry weight		Manual
	Stem dry weight		Manual
	Root and stolon dry weight		Manual
	Nutritional analysis by IPL, average per category		Manual

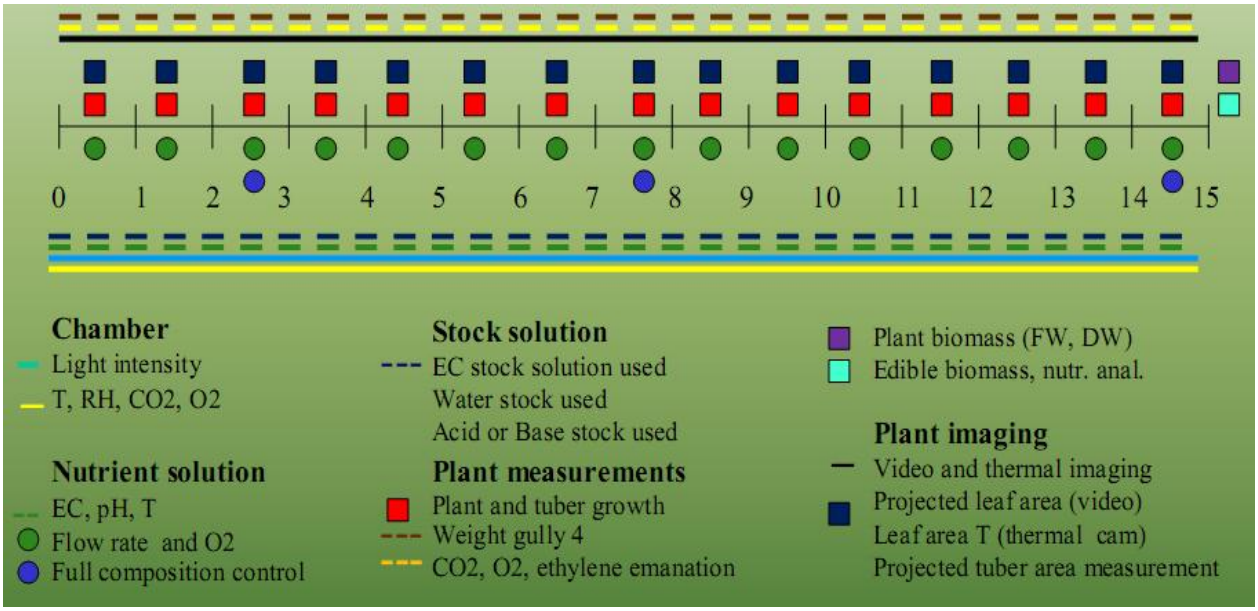


Fig. 45 UGent - Measuring schedule

4.1.2 Setup bench test UGent growth chamber

The setup with the 4 gullies is shown below. Air enters from the left perforated wall and exits through the right one. For more details see TN 98.4.11.
See 4.3.1 overviews of the plant growth shown as overviews in the configuration of the left panel of Fig. 46.

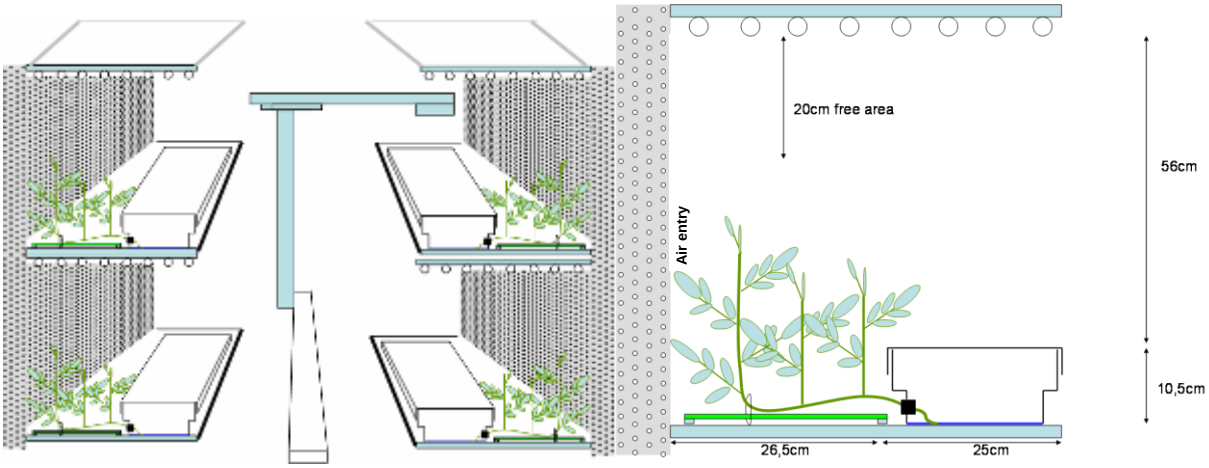


Fig. 46 UGent - Setup

4.2 Growth environment follow-up

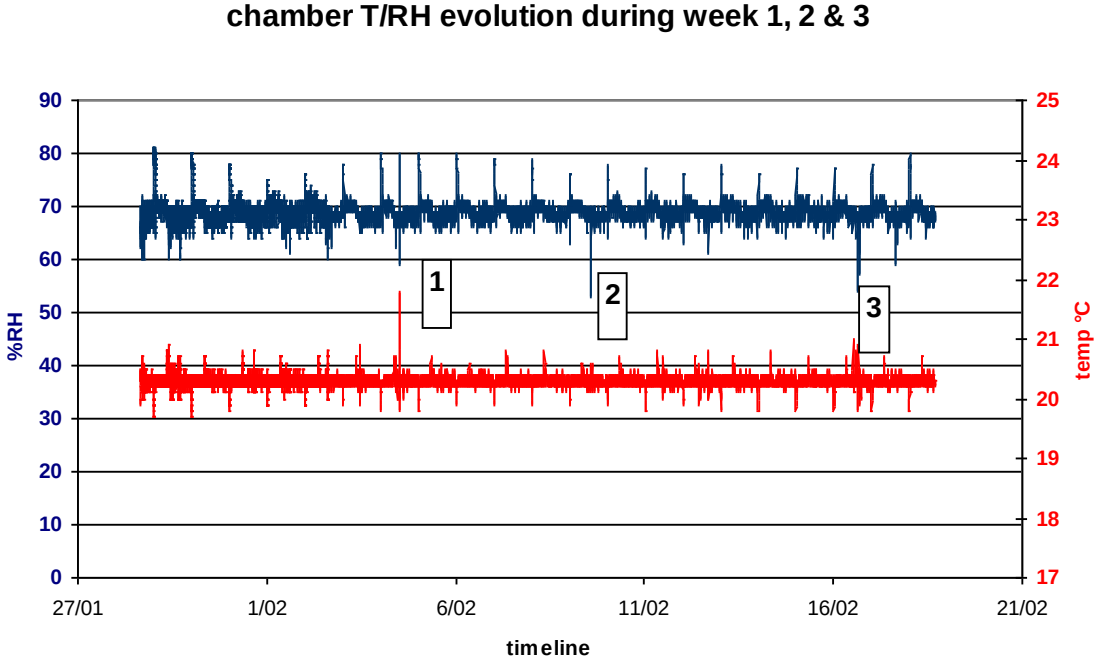
4.2.1 Settings

Tab. 29 UGent - Settings

Room	Nutritive solution
RH 70%	pH 5.5
T 20°C	EC 1800
	T 18.5 °C

4.2.2 Chamber T/RH evolution

Chamber level T and RH remained stable at the setpoints 20.3 degrees and 70% humidity.



remark	date	reason
1	4/feb	maintenance Daikin cooler, see graph 33b
2	9/feb	%RH dropped to 53%, caused by opening the door during pH sensor calibration
3	16/feb	%RH dropped to 54%, caused by opening the door during pH sensor calibration

Fig. 47 UGent - RH/ T growth room

4.2.3 Chamber CO_2 level

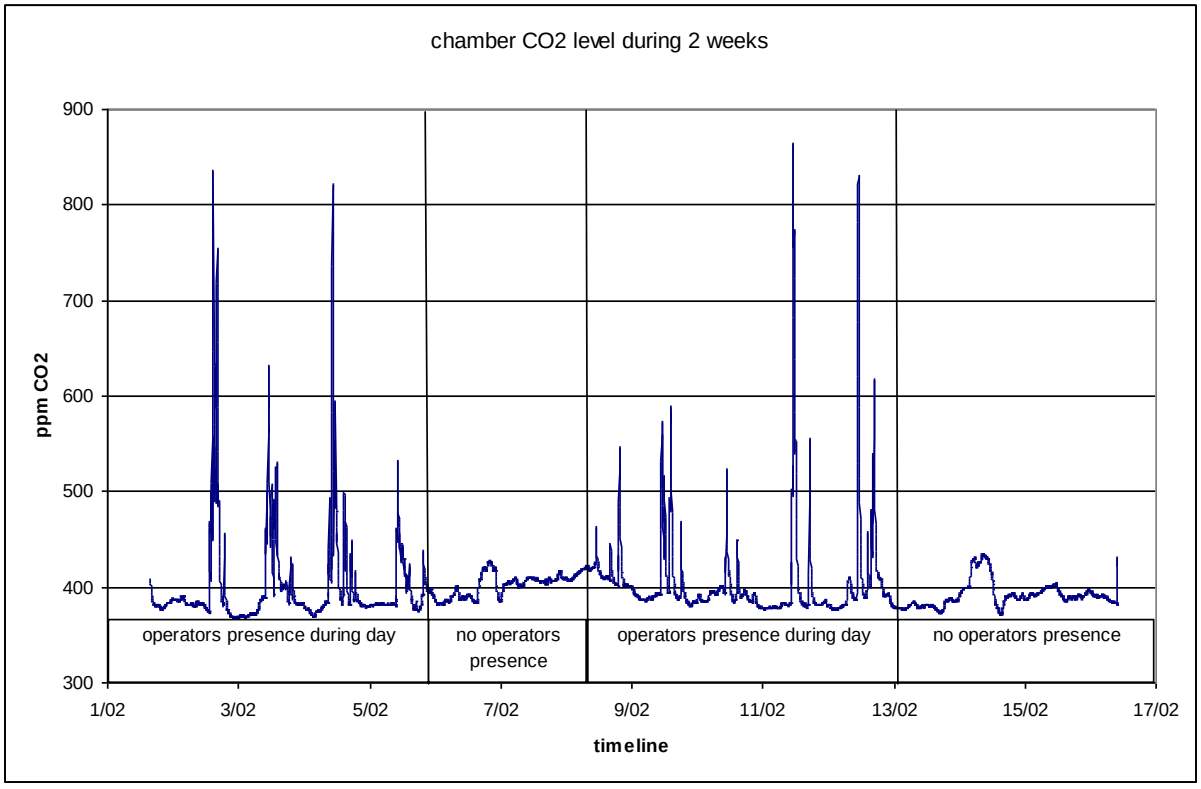


Fig. 48 UGent - CO_2 logging growth room for a long period

CO_2 levels corresponded to ambient values. Operator presence induced peaks of CO_2.
The O_2 sensor shows considerable sensor drift, and needs calibration in order to readout the ambient value thus measurements are not presented here.

4.2.4 Nutrient Solution Environment

4.2.5 pH and EC evolution

Automatic pH and EC compensation (and associated automated water addition) were not used during BT2. The sensor problems as encountered during BT1 could not be excluded from occurring again, despite minor modifications (see TN 98.4.12). Due to time constraints additional hardware pre-tests could not be carried out to solve the malfunction. As the cause of the BT1 plant health problems was not known, the experimental protocol was kept as simple as possible with a minimum of setup components involved.

At the start of the culture alcalinisation of the growth solution was compensated by H_3PO_4 addition. After nutrient exchange to tuberisation solution, KOH was used to compensate the acidification.

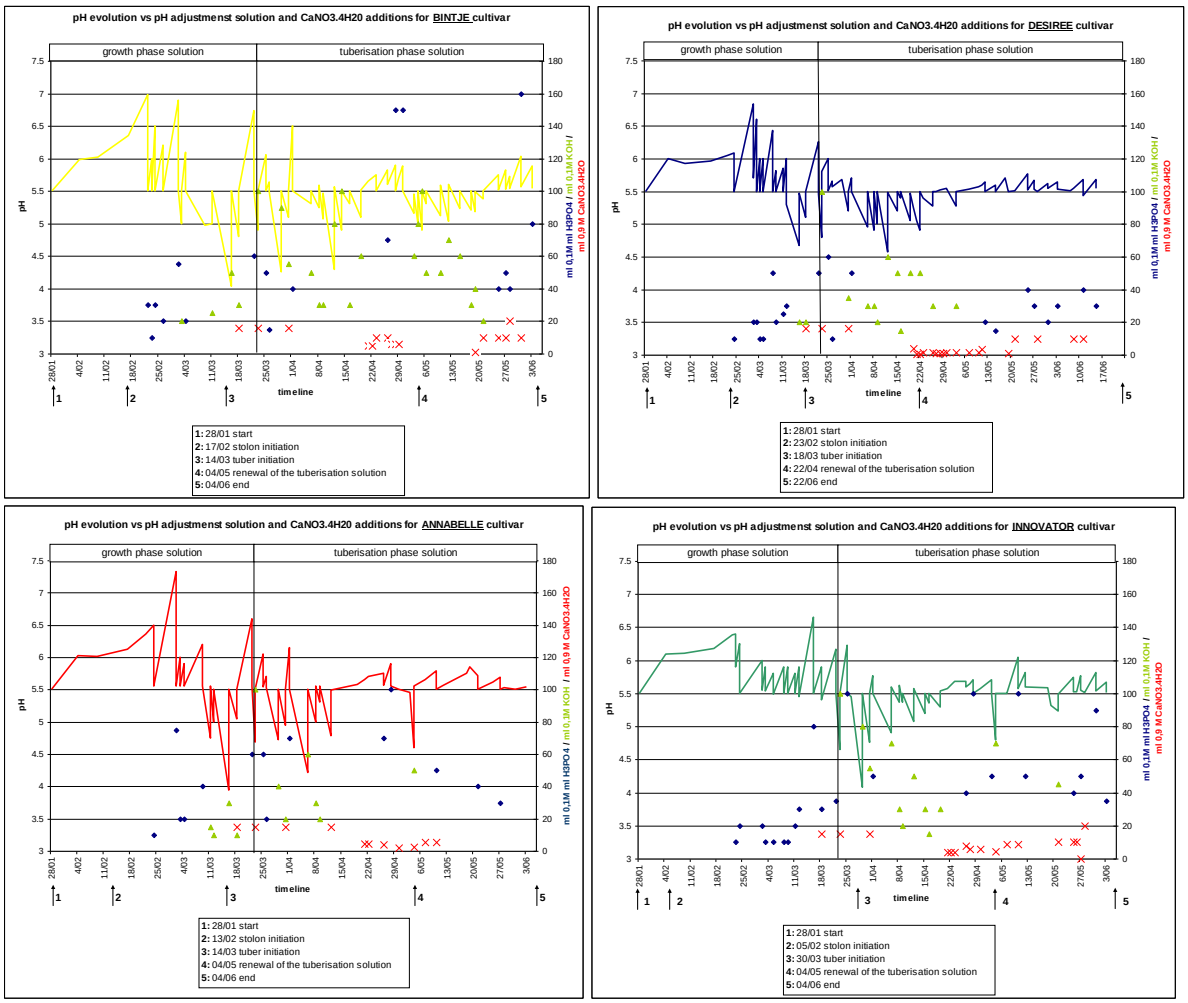


Fig. 49 UGent - pH data of each cultivar

pH was adjusted with either H_3PO_4 or KOH was carried out manually, since the magnitude of the effect of additions of Ca-nitrate was unknown, and control was limited to either acid or base addition.
The amounts needed were small, hence deviations were within the foreseen range (Fig. 51).

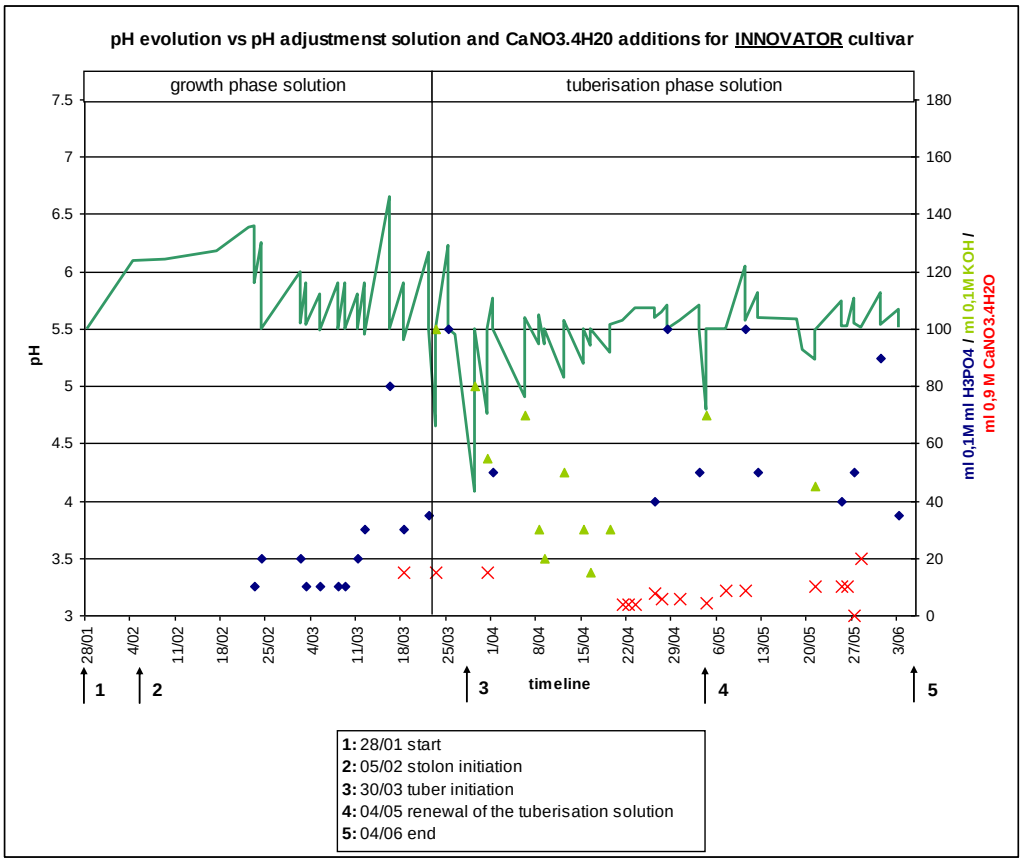


Fig. 50 UGent - Detailed pH evolution of innovator cultivar

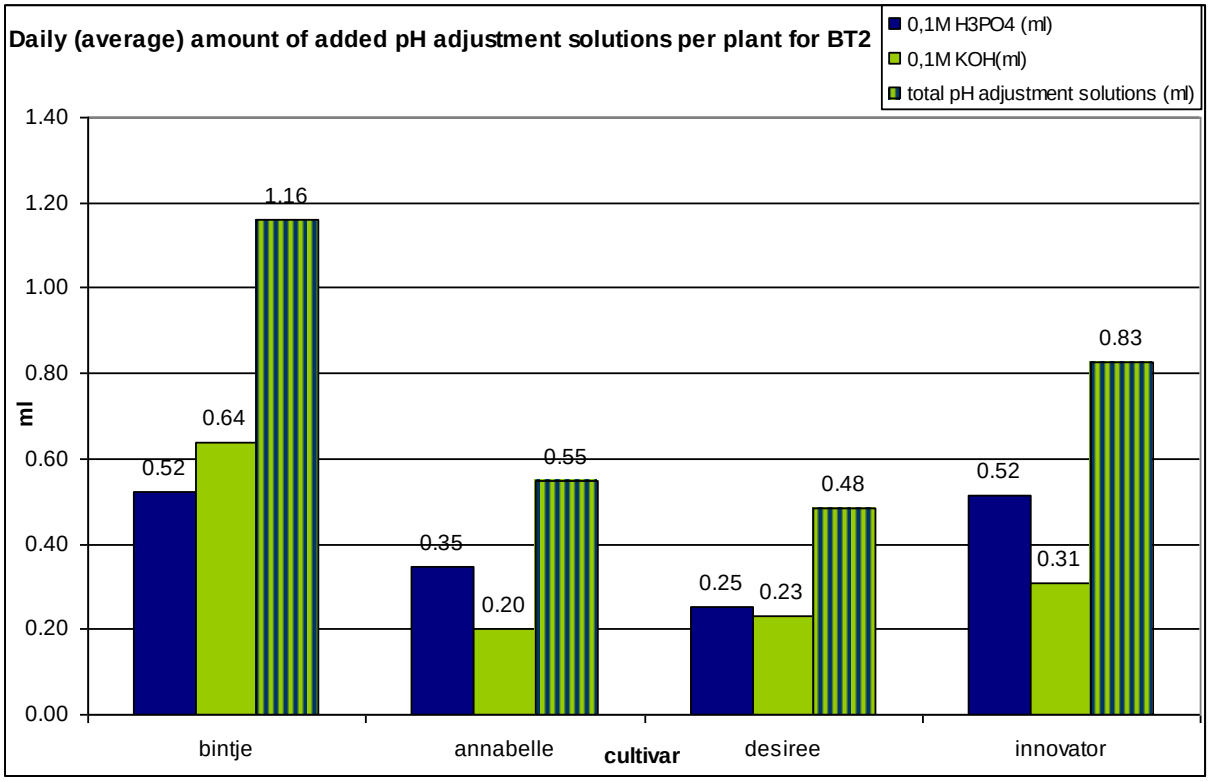


Fig. 51 UGent - Average daily amount of pH adjustment solutions added

EC control was carried out manually for the whole duration of the experiment.
EC compensation solution (K_2SO_4 during start-up growth, K_2SO_4 and K_3PO_4 in equal amounts during tuberisation) addition was triggered by manual level compensation with distilled water (the amounts of liquids added are shown in Fig. 54).

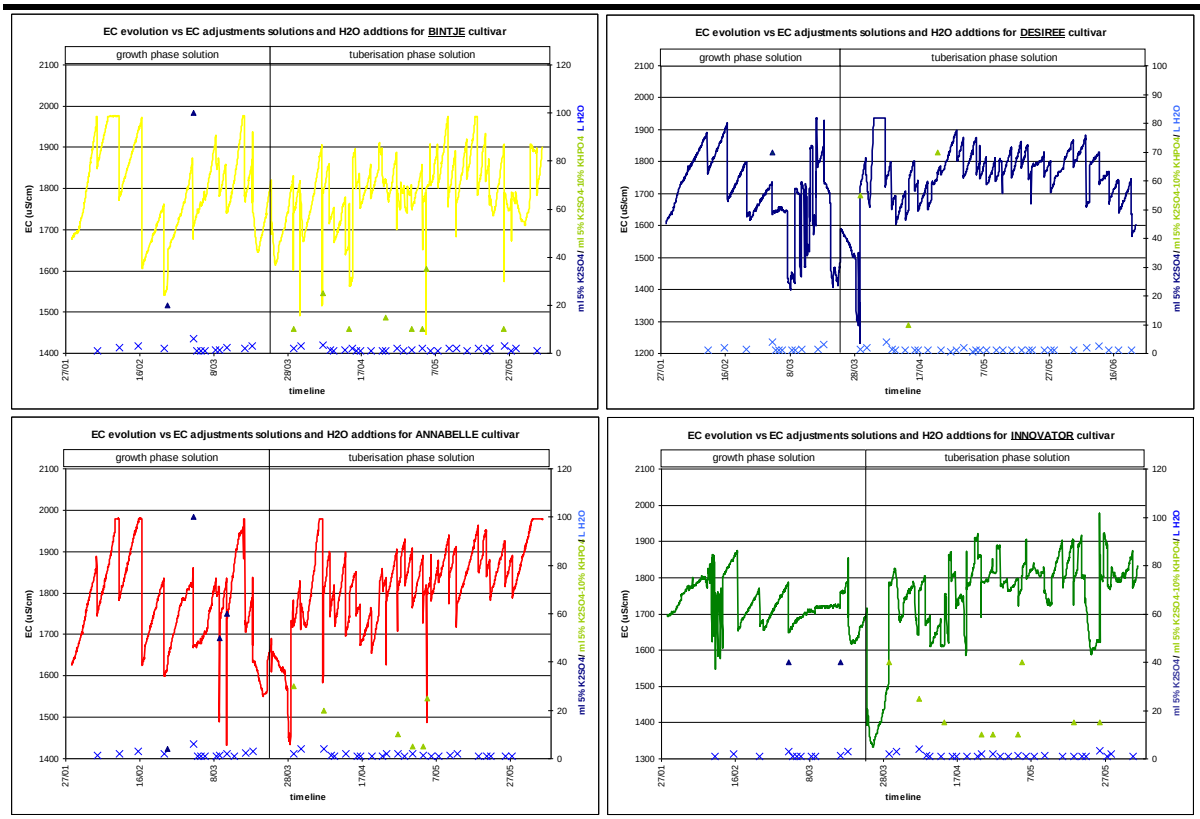


Fig. 52 UGent - EC data of each cultivar

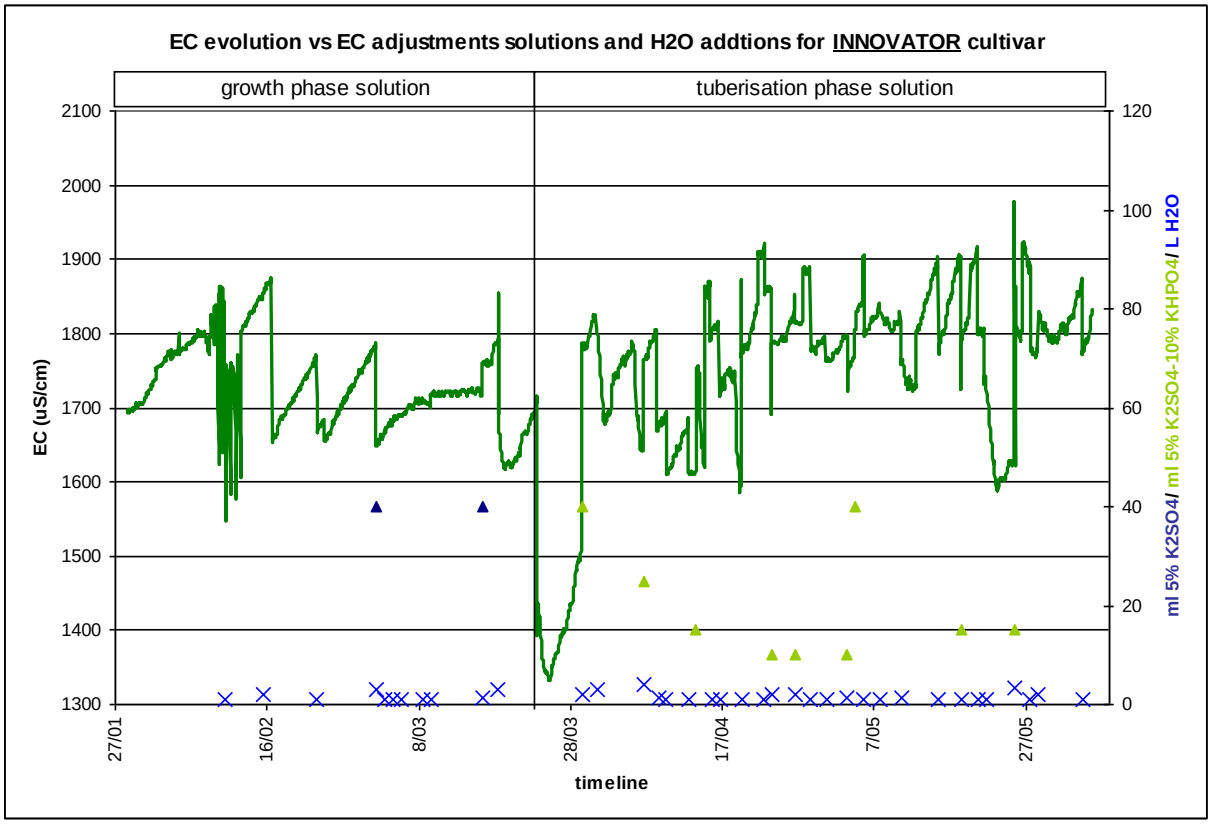


Fig. 53 UGent - Detailed EC evolution from Innovator cultivar

At the beginning of May most Annabelle plants started yellowing and some died (see 4.3.3), hence uptake graphs were not updated. All plants were dead by the end of May.
Plant water uptake is an integrated measurement of transpiration.

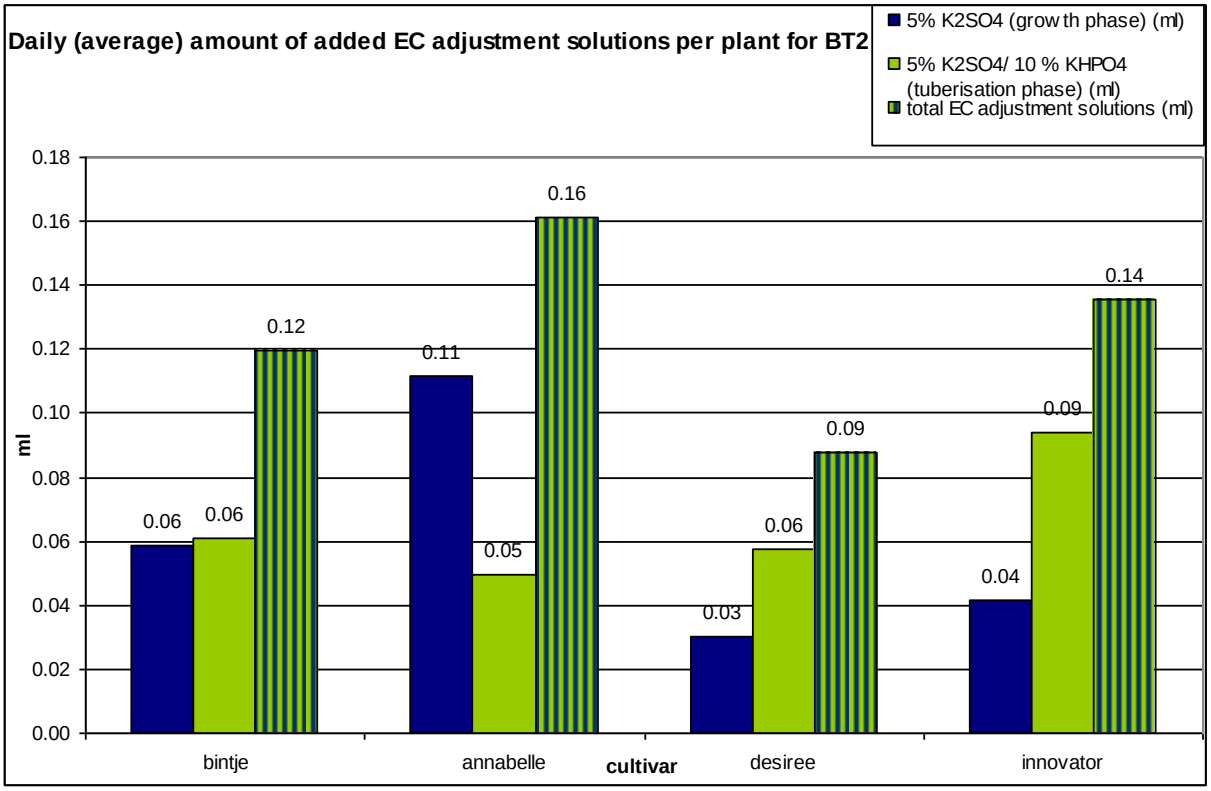


Fig. 54 UGent - Average of daily amount of electrolytes added for EC adjustment

4.2.6 Nutrient solution T

Temperature of the nutrient solution was controlled to approximately 20 degrees. The 2 coolers had a different output, likely due to their position in the chamber. Setpoints were matched to better coincide (see end of Fig. 55).

Total water consumption (Fig. 56) was calculated on the basis of the fresh nutrient solution added, distilled water, pH and EC adjustments. System water consumption (evaporation) was measured with gullies running without plants. It was then possible to back calculate the volume of water evaporated during the entire Bench Test. The volume of water used by the plants corresponds to the total water consumption less the system water consumption.

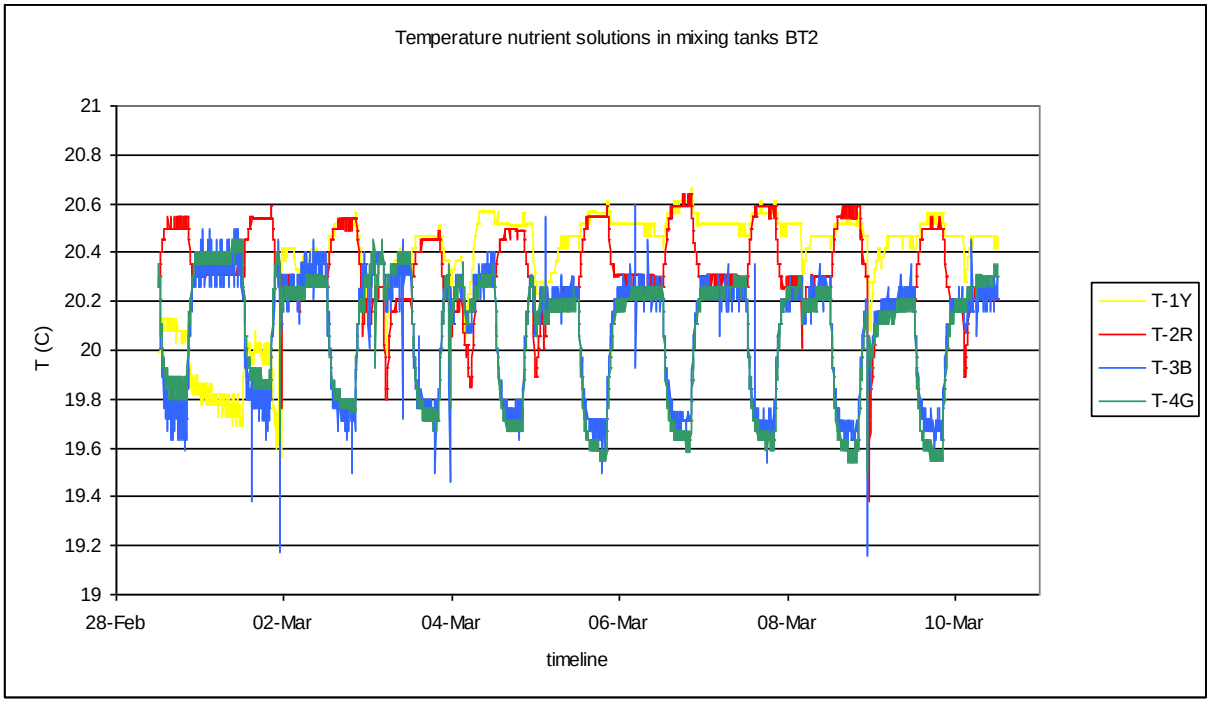


Fig. 55 UGent - Temperature nutrient solution in mixing tanks (setpoint chillers 18,5°C)

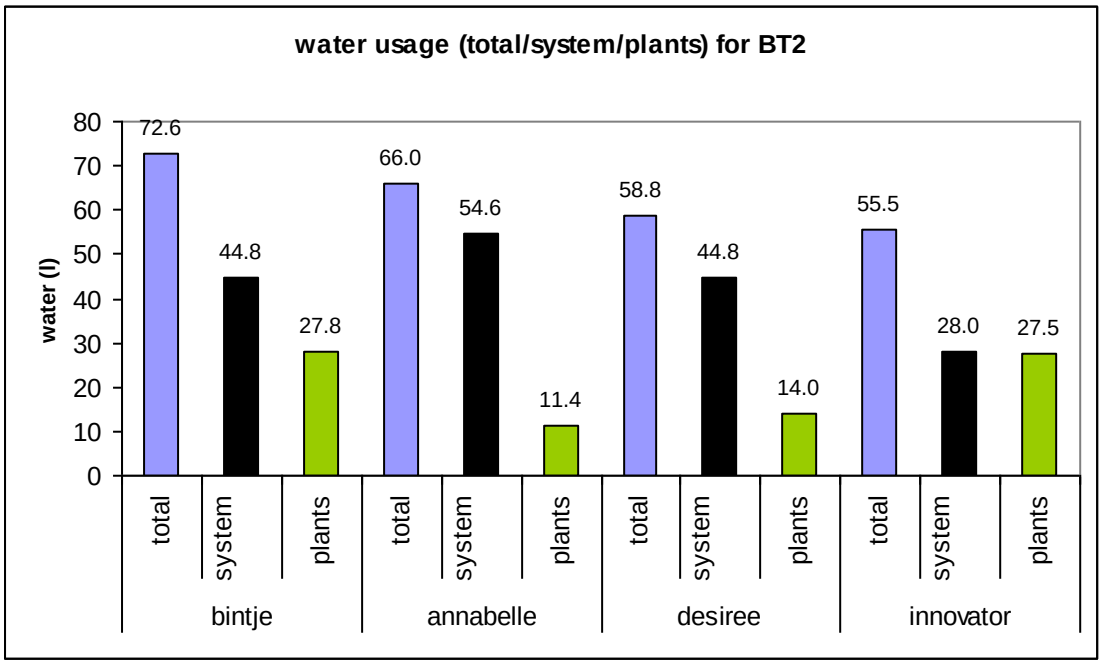


Fig. 56 UGent - Water usage (total-system-plant)

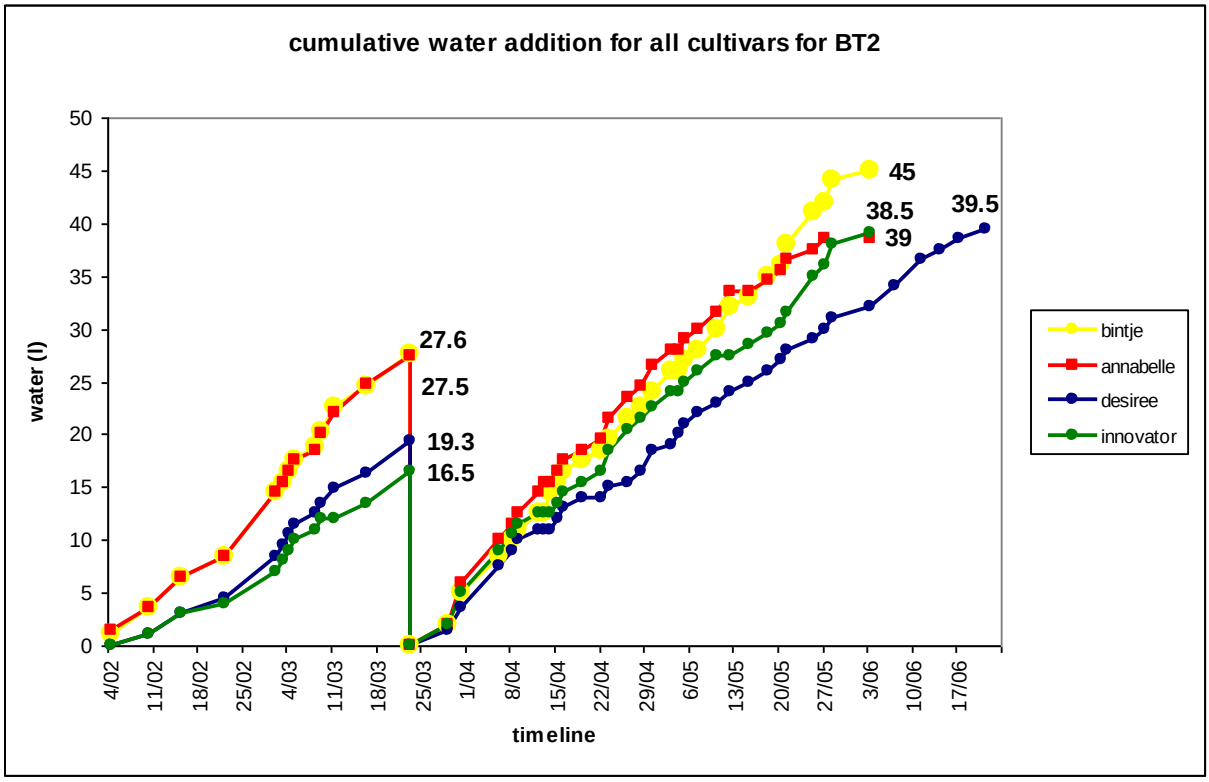


Fig. 57 UGent - Cumulative water addition for all cultivars

4.2.7 Nutrient solution analysis

Tab. 30 UGent - Overview nutrient solution analysis

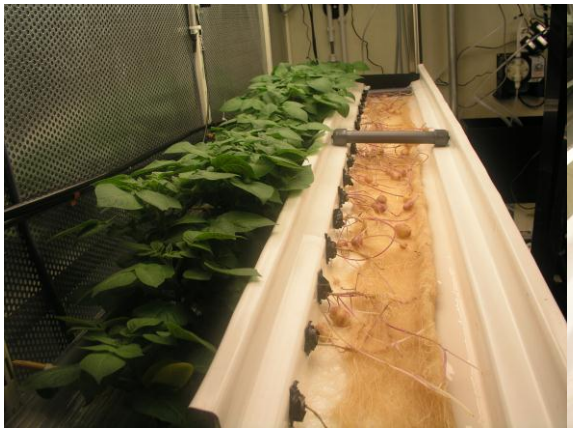
				mmol/l										umol/l				
	date sample		K	Mg	Ca	Na	NH_4	N	P	Cl	SO4	HCO3	Fe	Mn	Cu	Zn	B	Mo
all	28-Jan-10	start GPS	6	1.9	2.2	0.1	0	4.1	1.1	0	4.9	0.3	17.5	5.6	5.6	2.2	21.3	0.3
bintje	23/mrt/10	stop GPS	8.6	1.5	3	0.1	0	0.1	2	0	7.9	0.4	6.9	0.4	**29**	**15**	29.6	0.3
annabelle	23/mrt/10	stop GPS	8.5	1.2	2.3	0.1	0	0.3	1.9	0	7.1	0.3	3.3	1	**39.2**	**59.2**	13	0.2
desiree	23/mrt/10	stop GPS	7.6	2	3.7	0.1	0	0.7	3.1	0	7.6	0.5	6.8	0.5	**37.1**	**26.3**	23.1	0.4
innovator	23/mrt/10	stop GPS	6.9	1.9	3.4	0.1	0	0.2	3.1	0	7.3	0.2	7.5	0.2	**22.6**	**13.8**	20.4	0.2
all	23/mrt/10	start TS - without mn-cu,zn complex	6.2	1.5	0	0	0	0.1	4.3	0	2	0.3	21.9	0.4	0.1	0.5	20.4	0.3
bintje	23/mrt/11	start TS - normal EC (CaNO3 added)	9.9	2.4	1.1	0.1	0	1.8	7	0	3.9	0.9	28.3	6.7	10.7	5	25	0.4
innovator	23/mrt/12	start TS - low EC (CaNO3 added)	8.2	1.6	1	0.1	0	2	5.6	0	3	1.2	21.4	6.2	7.9	6.5	33.3	0.6
bintje	19-Apr-10	TS after 27 days	12.9	1.2	1.2	0.1	**0.1**	**0**	**9.9**	0	3.9	0.6	7.5	0.3	29	18.8	19.4	0.1
annabelle	19-Apr-10	TS after 27 days	10.8	1.3	2	0.1	0	**0**	**8.7**	0	3.9	1	2.9	2.9	35.2	59.3	13.9	0.3
desiree	19-Apr-10	TS after 27 days	11.4	1.3	1.3	0.1	0	**0**	**8.4**	0	4	0.5	5.5	0.6	38.9	36.9	22.2	0.3
innovator	19-Apr-10	TS after 27 days	12.6	1	1.4	0.1	**0.1**	**0**	**9.5**	0	4	0.7	5	2.5	26.2	89.6	24.1	0.3

N levels were rapidly depleted.

4.3 Monitoring of plant development

The in vitro plants were obtained after 21 days of in vitro growth at HZPC. 7 days of in-vitro acclimatisation with increasing exposure to the propagation room chamber atmosphere were also needed before transplanting into the gullies.
The potato plants at UGent were grown for 127 days (145 for Desiree) in the BT room.
All Annabelle plants died during the last month of BT2, only one plant died for Bintje and Innovator in the last week, and all plants survived for Desiree. Annabelle is an early cultivar and seems to have a short life cycle as for both bench tests all plants quickly died after tuber maturity.

4.3.1 Photographic follow-up



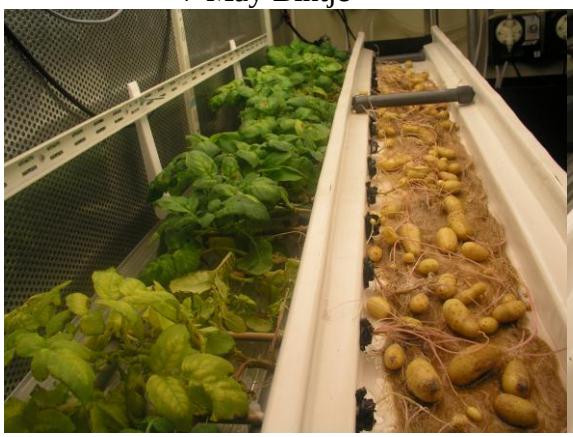
2 April Bintje

2 April Desiree

2 April Annabelle

2 April Innovator

7 May Bintje



7 May Desiree

7 May Annabelle

7 May Innovator

1 June Bintje

1 June Desiree

1 June Annabelle

1 June Innovator

Fig. 58 UGent - Photos growth evolution

Most of Annabelle plants wilted and died during May. To avoid rotting of dead plant's tubers, these ones were harvested before the end of the experiment.

4.3.2 Detailed photographic observations

1 June Bintje 1 June Desiree

12 April Annabelle 1 June Innovator

Fig. 59 UGent - Photos leaf size

Tab. 31 UGent - BT1 and BT2 leaf length comparison

	BT1 (cm)	BT2 (cm)
Annabelle	6.5	11
Bintje	7	14
Desiree	6.5	6
Innovator	7.5	15.5

Leaf size as shown in Fig. 59 was small compared to the HZPC test setup with the same in-vitro starting material.(see Tab. 31).
As can be seen in Fig. 60, plants of all cultivars were affected by yellowing of younger leaves and gradual drying of the older ones 3 months after start of the culture. Some plants rapidly wilted and completely died. PCR analysis of Annabelle's nutritive solution was carried out.

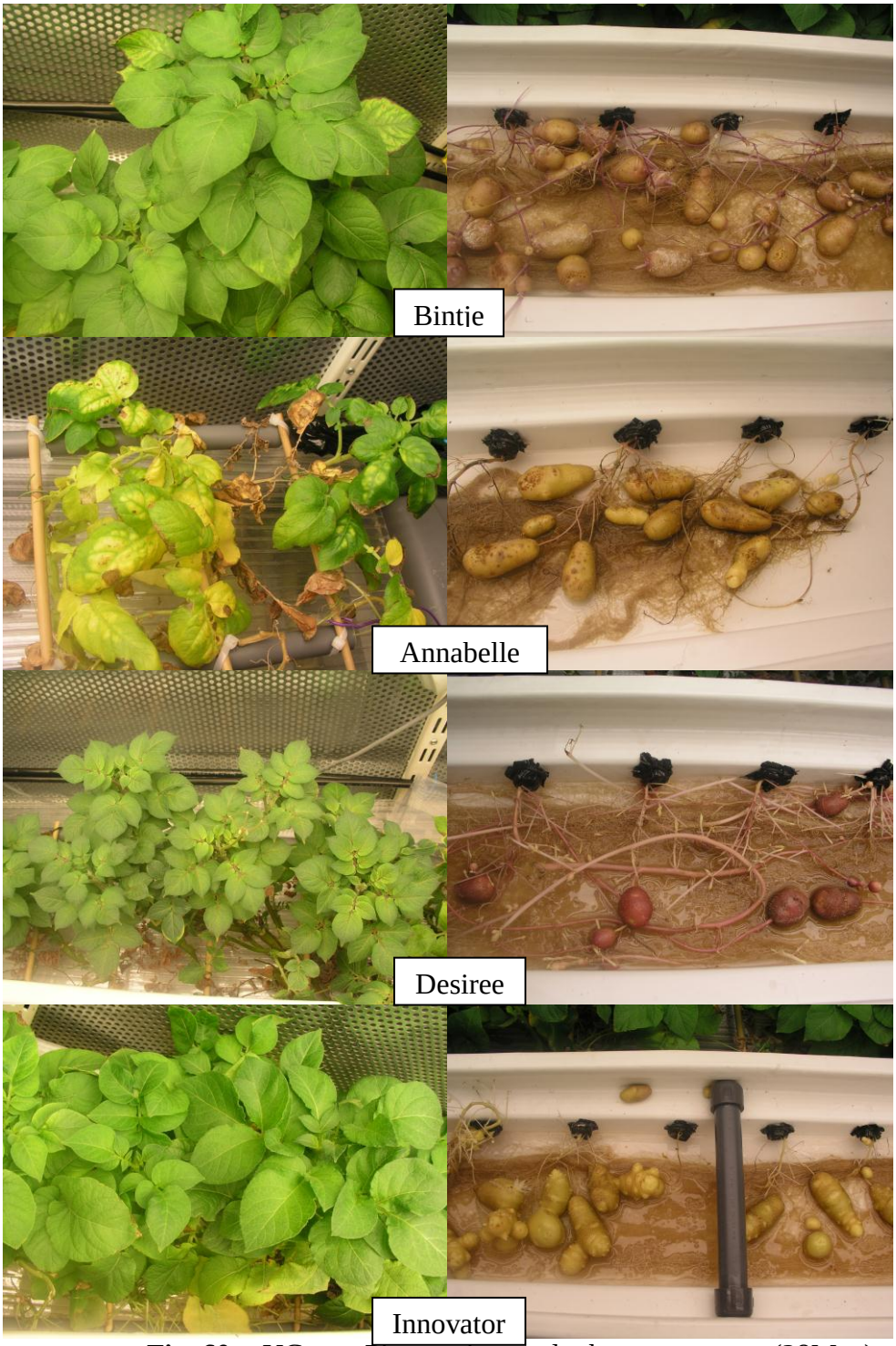


Fig. 60 UGent - Photos plant and tuber appearance (28May)

The results of PCR analysis (DNA Multiscan, from Sciencia Terrae Diagnosecentrum) of samples of nutritive solution (sampling 26/11/2009 and 04/05/2010) of both Bench test were received. The list of pathogens identified is presented in the following table.

Tab. 32 UGent - Pathogens present in Annabelle's nutrient solution at the end of BT1 and 2

Start of BT	BT 1 - 28/sep/09	BT 2 - 28/jan/10
sample date	24-Nov-09	4/may/2010
days after transfer to growth chamber	68	98
pathogens in solution:		
Botrytis cinerea	no	weak
Botrytis porri	no	weak
Botrytis tulipae	no	moderate
Colletotrichum spp.	strong	very strong
Colletotrichum acutatum	strong	strong
Colletotrichum coccodes	strong	moderate
Plectosphaerella cucumerinum	no	strong
Fusarium spp.	moderate	very strong
Fusarium oxysporum	weak	strong
Fusarium solani	no	moderate
Pythium sp.	strong	no
Pythium dissotocum	very strong	no

Tubers size was normal for Bintje but small for Desiree and Innovator. Tuber shape corresponded to respective typical appearance for each cultivar, although fluctuation of Nitrogen availability often induced "ginger shape" for Innovator and Bintje, and secondary growth of stolons on tubers of Bintje and Desiree.

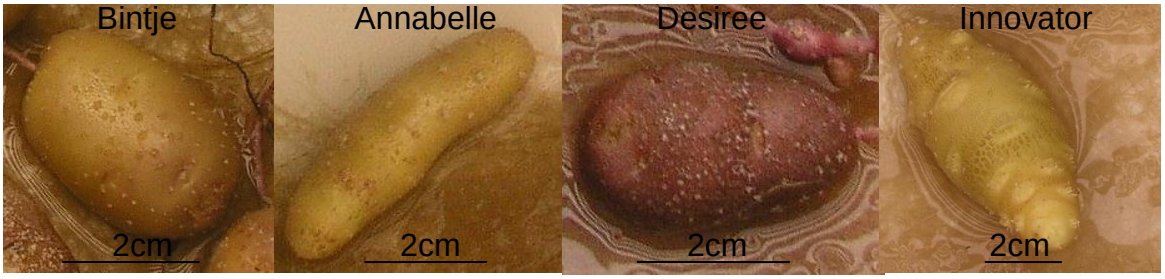


Fig. 61 UGent - Representative tuber of each cultivar 01/06/2010

4.3.3 Growth assessment

Fig. 62 illustrates the effect of the developmental problems, Annabelle being most susceptible with a short life cycle.
Shoot and tuber grew constantly and linearly all along the test, except for Desiree for which both halted after 123 days. Tubers of Annabelle kept on growing till the complete death of the plant allowing an acceptable harvest for this early cultivar. The precocity of this cultivar may also justify the rapid death of all the plants. Our consultant HZPC replaces all plants after 3 month of culture, after what plants get weaker, causing yield decrease and most of all, favourable conditions for diseases and infections spreading.

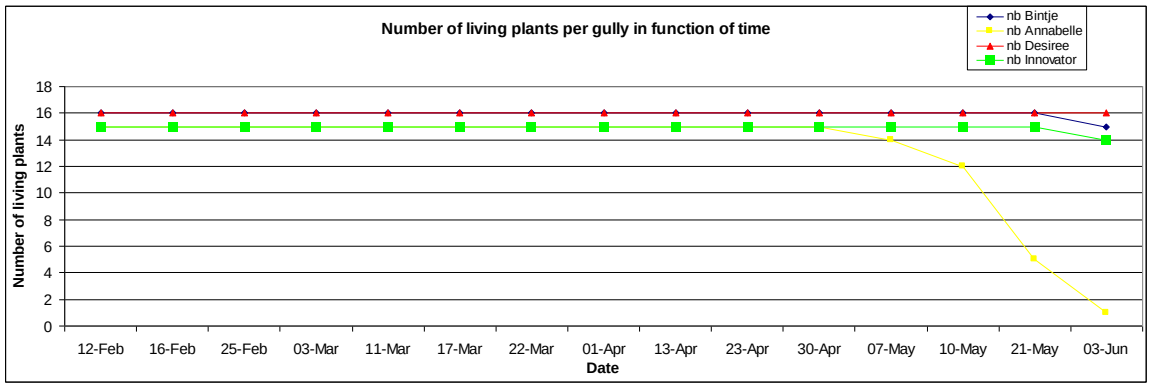


Fig. 62 UGent - Number of living plants per gully in function of time

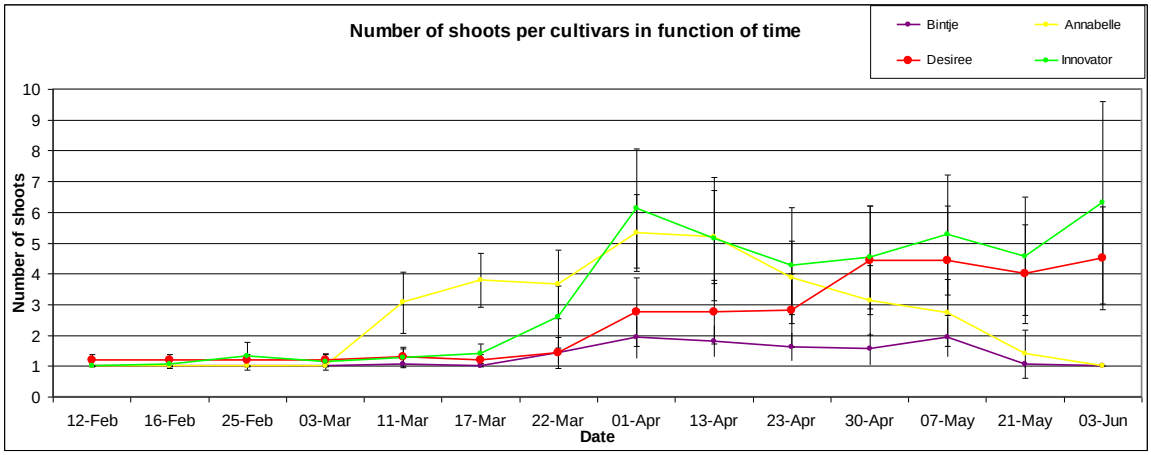


Fig. 63 UGent - Average number of branches per cultivar per plant as a function of time

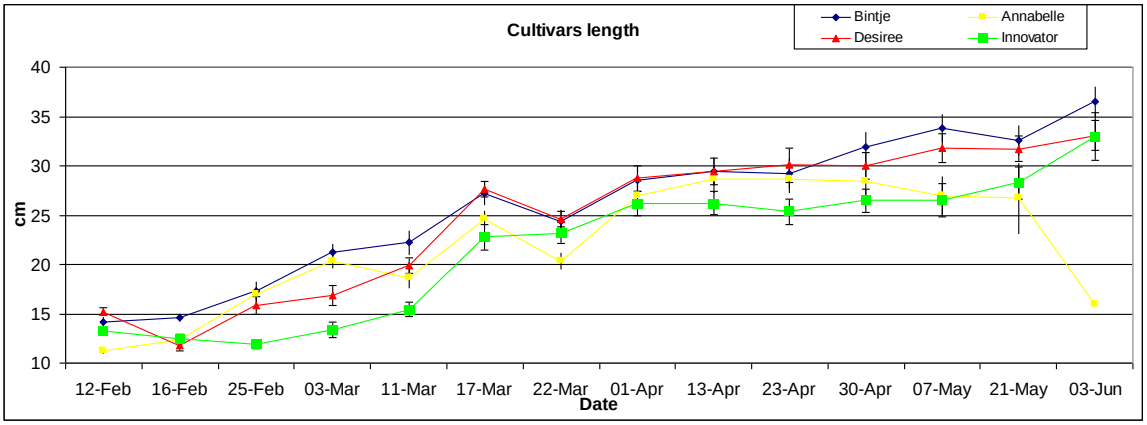


Fig. 64 UGent - Cultivars main stem length

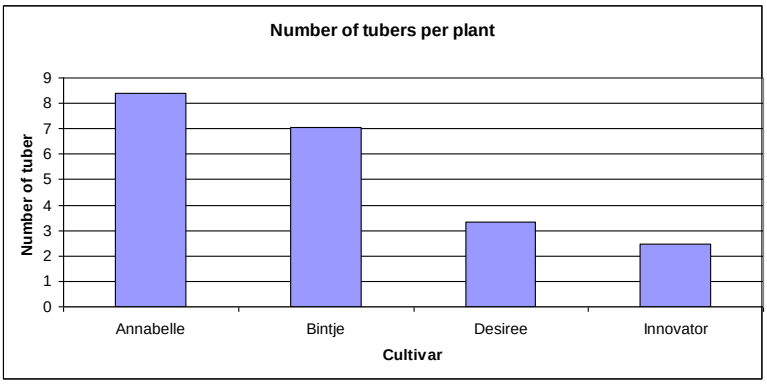


Fig. 65 UGent - Number of tuber per cultivars

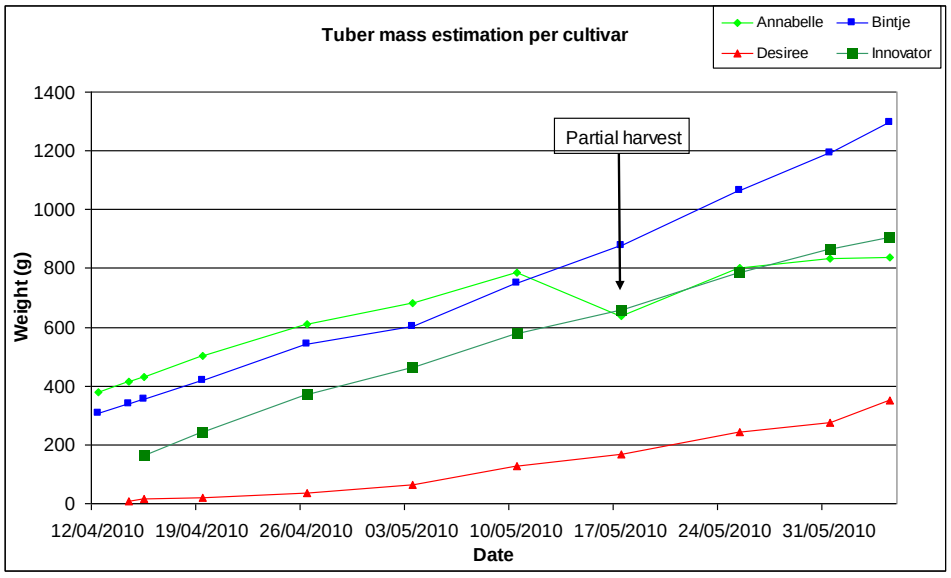


Fig. 66 UGent - Cumulative tuber mass estimation per cultivar

4.3.4 Gas exchange data

CO_2 gas exchange was measured during BT1 simultaneous measurements of 2 cultivars for a time span of a day proved unreliable and thus impossible with the available equipment (see TN 98.4.31).
The chamber CO_2 level was measured by a PPSystems WMA4 IRGA analyser (recorded by the dl2 data logger), with continuous hourly autocalibration.

4.3.5 Plant weight determination

The independent NFT gully system with the Annabelle cultivar provided an online weight measurement through load-cells supporting the gully, setup identical as for BT1.
A total biomass increase of 1.9kg was recorded. Modifying gully inclination and nutrient solution flow rate lead to immediate weight changes of maximum 600g due to a fluctuation of amount of liquid present in the gully.

Fig. 67 UGent - Weight Annabelle entire gully

4.4 Harvest results

This section summarizes the BT2 harvest results from the NFT hydroponic potato experiments: UGent and UCL.

The **edible part harvest** is summarised for UGent, UCL in Tab. 33. The tuber yield obtained in BT1 is included for comparison.
BT1 growth period was of 138 days and BT2 lasted 127 days for all cultivars except Desiree which had a 145 days growth period. For this last cultivar, length of the experiment had to be extended as the harvest was insufficient to allow nutritional analysis.

Tab. 33 Potato - Harvest results

		Annabelle	Bintje	Desiree	Innovator
Tuber harvest (kg)	HZPC 2008	1.872	-	1.141	0.676
	HZPC 2009	4.420	1.984	3.998	0.663
	UGent BT1	0.511	0.466	0.274	0.415
	UGent BT2	1.154	0.78	0.348	0.867
	UCL BT1	0.662	0.546	0.299	0.283
	UCL BT2	1.016	1.568	0.518	0.665
Tuber harvest (kg/m²)	HZPC 2008	2.5	-	1.52	0.9
	HZPC 2009	4.91	2.2	4.442	0.74
	UGent BT1	0.660	0.583	0.343	0.501
	UGent BT2	0.94	1.44	0.44	1.05
	UCL BT1	0.829	0.683	0.374	0.355
	UCL BT2	1.96	1.27	0.65	0.83
Tuber harvest (g/plant)	HZPC 2008	93.6	-	57.1	33.8
	HZPC 2009	184.2	82.7	166.6	27.6
	UGent BT1	34.1	29.1	17.2	27.2
	UGent BT2	52	72.1	21.8	57.8
	UCL BT1	41.4	34.1	18.7	17.7
	UCL BT2	98	63.5	32.4	41.6
Number of tubers per plant	HZPC 2008	-	-	-	-
	HZPC 2009	20.4	12.9	10.5	3.7
	UGent BT1	9.2	6.5	3.2	2.1
	UGent BT2	8.1	6.3	3.3	2.8
	UCL BT1	4.6	4.6	3.6	1.4
	UCL BT2	13.2	11.4	8.7	18.5

The **inedible part harvest** for UGent and UCL is summarised in Tab. 3434.

Tab. 34 Potato - FW and DW (g) of shoots and roots

		shoot FW	root+stolon FW	Total FW	shoot DW	root+stolon DW	Tolal DW	%DW
HZPC 2008	Annabelle	54.81	17.04	71.85	4.18	1.06	5.24	7.29
	Bintje	-	-	-	-	-	-	-
	Desiree	39.52	19.27	58.79	2.53	1.35	3.88	6.60
	Innovator	28.91	8.38	37.29	2.13	0.50	2.63	7.04
HZPC 2009	Annabelle	140.00	*20.29*	160.29			9.75	6.09
	Bintje	79.00	*8.21*	87.21			5.75	6.59
	Desiree	169.25	*32.38*	201.63			10.75	5.33
	Innovator	37.50	*2.96*	40.46			3.50	8.65
UGent BT1	Annabelle				1.99	0.21	2.20	
	Bintje				3.65	0.23	3.88	
	Desiree				4.03	0.49	4.52	
	Innovator				3.15	0.21	3.36	
UGent BT2	Annabelle							
	Bintje	49.24			4.82			9.8
	Desiree							
	Innovator	26.99			3.05			11.3
UCL BT1	Annabelle				2.77	0.30	3.07	
	Bintje				3.12	0.7	3.82	
	Desiree				5.57	0.94	6.51	
	Innovator				2.08	0.21	2.29	

No FW was measured for BT1 as it is a destructive measurement and because all plants died before the expected harvest time point.
At the end of BT2, 3 plants per cultivars were collected to measure shoot FW and DW. This wasn't possible for Annabelle as all plants died and dried before the expected harvest time point as in BT1. Hence only DW could be determined as a representative value for this cultivar.

The **nutritional analysis of the harvest** was carried out at IPL for all samples from UGent, UCL See TN 98.4.11, 4.3.10 Table 14 for experimental protocol overview.
- proximate analysis (moisture, ash, protein, lipid, fiber, carbohydrates by difference)
- elemental analysis, for harmonisation with human micronutrients to be analyzed by priority in processing trials of the same harvest samples, K, P, Ca, Mg, Zn, Cu were analysed
Na content was considered of more importance than Cl.
- cultivar specific toxic compounds: solanine, chaconine.

As a reference values from the USDA database are included “potato, flesh and skin, raw” http://www.nal.usda.gov/fnic/foodcomp/search/

Tab. 35 Potato - IPL tuber nutritional analysis results

BT2 UGent		Annabelle	Bintje	Desiree	Innovator
Water (%)		78,2	81,1	84.2	77,9
Protein (%)		1,62	1,20	1.58	1,39
Fat (%)		0,06	0,04	0.08	0,04
Available carbohydrates (%)		14,23	14,40	10.79	14,15
TDF (%)		1,53	1,80	2.2	1,79
Minerals (%)		1,16	1,18	1.13	1,08
Of which (mg/100g)	Potassium	504	507	477	440
	Calcium	5,5	7,5	7.4	8,7
	Magnesium	29,4	22,2	22.6	26,7
	Iron	0,7	0,8	0.4	0,6
	Copper	1,1	0,5	0.7	0,8
	Zinc	1,1	0,9	1	1,9
	Manganese	0,18	0,11	0.13	0,13
	Phosphorus	108	87	89	90
Solanine (mg/kg)		0	0	0	0
Chaconine (mg/kg)		0	0	0	0
Energy (for 100g)	kcal	67,0	66,4	54.6	66,1
	kJ	280,1	277,8	228.4	276,8

4.5 Conclusions

N is rapidly taken up by the plants after being added to the nutrient solution. EC and pH were manually kept stable. Addition of Nitrogen induces alkalinisation of the solution; oppositely, its depletion provokes an acidification. Nutrient solution composition has been improved since BT1 (yield more than doubled). Still, optimisation of Nitrogen availability has to be carried out in order to overcome tuber deformation and secondary stolon growth.

Shoot length was quite homogeneous; around 35 cm. Innovator was slightly smaller than the others as it is a small stature cultivar. Annabelle, which is an early cultivar, died before the end of BT2. Bintje and Desiree flowered. Innovator tubers are big but sensitive to greening and easily deformed by Nitrogen fluctuations. Annabelle doesn’t need a lot of attention, it induces tuberisation by itself. In contrast, Desiree is hard to manage: we hardly induced tuberisation

with very few tubers which didn't develop very well. In general all cultivars (except Innovator) developed a lot of roots and many very long stolons, probably due to an excess of Nitrogen.

Bintje and Annabelle had the best yields. Bintje had the highest yield. It was harvested after 3 months of culture during BT2, and the same plants produced a second and equal harvest only 2 months after the first harvest.

The results of UGent and UCL for BT2 were homogenous. In both cases yields have been at least doubled, and plant's life time extended. Problems as excessive roots and stolons development, or tuber induction (for Desiree) still have to be solved by the further optimization of the nutrient solution (nitrogen content).

5 Potato (UCL)

5.1 Experimental Layout

5.1.1 Measuring Plan

Plant development weekly follow-up

- Plant height
- Number of leaves
- Number of stolons
- Number of tubers
- Date of stolon formation
- Date of tuberisation
- Date of flowering
- Number of stolons and tubers
- Estimate of percentage of gully covered by the roots

Plant physiological parameter weekly assessment

- Net photosynthesis and instantaneous transpiration (portable Infra Red Gas analyzer LCA4 ADC Bioscientific Ltd)
- Stomatal conductance (porometer AP4 deltaT):
- Kinetics of chlorophyll fluorescence (fluorescence monitoring system 2 Hansatech Instruments)
- Chlorophyll concentration SPAD (CCM-200 opti-sciences):
- Leaf area (compact portable area meter AM 300 ADC Bioscientific Ltd, scanning width 10cm)

Destructive analysis

- Fresh weight of the leaves, stems, roots, tubers (for each tuber and total per plant).
- Dry weight of the leaves, stems, roots.

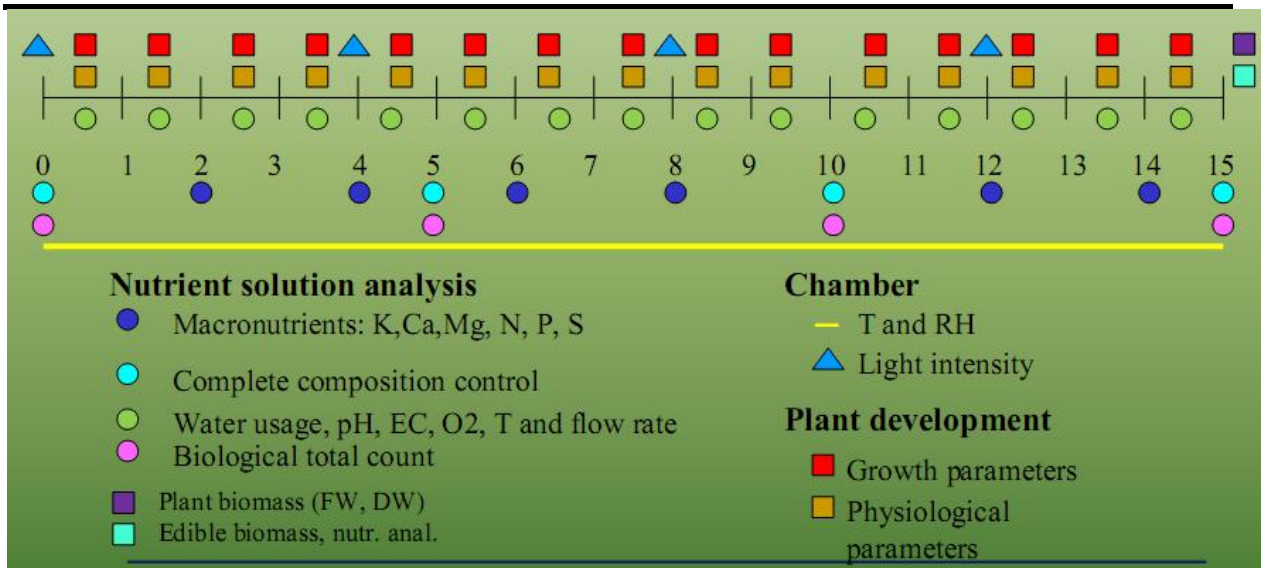


Fig. 68 UCL - Measuring plan

A culture of potato in NFT was realised in a growth room in Louvain-la-Neuve. Four cultivars were selected for this assay: Annabelle, Bintje, Desiree and Innovator. Sixteen plants per cultivar were grown per gully. There were four independent systems (one per cultivar). The conditions in the room were 16h photoperiod, light intensity between 150 and 250 µmol/m²s, temperature 20-25°C, relative humidity 60-90%. Vitro-plants received from HZPC were transplanted in gullies the 27th of January 2010 in the growth solution (high N concentration, 20L per gully). The solution was changed the 11th of March to induce tuberisation (low N concentration). The solution was changed a second time the 5th of May (low N concentration). Final harvest took place the 3rd of June (16th of June for Desiree). For each system, pH, EC and water level were measured and adjusted twice a week. The size of the plants, number of leaves, number of stolons and tubers of each plant were measured once a week. The instantaneous C exchanges (IRGA), stomatal conductance (porometer), fluorescence of the chlorophyll (fluorimeter), chlorophyll content (SPAD), leaf area (leaf area meter) were measured on the 5th youngest leaf of 8 plants per cultivar every two days. Bacteriological and element analysis of the nutrient solutions were realised before each solution change and at the end of the experiment. At harvest, the fresh weight and dry weight of the shoots, roots and stolons were measured for each plant. The fresh weight, volume, size of the tubers were analysed for each plant. The dry weight of three tubers per cultivar was also analysed.

5.1.2 Setup

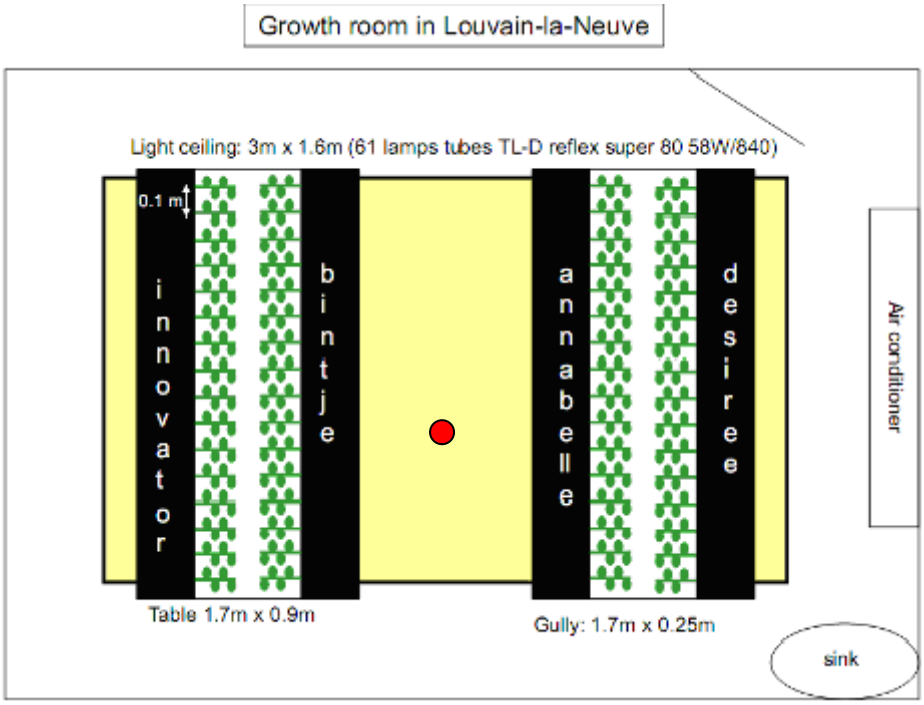


Fig. 69 UCL - Setup

5.2 Growth environment follow-up

5.2.1 Settings

Tab. 36 UCL - Settings

Photoperiod	16h
Light intensity	150-250µmol/m²/s
Room temperature	22±1°C

The photoperiod in the growth room was an on-off system with 16h light and 8h obscurity. The mean light intensity at the leaf canopy for each plant is shown in Fig. 70. Plants 1 to 4 and 12 to 16 were considered as cultivated under low light irradiance and the plants 5 to 13 were considered as cultivated under high light irradiance.

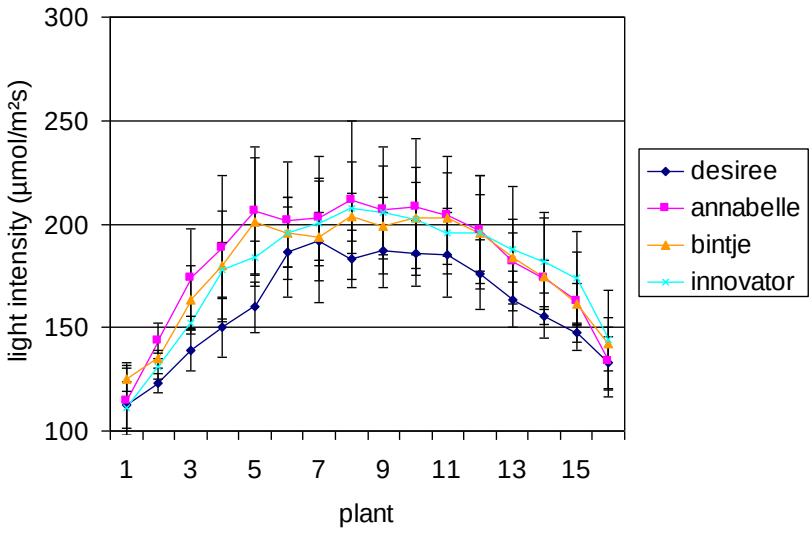


Fig. 70 UCL - Light intensity at leaf canopy for each plant along the gully (means of the measurements 19 February, 26 March and 5 May). Error bars are standard errors.

5.2.2 Chamber T/RH evolution

The temperature and relative humidity was measured every ten minutes by a tiny view data logger (Fig. 71). Three loggers were placed in the room: one in the middle on each table and one between the two tables. Table 1 corresponded to the gullies containing Desiree and Annabelle plants and Table 2 corresponded to the gullies containing Bintje and Innovator plants. The temperature set point in the room was 20°C.

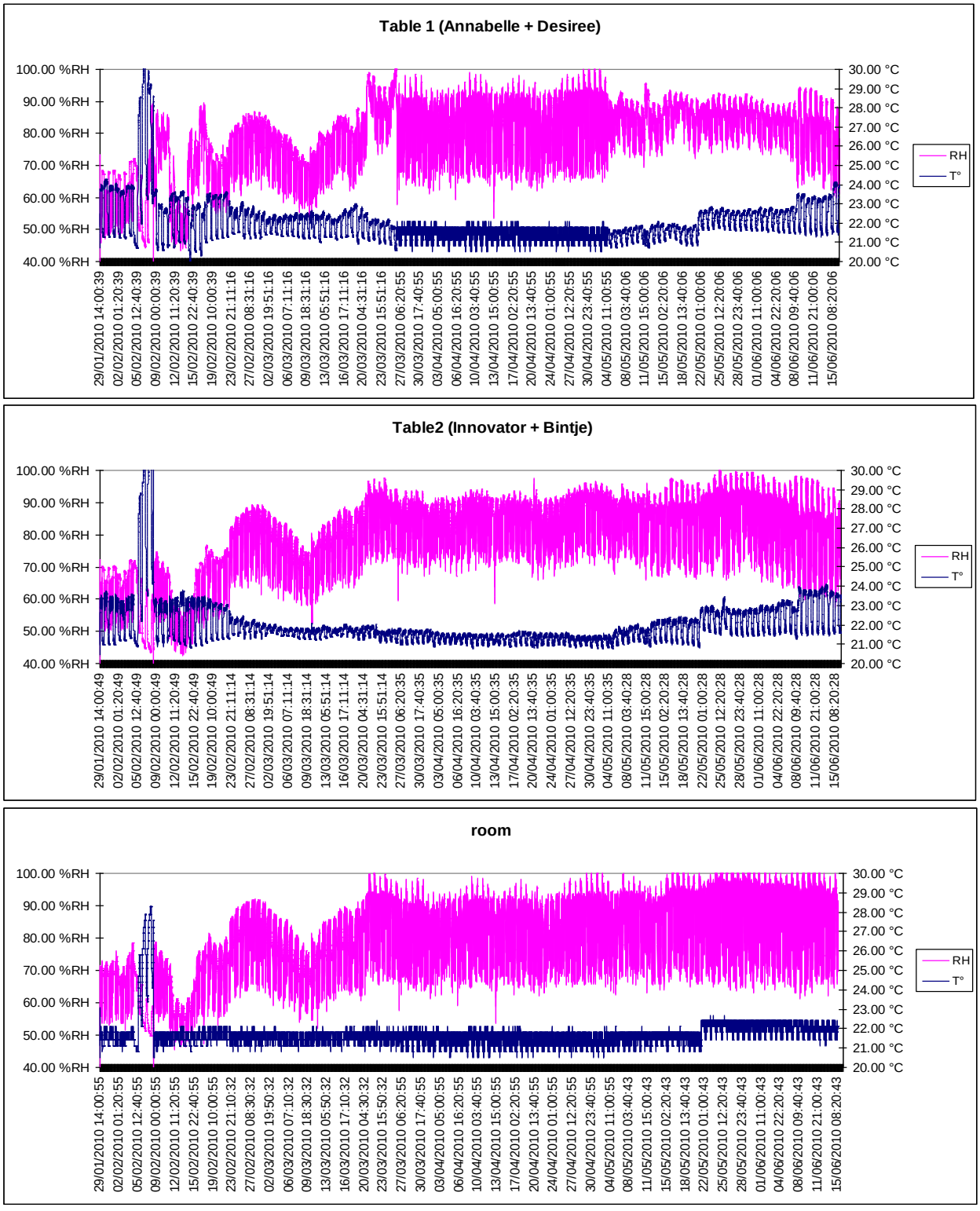


Fig. 71 UCL - Temperature and relative humidity

(A) middle of table 1 between the gullies containing the Desiree and Annabelle plants, (B) middle of table 2 between the gullies containing the Bintje and Innovator plants, (C) between the two tables.

A problem occurred with the room control during the week-end of the 6-7 February explaining the increase of temperature at this moment.

5.2.3 Chamber CO2 level

Measurements not available, only leaf level measurements using dedicated equipment. See 4.3.4.

5.2.4 Nutrient Solution Environment

The flow rate in the gully was 2 L/min at the beginning of the plant growth to allow good nutrient solution coverage inside the gully. With the roots, stolons and tubers growth, the flow rate was reduced at 1 L/min to avoid overflow.

A cooling system was used to reduce the nutrient solution temperature (Fig. 72). Air pumps were used to have a good oxygenation of the solutions.

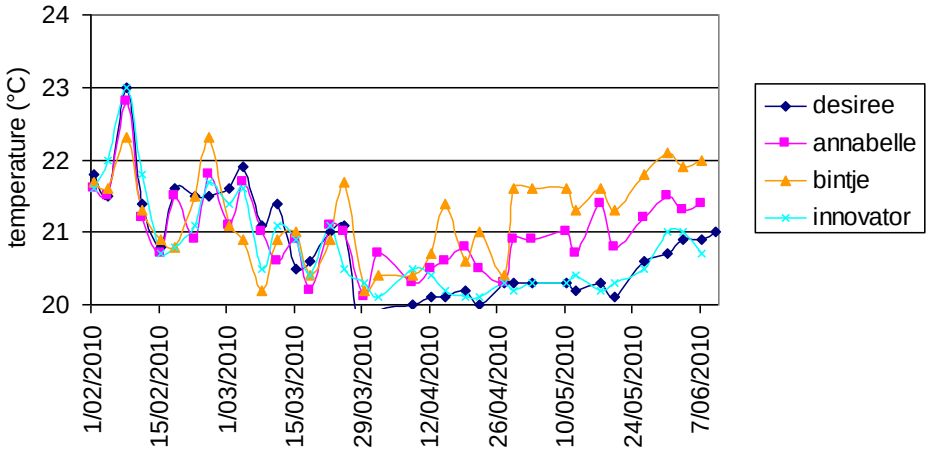


Fig. 72 UCL - Temperature of the nutrient solution

5.2.5 pH and EC evolution

The plants were first grown in a 'growth nutrient solution' containing N to allow the growth of the plants. After 6 weeks of culture (11th March) the solution was changed to the 'tuberization solution' containing no N and an increased amount of P in order to induce tubers initiation of the plants. This solution was changed a second time the 5th of May in order to refresh it. During the tuberization phase, $Ca(NO_3)_2$ was nevertheless added to allow a good growth of the plants (Fig. 75). The EC of the solution was maintained at 1800 (growth phase)-1700 µS/cm (tuber phase) by addition of K_2SO_4 during the growth phase and K_2SO_4 or KH_2PO_4 during the tuberization phase (Fig. 73, Fig. 76). The pH was maintained at 5.5 by addition of KOH or H_3PO_4 (Fig. 73, Fig. 76). The water level, EC and pH were measured and adjusted twice a week.

As shown on Fig. 73, during the growth phase, we observed first an alkalinisation of the solution followed by an acidification of the solution possibly due to the decrease of N in the solution. The pH variation was smaller during the tuberization phase. The EC evolution was similar for the different varieties (Fig. 73). The drop of EC around the 5-10 May is due to the solution change. Fig. 74 shows the water consumption (evaporation + plants uptake). Fig. 75 presents the N and Ca additions and concentration in the solution during the experiment.

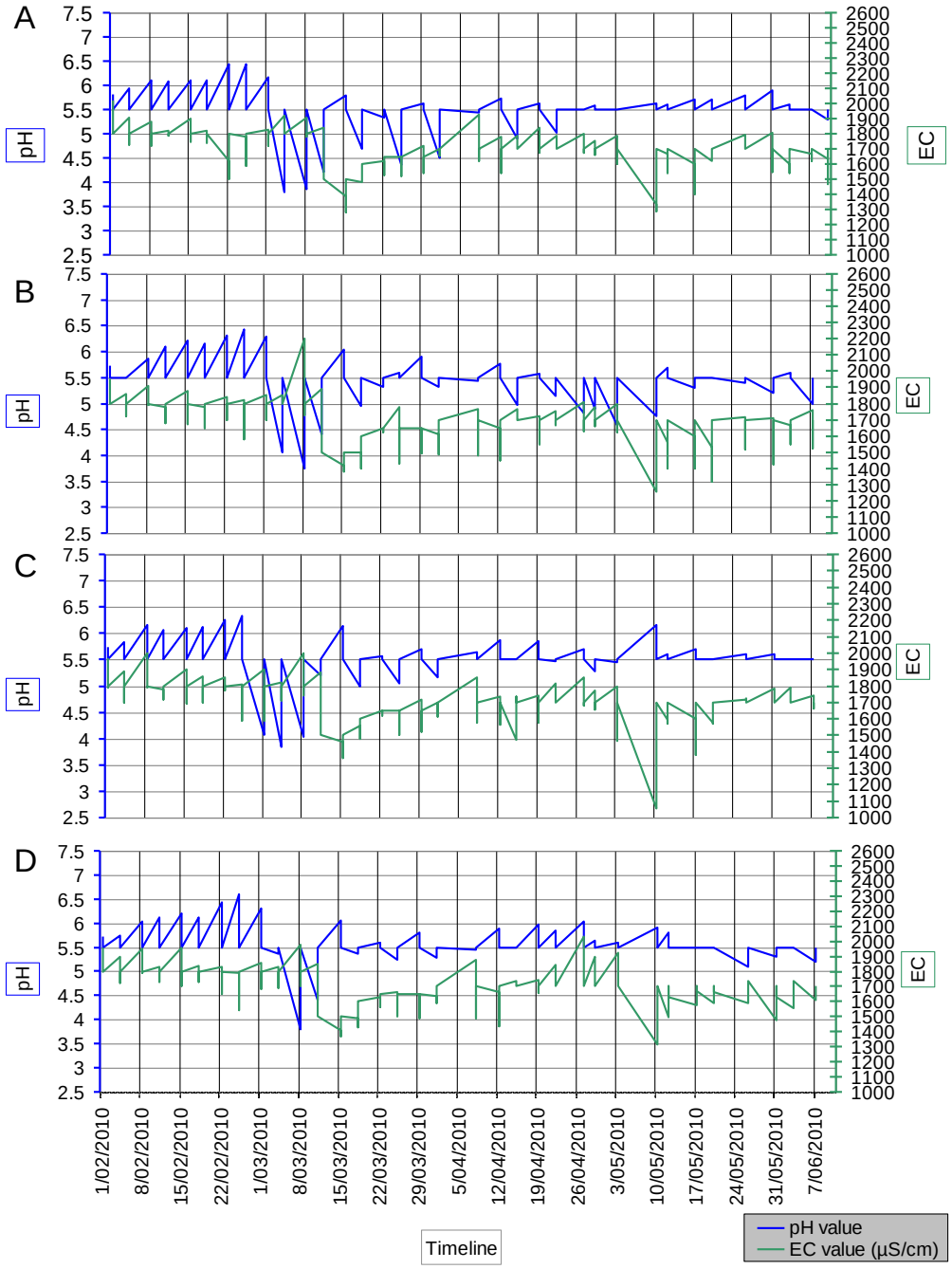


Fig. 73 UCL - EC and pH evolution of the nutrient solutions

5.2.6 Plant Water Usage

Water usage was similar among cultivars.

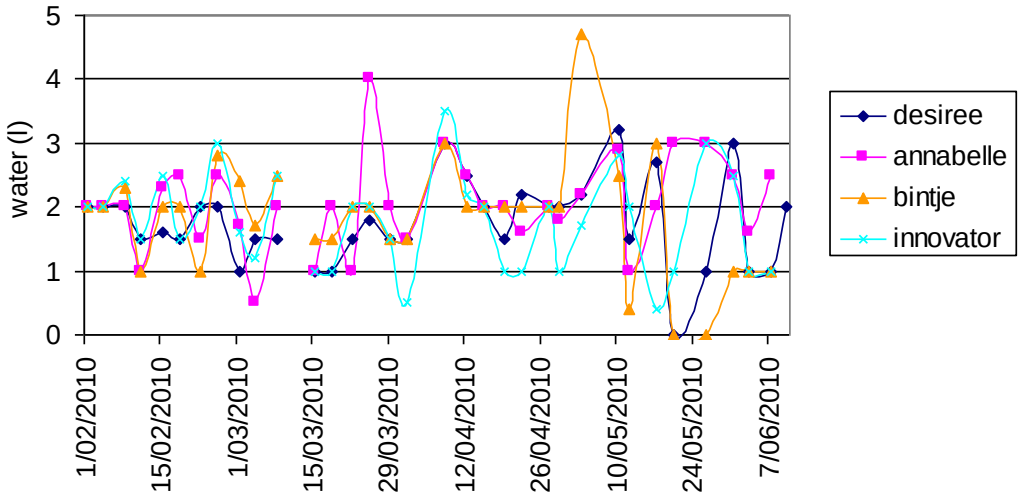


Fig. 74 UCL - Water consumption per gully between two adjustments

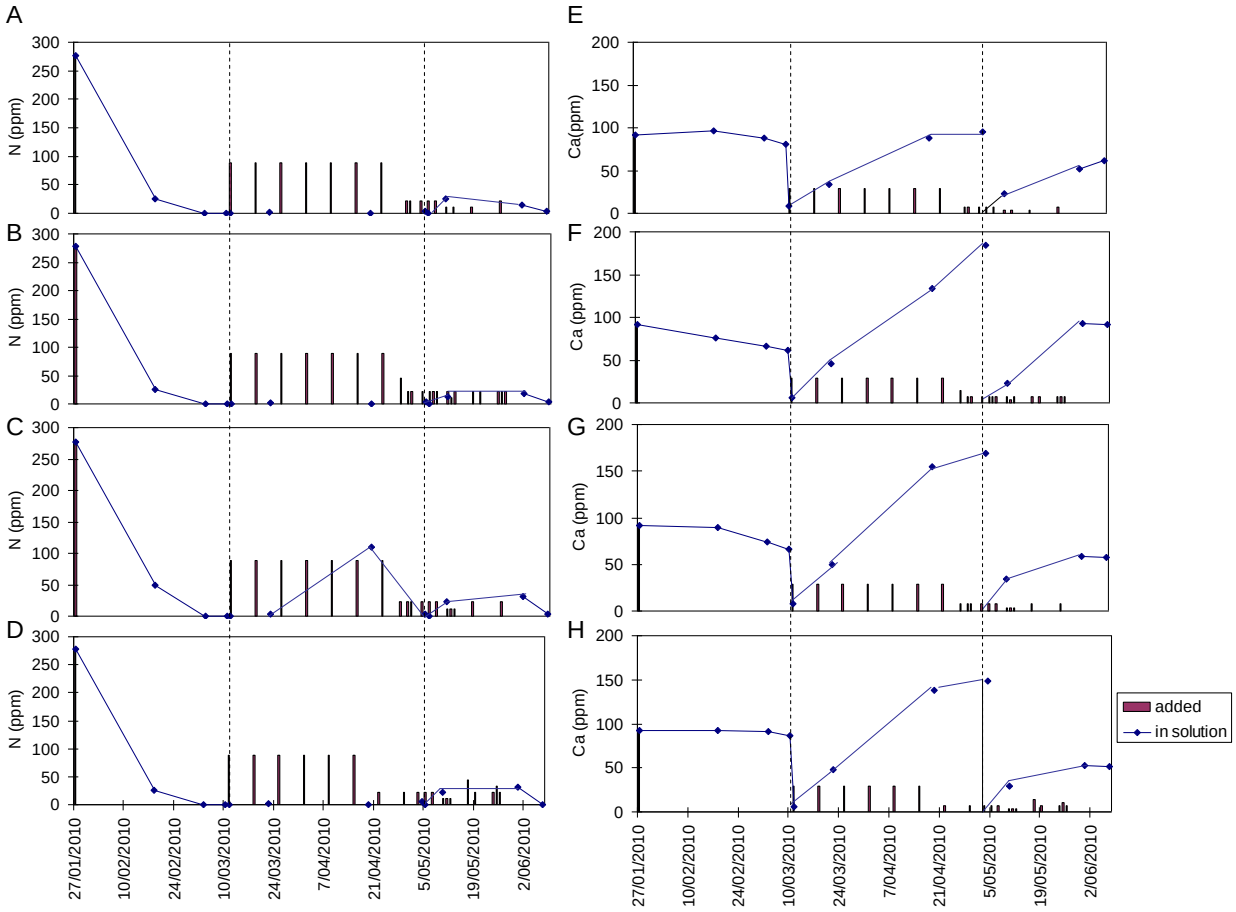


Fig. 75 UCL - N and Ca additions and concentrations in the solutions as a function of time

N (A, B, C, D) and Ca (E, F, G, H) additions and concentrations in the solutions as a function of time for the variety (A, E) Desiree, (B, F) Annabelle, (C, G) Bintje and (D, H) Innovator. Broken lines = change of solutions.

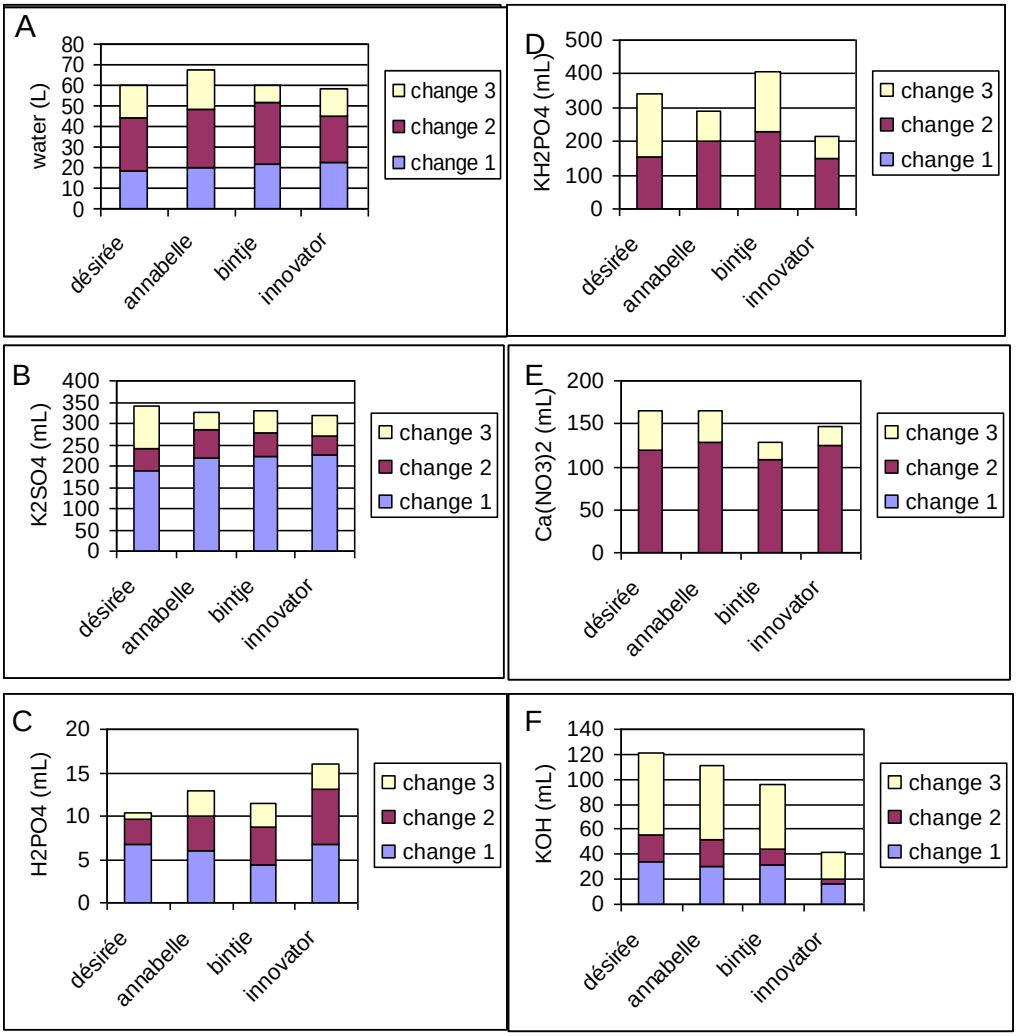


Fig. 76 UCL - Total amount of water, K_2SO_4, H_3PO_4, KH_2PO_4, $Ca(NO_3)_2$ and KOH added in the tanks during the plant cultivation

Change 1 corresponds to the growth phase solution and changes 2 and 3 correspond to the changes of tuberisation solution.

Concerning the water consumption, the tanks and gullies were covered to avoid maximum water evaporation. Nevertheless we were not able to separate the water loose due to plant transpiration and consumption and water evaporation. The total amount of water added in the tanks corresponds thus to the sum of them (Fig. 76A). The total water used per plant per day was 27.63ml for Desiree, 31.06 ml for Annabelle, 27.9 ml for Bintje and 26.9 ml for Innovator.

5.2.7 Nutrient solution T

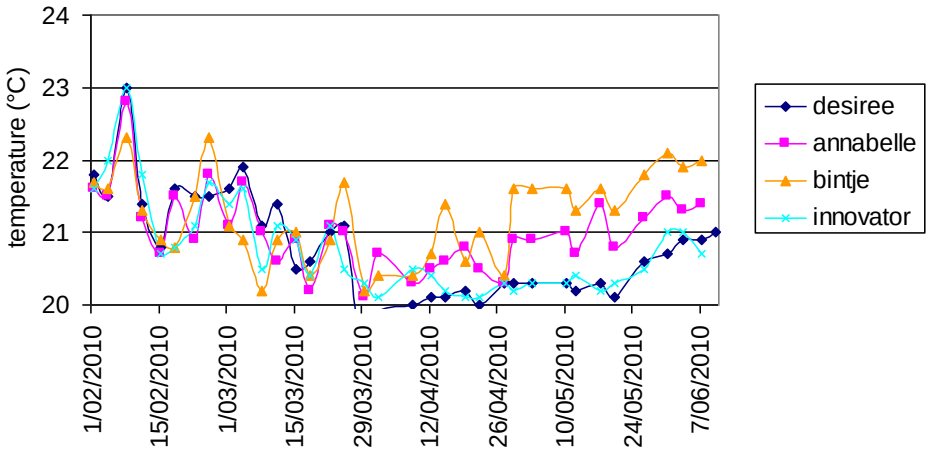


Fig. 77 UCL - Nutrient solution T

5.2.8 Nutrient solution analysis

Tab. 37 UCL nutrient solution analysis

	date	desiree	Ca ppm	Fe ppm	K ppm	Mg ppm	Na ppm	Mn ppb	Cu ppb	Mo ppb	Zn ppb
start GP	27/01/10	desiree	91.9	0.8	236.0	54.1	8.6	294.5	293.1	42.0	76.8
	4/03/10	desiree	88.2	0.6	387.5	50.5	12.5	113.7	248.2	11.0	1014.0
end GP	10/03/10	desiree	80.6	0.6	406.4	45.0	12.8	93.1	206.7	13.8	1525.0
start TP	11/03/10	desiree	8.7	0.8	288.4	39.8	11.6	276.7	286.8	30.6	154.7
	19/04/10	desiree	87.8	0.8	409.3	44.3	13.4	39.3	330.9	40.4	644.1
	4/05/10	desiree	95.3	0.6	464.3	37.8	7.2	48.5	378.9	49.2	978.9
solution change	10/05/10	desiree	23.3	0.9	444.7	53.9	5.1	236.5	399.5	28.1	997.3
	31/05/10	desiree	51.5	0.8	469.0	40.4	5.3	141.5	307.5	37.4	1004.0
harvest	7/06/10	desiree	61.1	0.7	541.1	39.2	5.9	133.9	329.7	25.2	1376.0
	date	annabelle	Ca ppm	Fe ppm	K ppm	Mg ppm	Na ppm	Mn ppb	Cu ppb	Mo ppb	Zn ppb
start GP	27/01/10	annabelle	91.9	0.8	236.0	54.1	8.6	294.5	293.1	42.0	76.8
	4/03/10	annabelle	66.4	0.5	415.0	38.0	11.8	66.8	163.6	10.2	703.5
end GP	10/03/10	annabelle	61.6	0.6	423.5	35.0	8.6	54.7	143.6	9.4	1185.0
start TP	11/03/10	annabelle	6.0	0.8	283.0	33.5	7.9	243.1	241.4	32.5	122.2
	19/04/10	annabelle	134.1	0.7	393.5	31.7	10.9	17.3	236.1	33.7	752.7
	4/05/10	annabelle	184.7	0.5	393.1	27.2	7.4	13.4	352.2	45.5	744.6
solution change	10/05/10	annabelle	23.2	0.9	454.2	50.8	5.2	225.4	365.3	57.5	903.1
	31/05/10	annabelle	92.8	0.9	405.0	44.3	6.4	169.7	101.3	45.7	1035.0
harvest	7/06/10	annabelle	91.6	0.9	423.6	44.2	6.3	167.9	150.4	41.7	1114.0
	date	bintje	Ca ppm	Fe ppm	K ppm	Mg ppm	Na ppm	Mn ppb	Cu ppb	Mo ppb	Zn ppb
start GP	27/01/10	bintje	91.9	0.8	236.0	54.1	8.6	294.5	293.1	42.0	76.8
	4/03/10	bintje	74.3	0.5	407.5	41.0	10.3	92.6	191.9	6.0	605.4
end GP	10/03/10	bintje	66.0	0.6	427.6	35.6	11.3	83.2	164.6	8.0	1065.0
start TP	11/03/10	bintje	8.0	0.7	279.9	36.3	9.7	292.0	297.1	35.2	172.6
	19/04/10	bintje	155.1	0.5	394.3	28.9	10.8	64.8	260.0	36.1	621.1
	4/05/10	bintje	169.4	0.4	441.0	21.1	6.1	24.5	258.2	40.2	499.0
solution change	10/05/10	bintje	37.0	0.8	461.9	49.6	4.9	208.9	347.6	55.2	836.4
	31/05/10	bintje	58.1	0.7	465.1	36.4	5.2	175.9	128.0	28.1	1062.0
harvest	7/06/10	bintje	57.7	0.6	510.4	36.2	5.6	158.0	165.2	25.3	1206.0
	date	innovator	Ca ppm	Fe ppm	K ppm	Mg ppm	Na ppm	Mn ppb	Cu ppb	Mo ppb	Zn ppb
start GP	27/01/10	innovator	91.9	0.8	236.0	54.1	8.6	294.5	277.6	42.0	76.8
	4/03/10	innovator	91.1	0.6	372.8	48.3	11.2	19.2	233.0	36.1	406.6
end GP	10/03/10	innovator	86.7	0.6	398.5	45.3	12.6	136.0	228.0	27.1	620.5
start TP	11/03/10	innovator	6.4	0.8	274.3	34.3	10.0	305.6	314.0	33.2	133.0
	19/04/10	innovator	138.1	0.6	399.3	30.8	11.1	34.0	278.0	40.2	471.5
	4/05/10	innovator	148.9	0.4	444.8	23.1	6.2	77.0	326.9	46.7	575.6
solution change	10/05/10	innovator	29.3	0.8	457.6	45.1	5.2	221.5	339.8	56.1	838.6
	31/05/10	innovator	53.2	0.8	542.9	41.9	6.4	203.3	239.9	43.7	956.7
harvest	7/06/10	innovator	51.4	0.7	522.3	40.4	4.9	191.9	266.5	41.9	968.2
	date	desiree	P ppm	S ppm	B ppb	F(ppm)	Cl(ppm)	NO2(ppm)	SO4(ppm)	NO3(ppm)	PO4(ppm)
start GP	27/01/10	desiree	36.0	156.6	206.8	<0,5	12.1	<0,5	465.3	277.3	100.4
	4/03/10	desiree	98.8	260.3	182.4	<0,5	2.1	<0,5	773.1	<0,5	282.3
end GP	10/03/10	desiree	91.5	261.7	163.2	<0,5	3.1	<0,5	769.1	<0,5	258.2
start TP	11/03/10	desiree	173.4	88.7	203.7	<0,5	8.6	<0,5	254.8	<0,5	491.4
	19/04/10	desiree	342.3	132.1	168.5	<0,5	2.1	<0,5	385.0	<0,5	980.8
	4/05/10	desiree	349.7	123.0	190.1	<0,5	1.3	<0,5	373.4	3.0	1128.0
solution change	10/05/10	desiree	267.7	114.8	200.4	<0,5	2.9	<0,5	344.1	25.8	842.7
	31/05/10	desiree	280.7	117.8	114.3	<0,5	1.6	<0,5	345.6	14.9	861.2
harvest	7/06/10	desiree	355.4	116.1	64.3	<0,5	1.7	<0,5	339.5	3.1	1101.4
	date	annabelle	P ppm	S ppm	B ppb	F(ppm)	Cl(ppm)	NO2(ppm)	SO4(ppm)	NO3(ppm)	PO4(ppm)
start GP	27/01/10	annabelle	36.0	156.6	207.0	<0,5	12.1	<0,5	465.3	277.3	100.4
	4/03/10	annabelle	73.2	252.4	102.7	<0,5	4.3	<0,5	745.9	<0,5	207.2
end GP	10/03/10	annabelle	69.0	249.2	90.8	<0,5	5.4	<0,5	732.4	<0,5	195.3
start TP	11/03/10	annabelle	165.1	89.3	172.3	<0,5	6.6	<0,5	254.7	<0,5	467.8
	19/04/10	annabelle	374.5	125.4	70.8	<0,5	0.8	<0,5	361.3	<0,5	1061.9
	4/05/10	annabelle	393.6	123.0	109.4	<0,5	1.4	<0,5	371.3	3.2	1250.2
solution change	10/05/10	annabelle	282.1	107.5	203.8	<0,5	2.9	1.2	322.4	12.6	888.2
	31/05/10	annabelle	328.3	103.2	145.3	<0,5	1.9	<0,5	305.1	19.0	1024.6
harvest	7/06/10	annabelle	348.0	102.2	134.1	<0,5	1.9	<0,5	303.9	3.4	1095.4
	date	bintje	P ppm	S ppm	B ppb	F(ppm)	Cl(ppm)	NO2(ppm)	SO4(ppm)	NO3(ppm)	PO4(ppm)
start GP	27/01/10	bintje	36.0	156.6	206.8	<0,5	12.1	<0,5	465.3	277.3	100.4
	4/03/10	bintje	77.9	259.8	142.3	<0,5	3.3	<0,5	762.0	<0,5	218.6
end GP	10/03/10	bintje	68.8	256.9	123.0	<0,5	1.8	<0,5	740.0	<0,5	190.9
start TP	11/03/10	bintje	164.2	85.6	209.3	<0,5	13.3	<0,5	245.7	<0,5	471.6
	19/04/10	bintje	372.9	107.0	134.3	<0,5	1.1	<0,5	310.0	109.1	1064.6
	4/05/10	bintje	427.2	105.0	174.7	<0,5	1.1	<0,5	319.9	3.4	1368.2
solution change	10/05/10	bintje	295.5	106.1	189.5	<0,5	2.8	<0,5	316.3	23.5	920.7
	31/05/10	bintje	273.8	119.9	123.2	<0,5	1.4	<0,5	352.2	21.5	850.2
harvest	7/06/10	bintje	315.1	121.8	114.5	<0,5	1.6	<0,5	352.4	3.2	970.9
	date	innovator	P ppm	S ppm	B ppb	F(ppm)	Cl(ppm)	NO2(ppm)	SO4(ppm)	NO3(ppm)	PO4(ppm)
start GP	27/01/10	innovator	36.0	156.6	206.8	<0,5	12.1	<0,5	465.3	277.3	100.4
	4/03/10	innovator	92.7	251.5	160.1	<0,5	3.1	<0,5	740.1	<0,5	262.3
end GP	10/03/10	innovator	85.3	263.0	136.3	<0,5	4.1	<0,5	772.2	<0,5	241.0
start TP	11/03/10	innovator	168.9	82.4	219.5	<0,5	7.7	<0,5	237.1	<0,5	481.7
	19/04/10	innovator	408.7	114.9	126.7	<0,5	0.8	<0,5	332.7	<0,5	1166.8
	4/05/10	innovator	414.0	99.0	153.7	<0,5	1.1	<0,5	303.0	5.0	1306.7
solution change	10/05/10	innovator	289.3	95.0	187.8	<0,5	5.4	<0,5	292.6	23.1	933.0
	31/05/10	innovator	357.2	104.8	166.8	<0,5	2.0	<0,5	308.1	30.6	1114.0
harvest	7/06/10	innovator	349.1	101.7	159.5	<0,5	1.5	<0,5	304.8	<0,5	1096.3

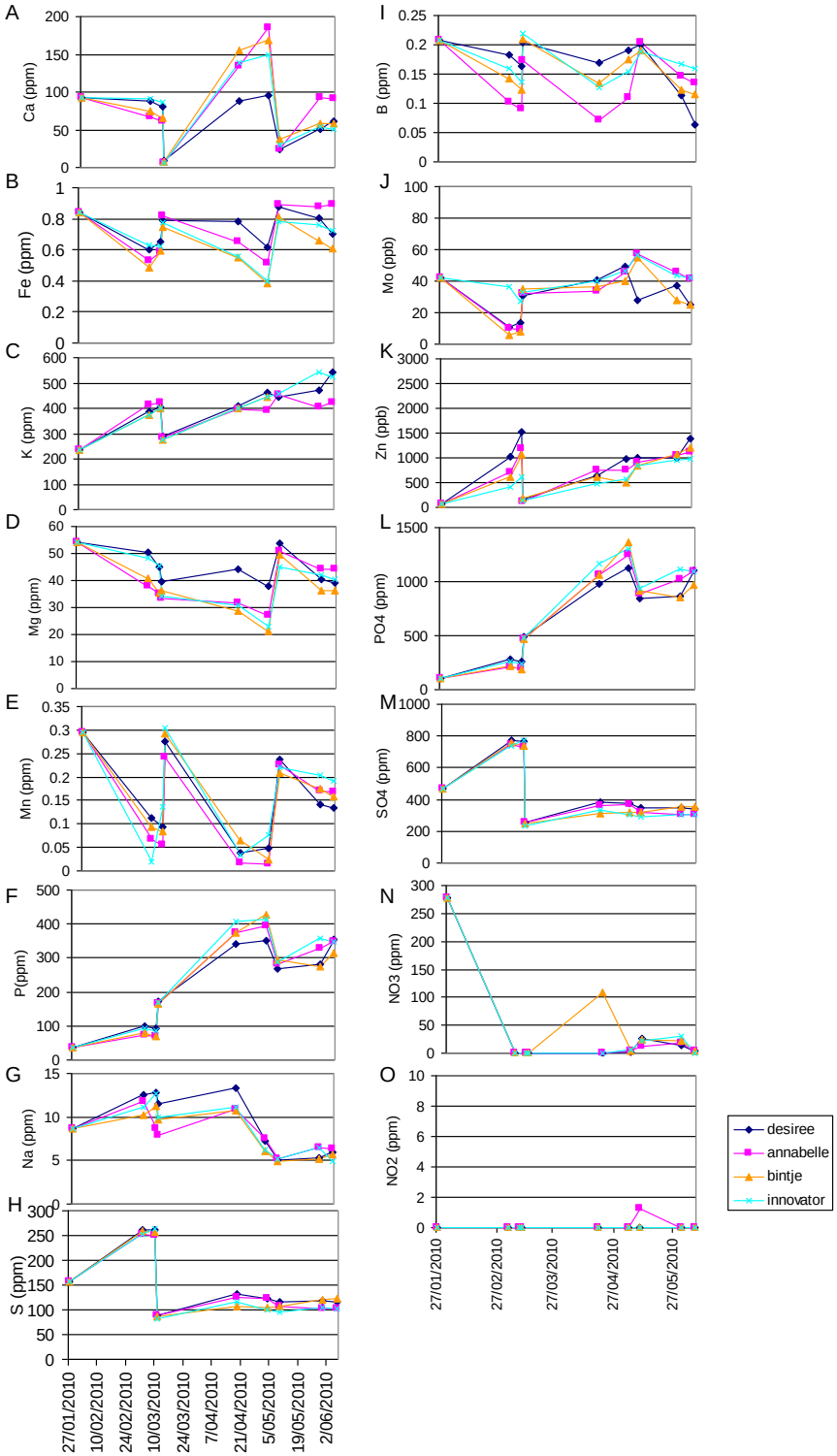


Fig. 78 UCL - Element concentration in the nutrient solution during plant growth

The composition of the nutrient solution was analysed at the beginning of the culture, before and after each solution change and at harvest (Fig. 78). As shown on Fig. 78, the evolution of the nutrient solution composition was similar for the 4 cultivars. The concentration of S (Fig. 78H) was higher during the growth phase than during the tuberisation phase and the concentration of K (Fig. 78C) and P (Fig. 78F) was higher during the tuberisation phase due to the difference of composition of both solutions. The concentration of these elements increased between two solution changes because K_2SO_4 and KH_2PO_4 were used to adjust EC (only K_2SO_4 during the growing phase and both during the tuberisation phase, Fig. 78F,H). Ca concentration also increased because $Ca(NO_3)_2$ was added in the solution to bring addition N to the plants during the tuberisation phase (Fig. 78A).The concentration of Mg (Fig. 78D), Fe (Fig. 78B), Mn (Fig. 78E) and B (Fig. 78I) decreased between two solution changes whatever the plant development phase. The amount of N was rapidly consumed by the plants (Fig. 75A-D; Fig. 78N). It is known that in hydroponic, potato plants accumulate and stock as much N as possible and use it later to produce amino acid and proteins (HZPC personal communication). During the experiment, we observed an accumulation of Zn in the solution (Fig. 78K). The cause of this accumulation needs to be determined.

Nitrate content was rapidly depleted. The microelement Zn accumulated.

5.2.9 Microbial count

The order of magnitude of the reported bacterial count is considered not significantly different among cultivars.
Stock solution already contained significant levels of bacteria.

Tab. 38 UCL - Microbiological total count of the nutrient solution during plant growth

bacteria				
date	**Désirée**	**Annabelle**	**Bintje**	**Innovator**
growth solution	10	10	10	10
10-mars	107000	207000	33000	99000
tuber solution	230	230	230	230
4-mai	43000	38000	81000	47000
14-juin	210000	270000	390000	740000
yeast (CFU/ml)				
date	**Désirée**	**Annabelle**	**Bintje**	**Innovator**
growth solution	<1	<1	<1	<1
10-mars	11	<1	10	34
tuber solution	1	1	1	1
4-mai	1	2	32	1
14-juin	600	1700	300	700
mould (CFU/ml)				

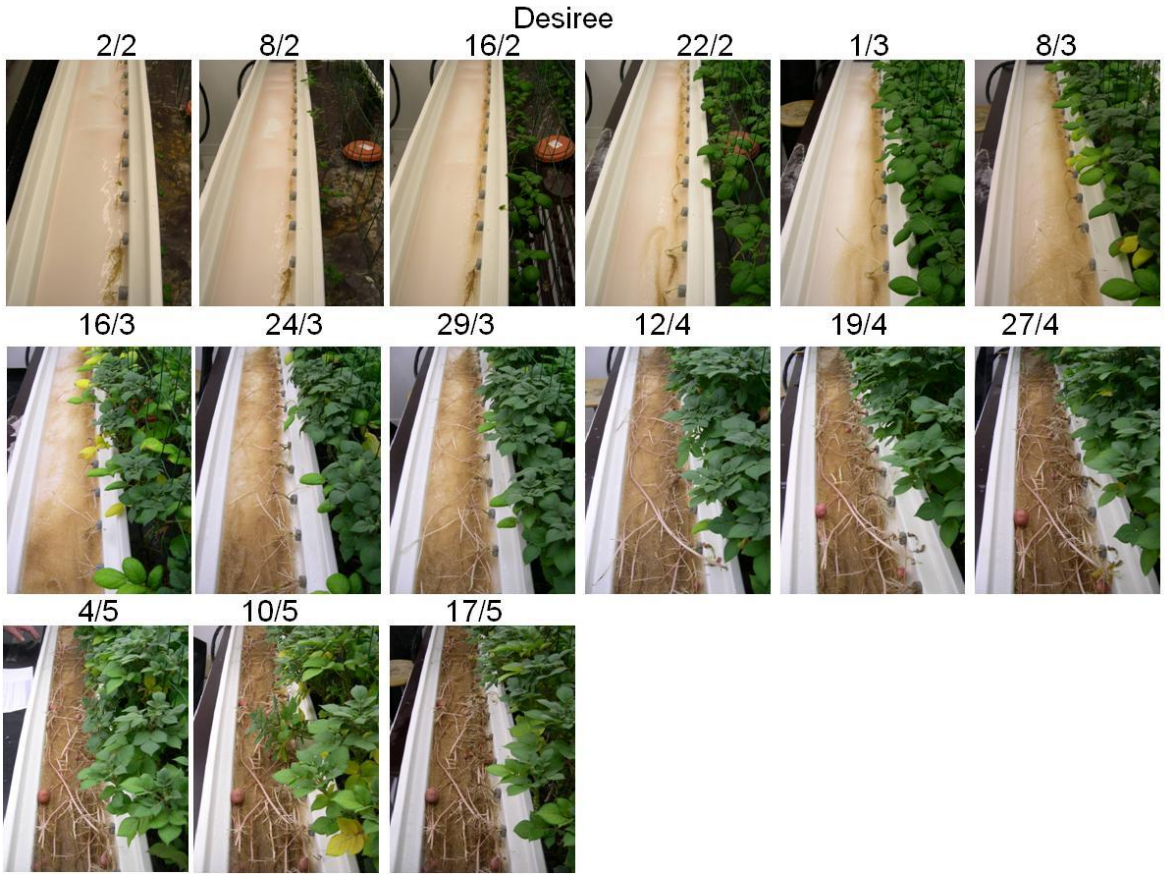
date	Désirée	Annabelle	Bintje	Innovator
growth solution	<1	<1	<1	<1
10-mars	17	30	41	21
tuber solution	<1	<1	<1	<1
4-mai	2	18	6	2
14-juin	5100	700	1600	2800

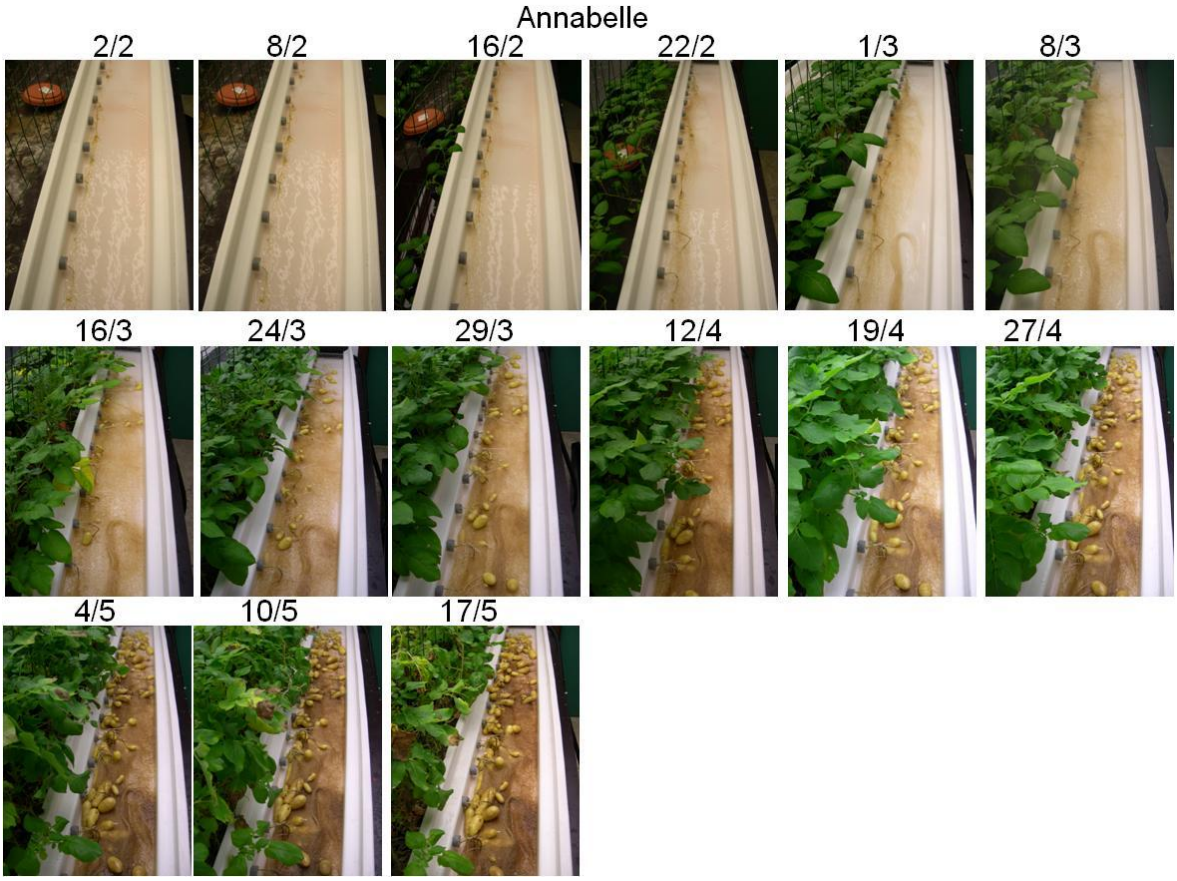
A microbiological total count was also realized before and after each solution change and at harvest (0). The number of bacteria in the nutrient solution was higher than the number of mould and the number of yeast.

5.3 Monitoring of plant development

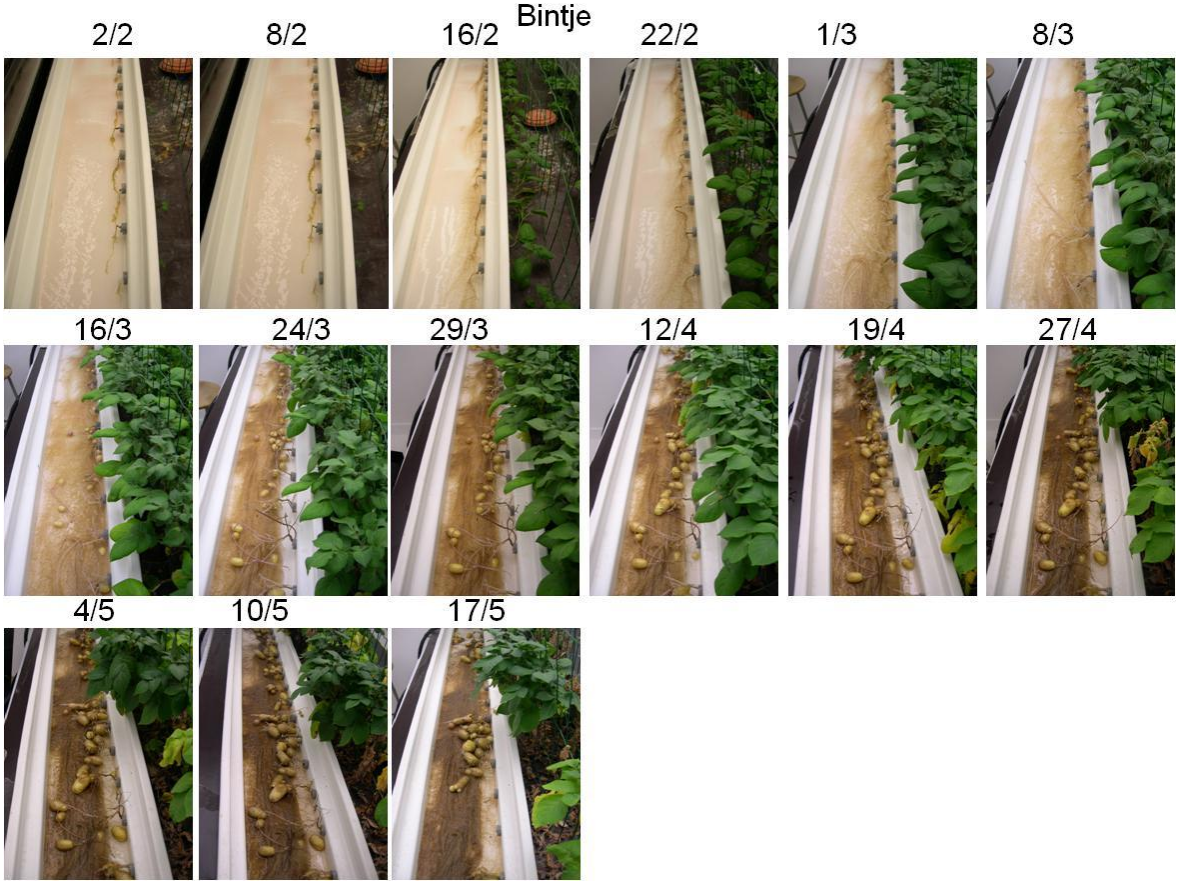
The plants grew well during the growth phase (Fig. 79). After the second solution change, some innovator and Bintje plants began to lose their leaves, turned yellow and died. Only the Desiree plants stayed alive throughout the experiment.

5.3.1 Photographic follow-up





Bintje



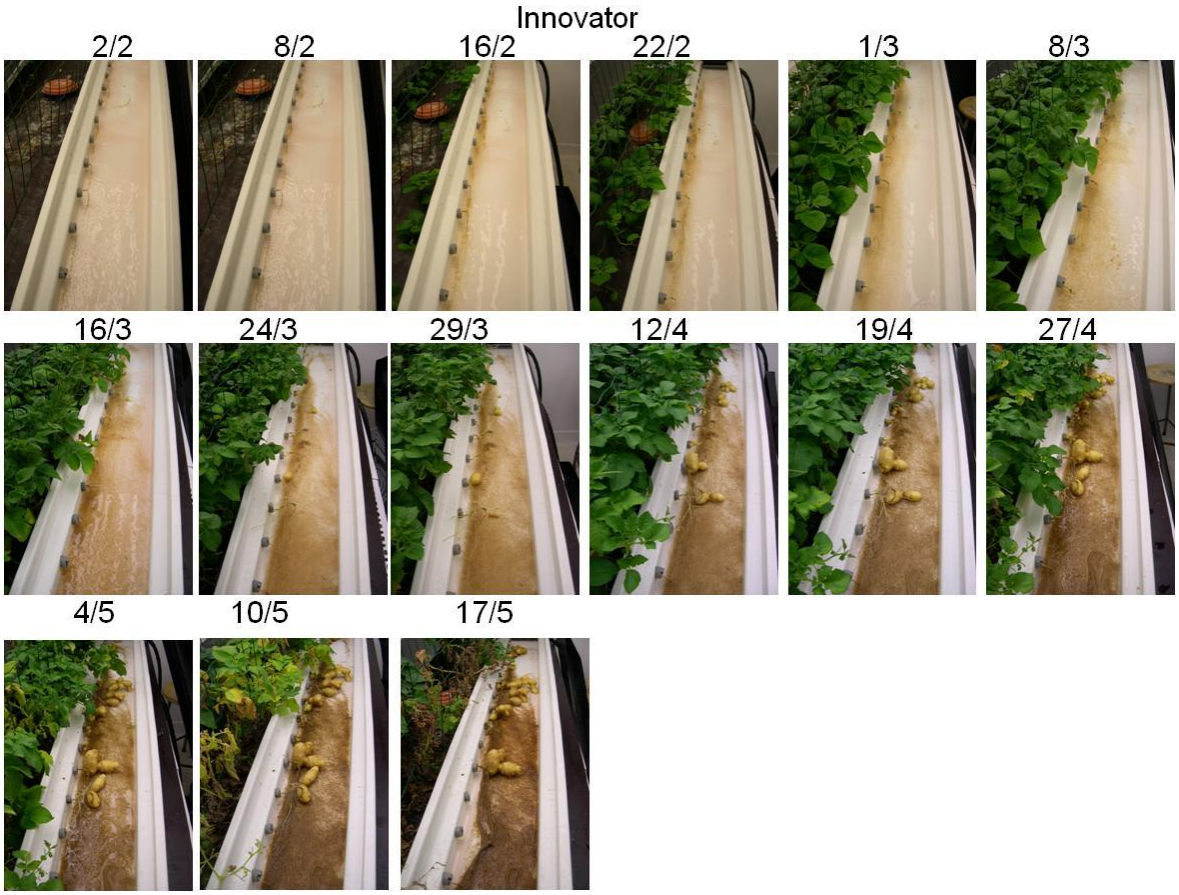


Fig. 79 UCL - Gully pictures

5.3.2 Detailed observation

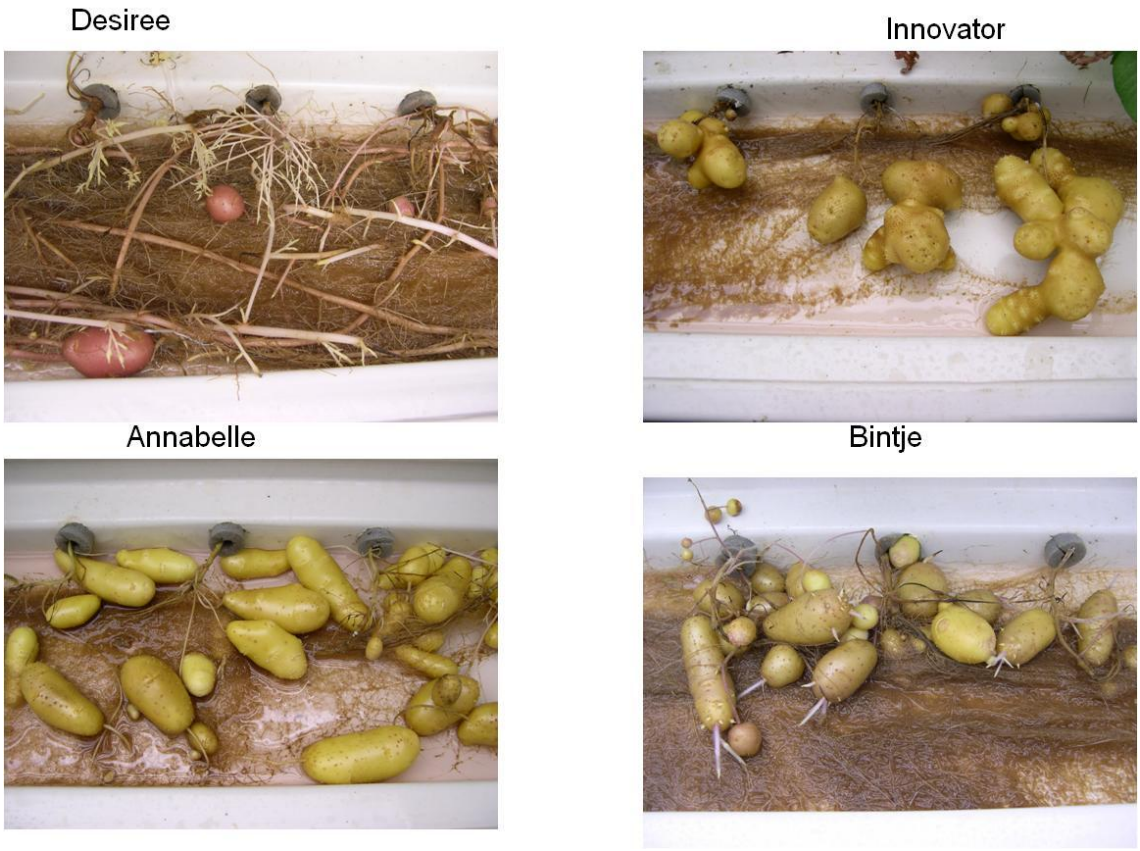


Fig. 80 UCL - Tuber detailed pictures

5.3.3 Growth assessment

The plants grew well during the growth phase (Fig. 81). After the second solution change, some Innovator and Bintje plants began to loose their leaves, turn yellow and die. Only the Desiree plants stay alive throughout the experiment.

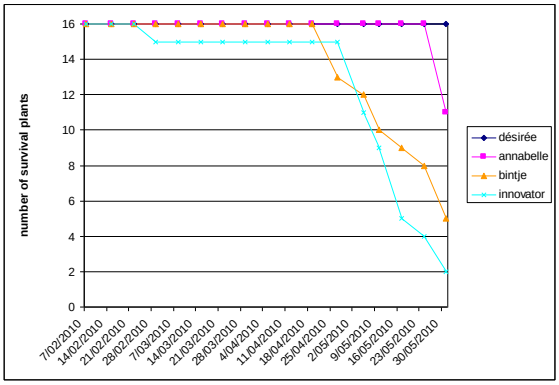


Fig. 81 UCL - Evolution of living plants number

The size of the plant, number of leaves and number of axillaries were measured weakly for each plant. Statistical analysis (ANOVA II) were realised to see the effect of the variety and the light intensity (150-200 µmol/m²s, 200-250 µmol/m²s) on the growth parameters. Statistical results showed that the variety effect was mainly significant (Fig. 82, Fig. 83) while the light intensity effect was not significant. We thus only present the difference between varieties.

As shown on Fig. 82, the plants reached a final size of around 40- 45 cm for Bintje, Annabelle and Desiree and around 30 cm for Innovator. At the exception of Innovator where a plateau was observed, the plants continued to increase in size up to harvest.

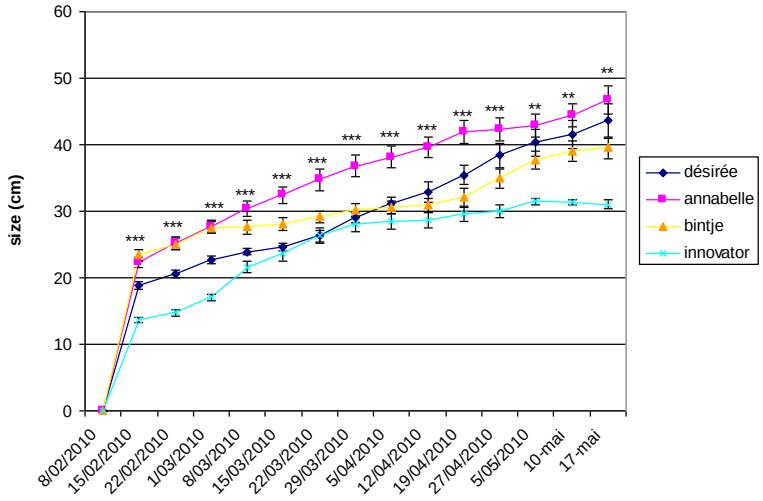


Fig. 82 UCL - Plant size evolution
Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

Desiree, Annabelle and Bintje plants produced more nodes and more leaves than Innovator plants on the main stem (Fig. 83A, B). Bintje produced less axillary branches than the other varieties (Fig. 83C). The total number of green leaves on the plant at the end of the experiment was around 50 in Desiree and Innovator, 40 in Annabelle and 30 in Bintje (Fig. 83D).

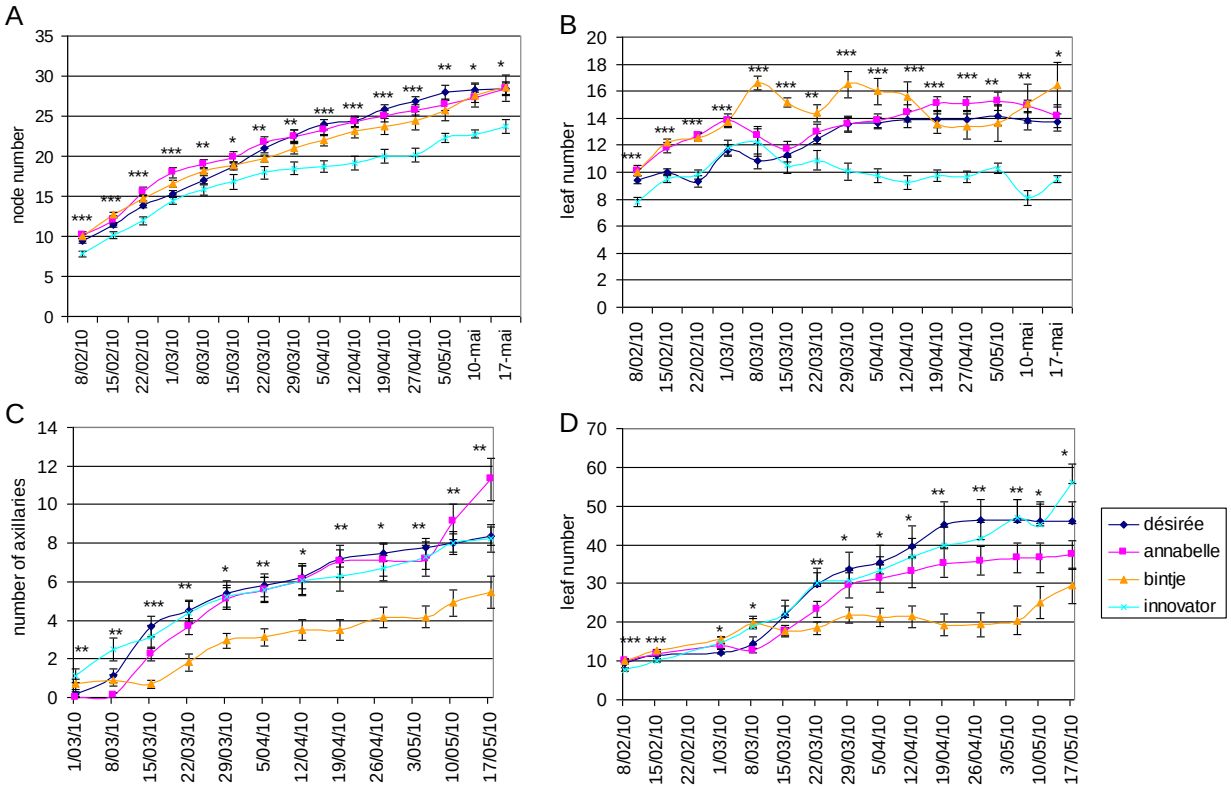


Fig. 83 UCL - Development of the plant aerial part

(A) number of nodes on the main stem, (B) number of green leaves on the main stem, (C) number of axillary branches, (D) total number of green leaves (main stem + axillary branches). Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

The development of the root system was important. Desiree produced more roots and Innovator less roots than the other varieties (Fig. 84).

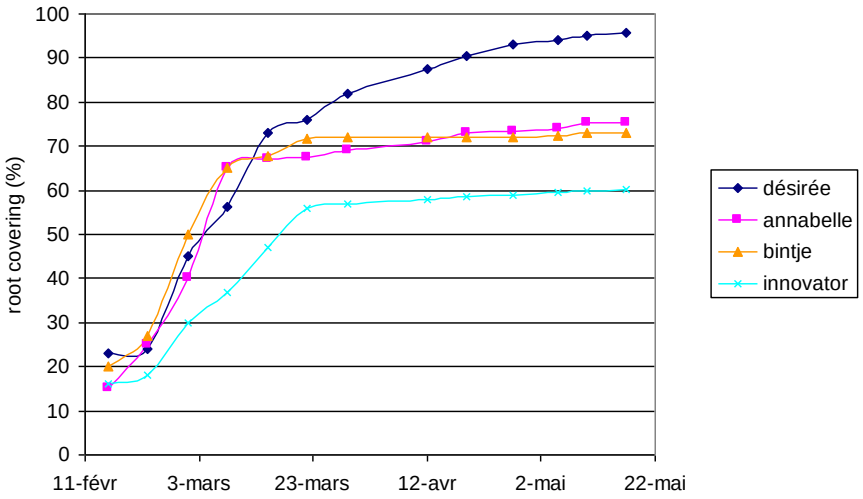


Fig. 84 UCL - percentage of the gully covered by roots

The number of stolons and tubers were measured weakly for each plant. Statistical analysis (ANOVA II) were realised to see the effect of the variety and the light intensity (150-200 µmol/m²s, 200-250 µmol/m²s) on these parameters. Statistical results showed that the variety effect was significant (Fig. 85). The light intensity effect was only significant at the 5% level for the number of tubers at some dates and for the date of tuber apparition. We only present the difference between varieties. The first stolon appeared 25-30 days after transfer of the plants in the gully and apparition of the first tuber occurred 20-50 days later depending on the varieties (Fig. 85A). Annabelle and Bintje plants were the first to initiate tubers and Desiree plants were the last. Annabelle produced more stolons than the other varieties (Fig. 85B). The number of tubers was higher in Annabelle and Bintje compared to Innovator and Desiree (Fig. 85C). Harvest of Desiree tubers occurred later because their initiation and growth started later compared to the other varieties; Desiree plants still produced tubers at harvest. The number of tubers harvested was 119 for Annabelle, 89 for Bintje, 59 for Desiree and 36 for Innovator.

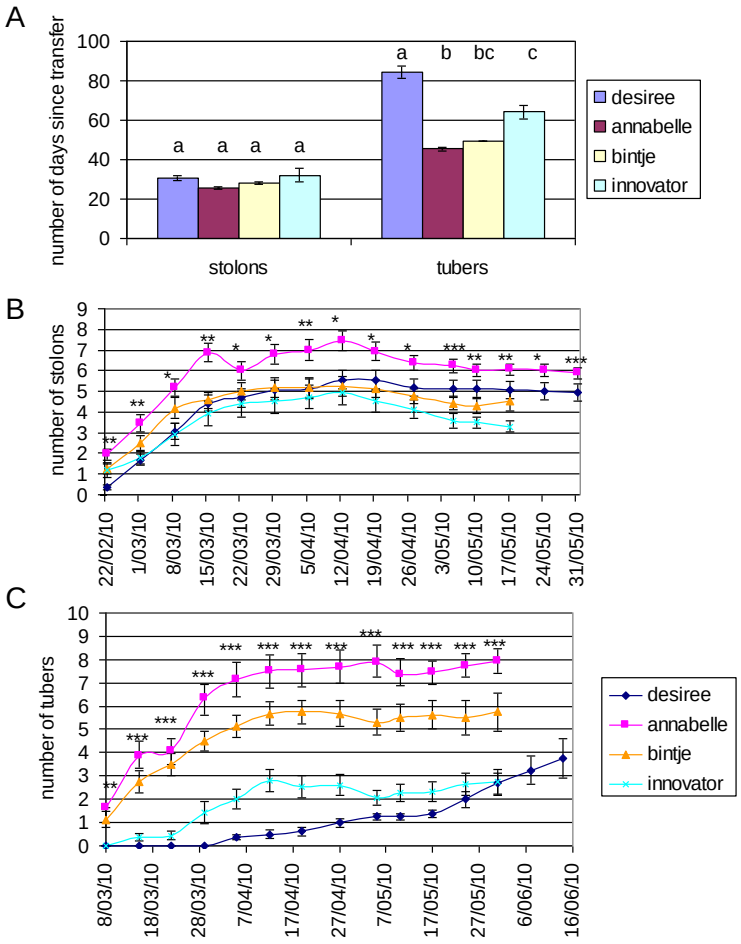


Fig. 85 UCL - Development of stolons and tubers

(A) time of apparition of the first stolon and tuber per plant, (B) number of stolons per plant, (C) number of tubers per plant. Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level). (ANOVA).

Development of stolons from tubers was observed for Bintje (Fig. 86) and for some Annabelle plants. Tuber germination was due to a too high amount of N. The addition of N during the tuber phase was thus reduced.

Fig. 86 UCL - Germination of Bintje tubers

5.3.4 Physiological observations

The physiological parameters of the plants were followed every two weeks for 8 plants per cultivar on the 5th youngest leaf (young leaf photosynthetic active). We observed the instantaneous net photosynthesis and instantaneous transpiration (portable Infra Red Gas analyzer LCA4 ADC Bioscientific Ltd), the stomatal conductance (porometer AP4 deltaT), the kinetics of chlorophyll fluorescence (fluorescence monitoring system 2 Hansatech Instruments) and the chlorophyll concentration SPAD (CCM-200 opti-sciences). Statistical analysis (ANOVA II) were realised to see the effect of the variety and the light intensity (150-200 µmol/m²s, 200-250 µmol/m²s) on the physiological parameters. Statistical results showed that the light intensity effect was rarely significant. We thus only present the difference between varieties. Fig. 87 presents the leaf area of the analysed leaf; the size was slightly higher for the Bintje plants.

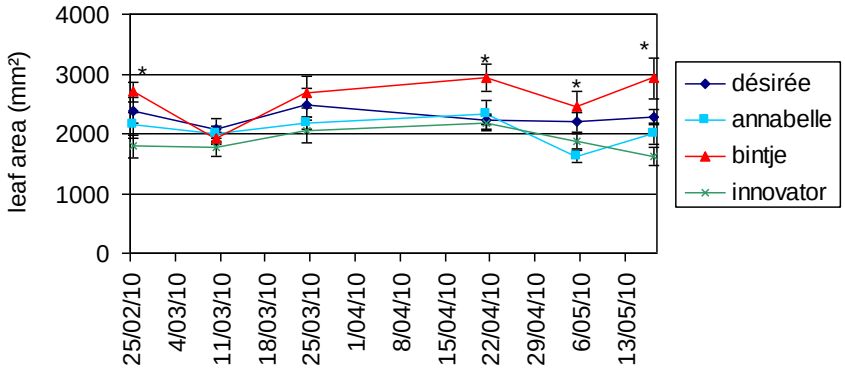


Fig. 87 UCL - Leaf surface of the 5th youngest leaf (young leaf photosynthetic active) used to analysed the physiological parameters. Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

The instantaneous CO_2 assimilation (Ai) was the same for all varieties while the instantaneous evapotranspiration (Ei) was higher in Annabelle (Fig. 89).

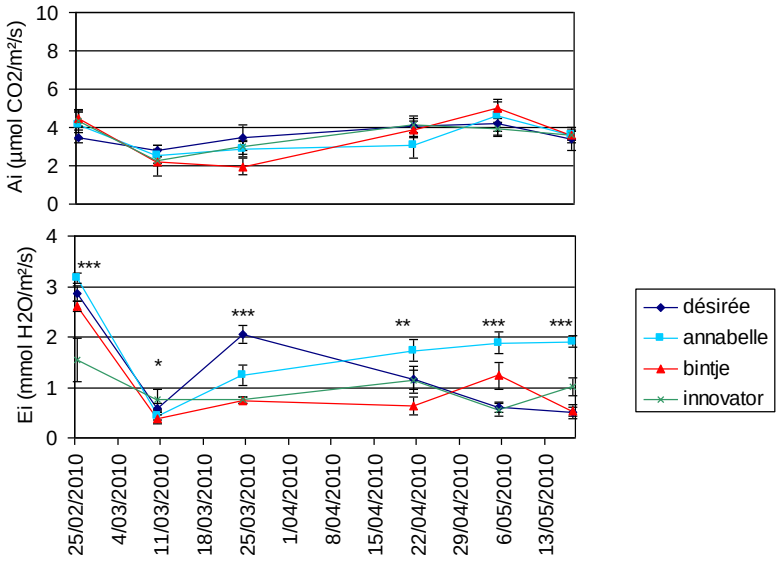


Fig. 88 UCL - Instantaneous CO_2 assimilation and instantaneous transpiration of the 5th youngest leaf

Instantaneous CO_2 assimilation (A) and instantaneous transpiration (B) of the 5th youngest leaf (young leaf photosynthetic active). Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

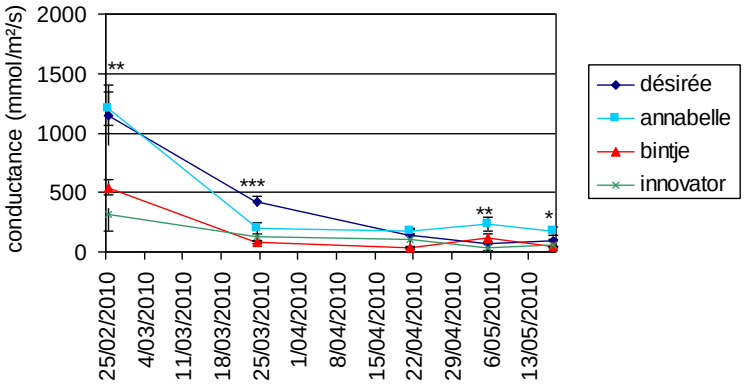


Fig. 89 UCL - Stomatal conductance

Stomatal conductance of the 5th youngest leaf (young leaf photosynthetic active). Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

The stomatal conductance was higher in the plantlets than later during plant development (Fig. 89). The stomatal conductance was higher in plantlets in Desiree and Annabelle than in Bintje and Innovator. Later, Annabelle showed higher stomatal conductance.

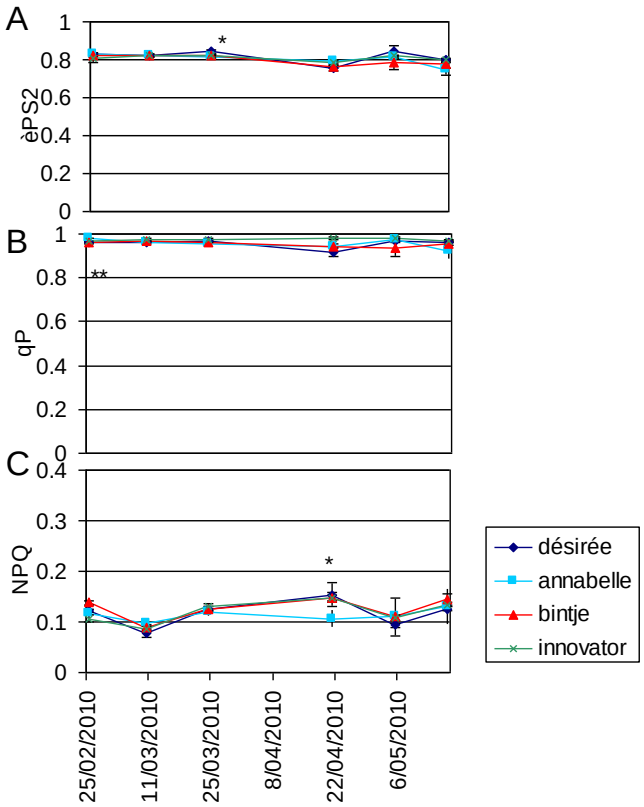


Fig. 90 UCL - Kinetics of chlorophyll fluorescence

Kinetics of chlorophyll fluorescence of the 5th youngest leaf (young leaf photosynthetic active). (A) photosystem II quantum efficiency, (B) photochemical quenching, (C) non photochemical quenching. Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

The results obtained for the kinetics of the chlorophyll fluorescence showed that there were not strong differences between varieties for the analysed parameters (Fig. 90). These parameters evaluate the photosynthetic performance of the photosystem II. The photosystem II efficiency (Fig. 9090A) gives the proportion of the light absorbed by the chlorophyll that will be used for the photosynthesis. A normal value for this parameter is 0.8 as was observed in our experiment. The photochemical quenching (Fig. 90B) indicates the redox state of the quinone, the first electron acceptor of the photosystem II. This gives information on the proportion of the reaction centers of the photosystem II which are open. The non photochemical quenching (Fig. 90C) informs on the heat dissipation. Together, our data show that the photosynthesis was correct during our experiment and similar in all varieties.

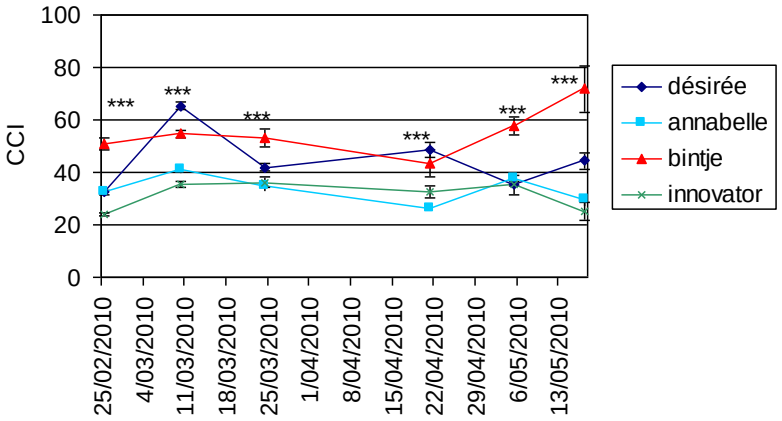


Fig. 91 UCL - Chlorophyll concentration SPAD

Chlorophyll concentration SPAD of the 5th youngest leaf (young leaf photosynthetic active). Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

As showed on Fig. 91, the highest chlorophyll content was observed in Bintje plants and the lowest in Annabelle.

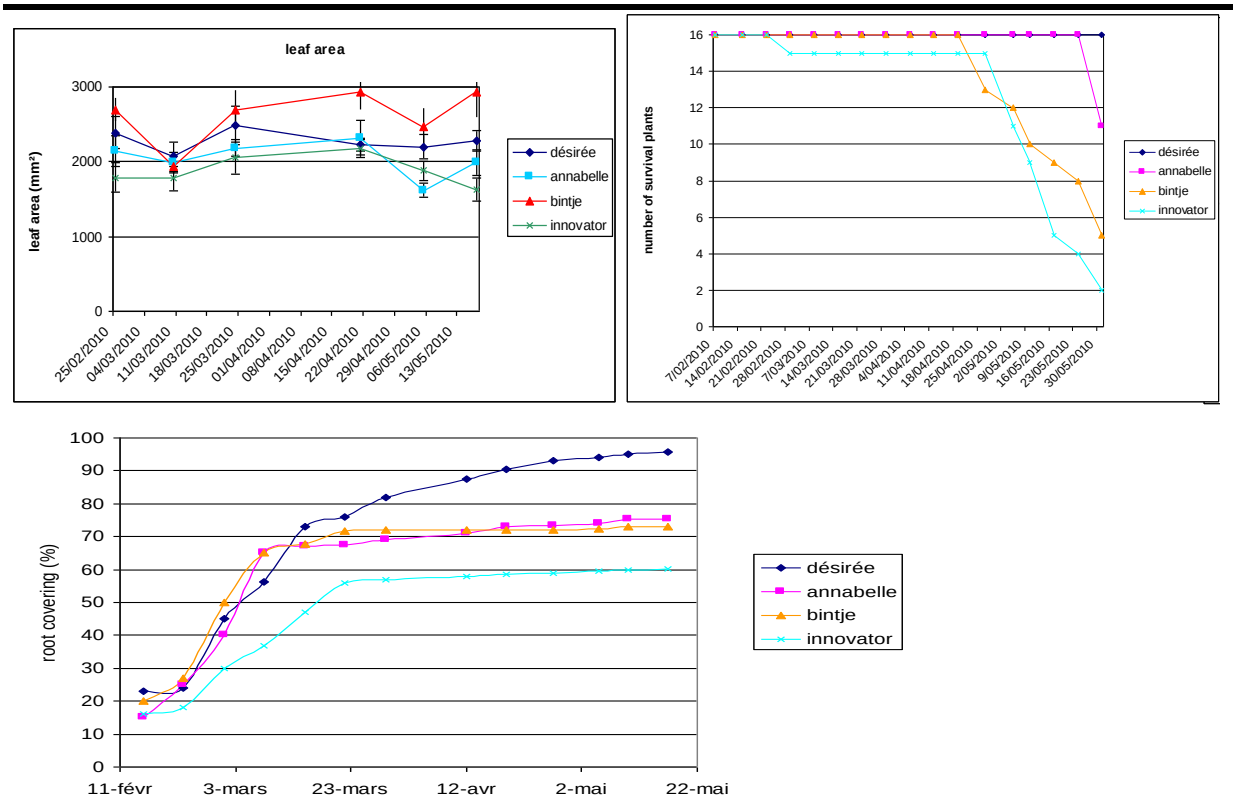


Fig. 92 UCL - Development of potato cultivars as a function of time

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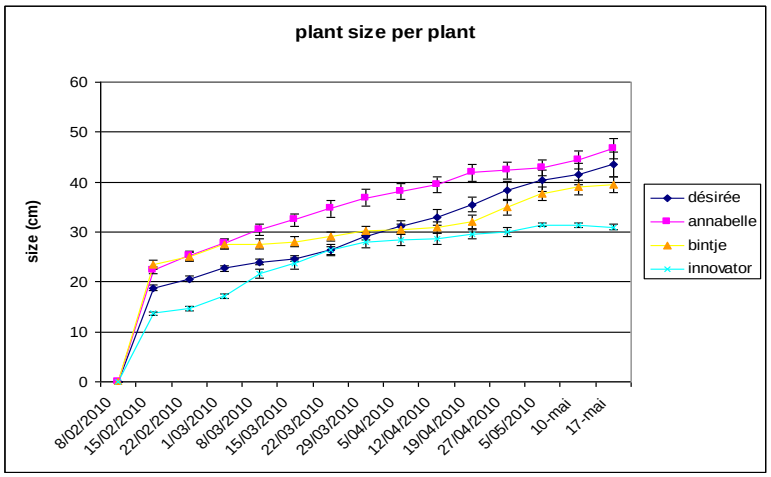


Fig. 93 UCL - Plant size evolution

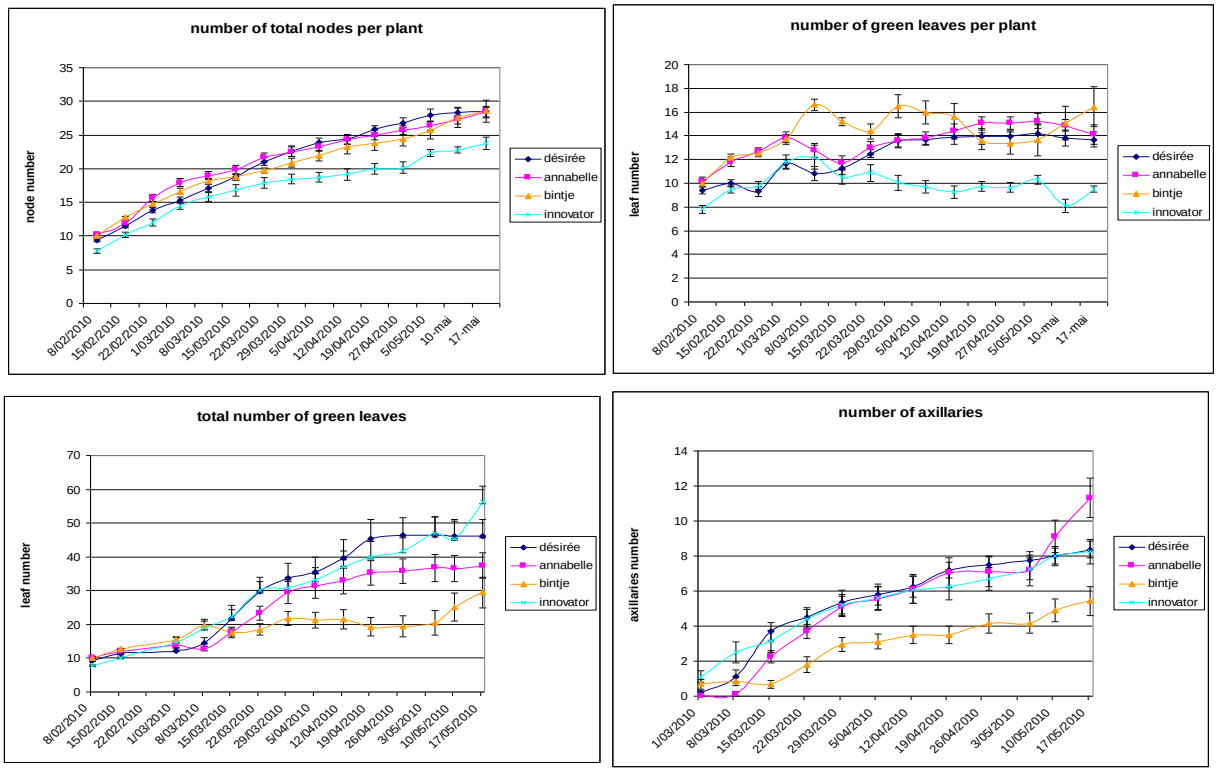


Fig. 94 UCL - Development of the plant aerial part

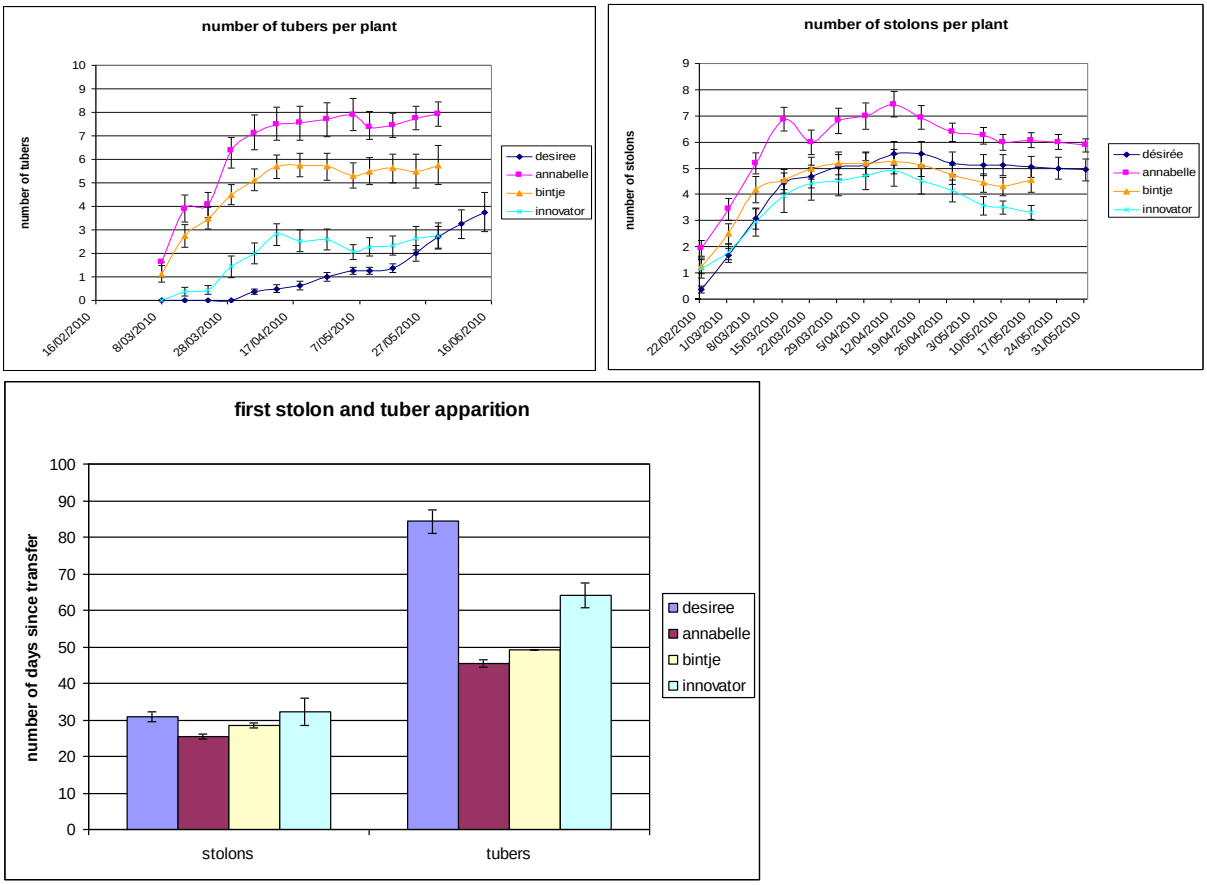
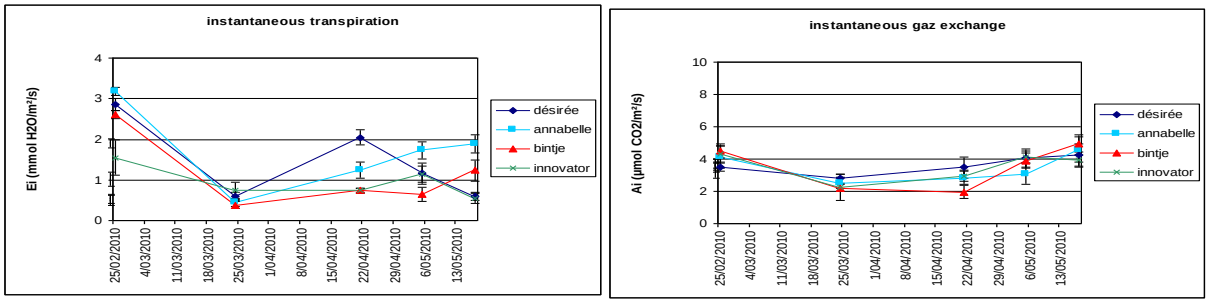


Fig. 95 UCL - Development of stolons and tubers

5.3.5 Gas exchange data

The instantaneous CO_2 assimilation (Ai) was the same for all varieties while the instantaneous evapotranspiration (Ei) was higher in Annabelle.



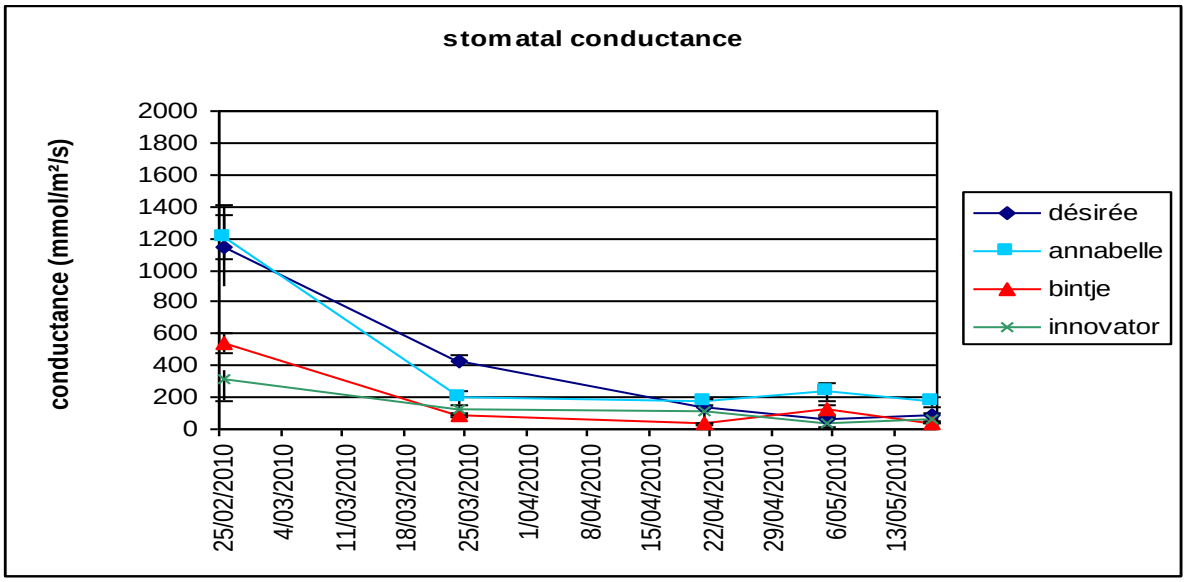


Fig. 96 UCL - Gas exchange

5.3.6 Extra plant physiological measurements

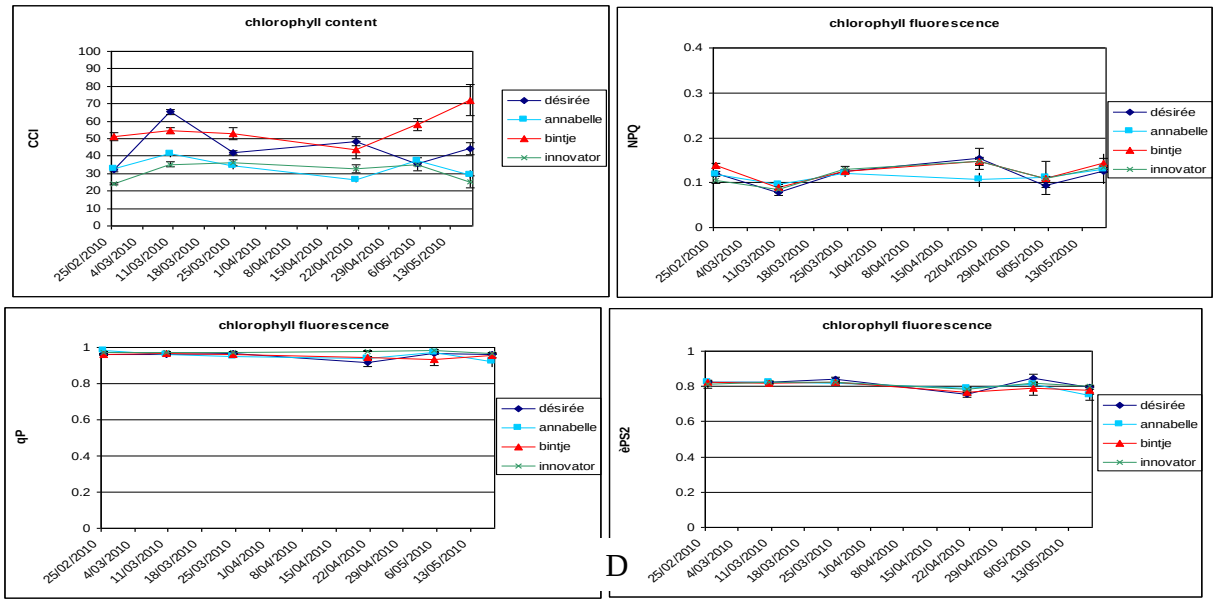


Fig. 97 UCL - Chlorophyll measurements

5.4 Harvest results

Annabelle showed the highest number of harvested tubers followed by Bintje, Desiree and Innovator (Fig. 98A, B, E). Innovator produced bigger tubers than the other varieties (Fig. 98A,C) even if the difference of fresh weight per tuber was not statistically significant between varieties. The difference between variety for tuber size was neither significant (Fig. 98D,G). The best yield was nevertheless observed in Annabelle and the lowest yield in Desiree (Fig. 98F).

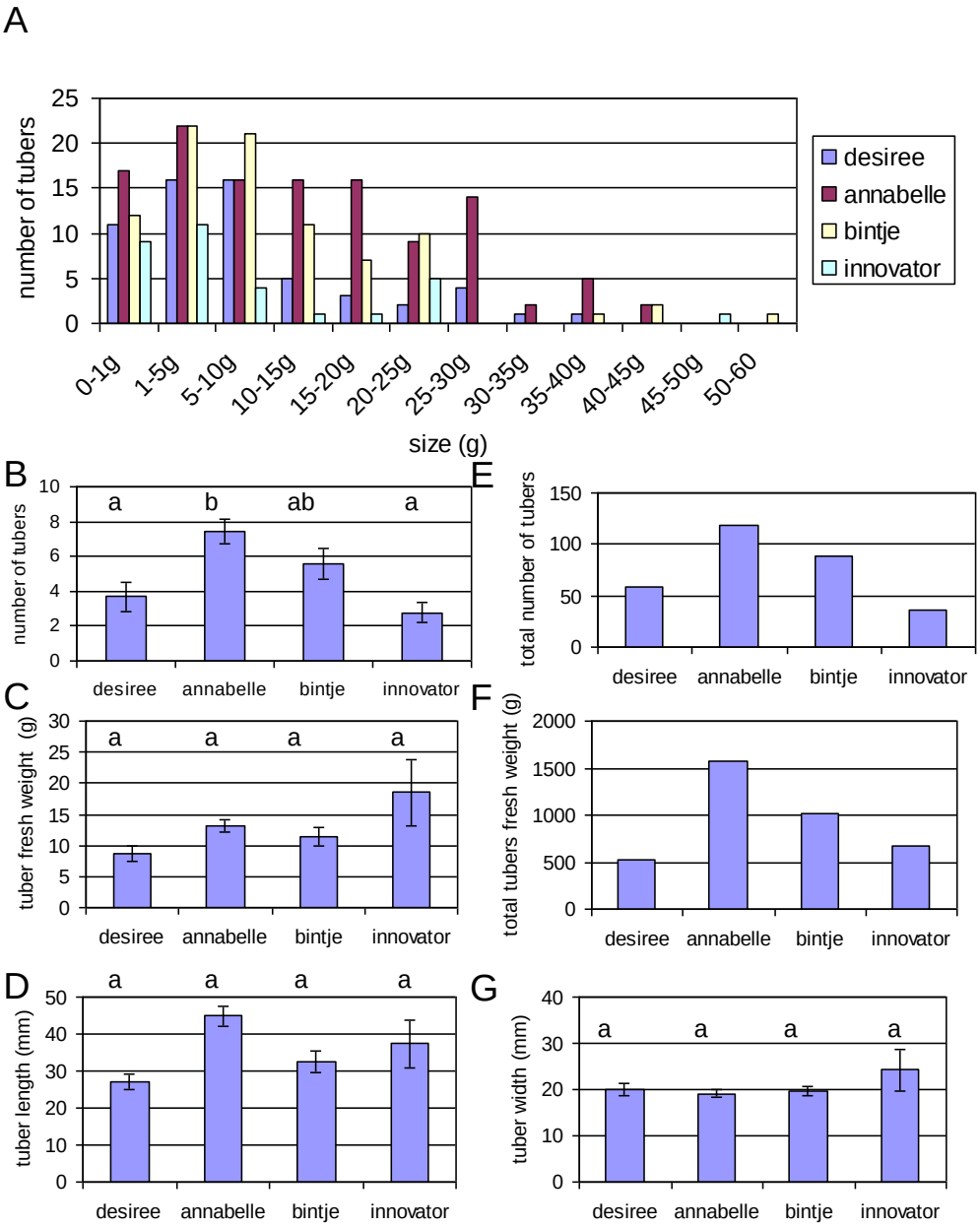


Fig. 98 UCL - Number, weight and size of the harvested tubers

Number, weight and size of the harvested tubers. (A) number of tubers per variety according to grade. Average tuber (B) number, (C) fresh weight, (D) length and (G) width for each variety. Total harvested tuber (E) number and (F) fresh weight per variety. Vertical bars are standard errors. Differences between varieties are statistically significant (*, 5% level), highly significant (**, 1% level) or very highly significant (*** 0.1% level) (ANOVA).

As shown on Fig. 99, Bintje plants produced the highest total biomass and Desiree plants the smallest in term of dry weight (Fig. 99A, C) while Annabelle plants produced the highest total biomass and Innovator the smallest in term of fresh weight (Fig. 99E). This difference is mainly due to the difference in the water content of the tubers (Fig. 99F). The aerial part, stolons and roots were more developed in Desiree compared to the other varieties (Fig. 99A, C, E). Annabelle showed the highest edible to non-edible biomass ratio and Desiree the lowest (Fig. 99B, D). Bintje showed the best water use efficiency for both total biomass production and tuber production in term of dry weight while Annabelle showed the best ratio in term of fresh weight (Fig. 100A, B).

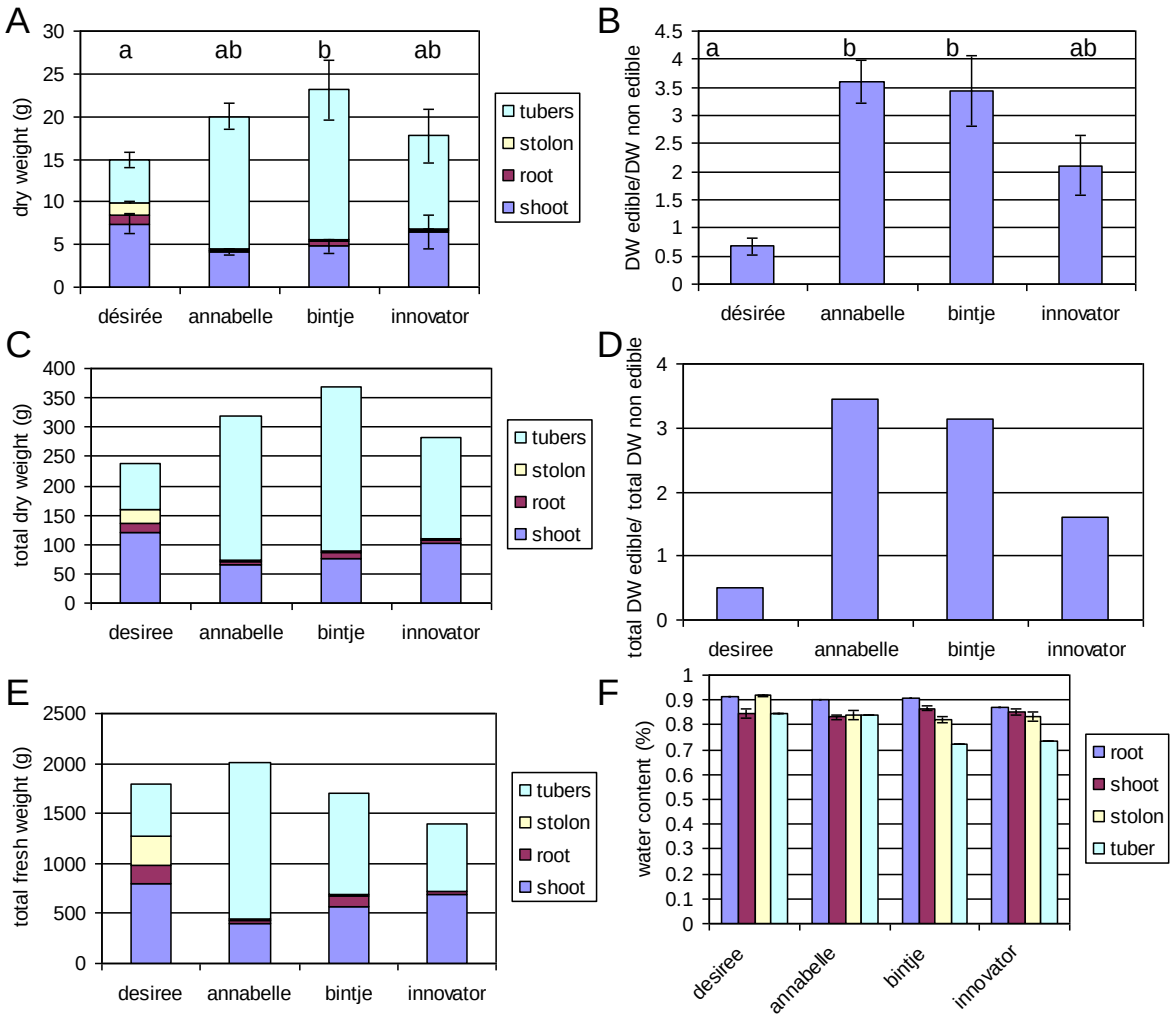


Fig. 99 UCL - Biomass produced by the plants

Biomass produced by the plants. Dry weight produced per cultivar according to the organs (A) per plant, (C) for all the plants. Ratio between total edible dry weight (tubers) and total non edible dry weight (aerial part + stolons + roots) (B) per plant and (D) for all the plants. (E) Fresh weight produced per cultivar according to the organs for all the plants. (F) water content produced per cultivar according to the organs. Vertical bars are standard errors. Histograms followed by the same letter is not statistically different at 5% level (ANOVA - Scheffé).

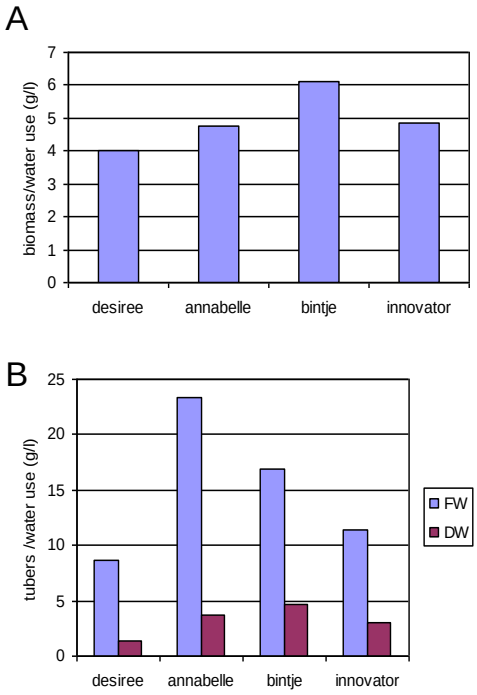


Fig. 100 UCL - Water use efficiency
(A) total plant biomass (DW) produced per litter, (B) tuber biomass produced by litter.

Tab. 39 Potato - IPL nutritional analysis results

BT2 UCL		Annabelle	Bintje	Desiree	Innovator
Water (%)		80,8	73,9	84.7	76.8
Protein (%)		1,39	2,16	1.47	1.95
Fat (%)		0,04	0,03	0.08	0.07
Available carbohydrates (%)		15,50	18,13	10.83	17.93
TDF (%)		1,47	1,95	1.82	2.2
Minerals (%)		0,88	1,27	1.07	1.07
Of which (mg/100g)	Potassium	365	495	470	447
	Calcium	6,2	12,5	4.9	7.9
	Magnesium	24,9	26,0	20.2	25.6
	Iron	0,6	0,7	0.5	0.6
	Copper	0,3	0,5	0.3	0.4
	Zinc	0,5	0,6	0.4	0.5
	Manganese	0,22	0,26	0.23	0.22
	Phosphorus	79	110	195	248
Solanine (mg/kg)		0	0	0	0
Chaconine (mg/kg)		0	0	0	0
Energy (for 100g)	kcal	62,4	72,8	53.6	84.6
	kJ	261,1	304,5	224.1	353.8

5.5 Conclusions

There was no strong difference between cultivars for the pH and EC variation, elements and water consumption and physiological parameters. We observed again an accumulation of Zn in the nutrient solution. The cause of this accumulation is unknown.

Annabelle produced the taller plants. Bintje produced plants with a good development of leaves on the main stem and few axillaries. Innovator produced small but branched plants and few roots. Desiree produced more roots and stolons.

Annabelle and Bintje were the first to induce tubers production and showed the best yield. Annabelle produced more tubers and showed the best yield, edible to non edible biomass ratio and water use efficiency in term of fresh weight while Bintje showed the best yield, edible to non edible biomass ratio and water use efficiency in term of dry weight. Innovator produced

the biggest tubers. Tuber initiation was delayed in Desiree so that the harvest of this cultivar was postponed.

The conditions (mainly solution composition) were better in BT2 compared to BT1 since the tuber yield increased between 2-3 times. Nevertheless, the amount of N added during the tuberisation phase was not yet optimal. The level was too high at the beginning in Desiree so that the tuber induction was delayed. It was also too high in Bintje and in less extent in Annabelle since stolons were initiated from the tubers. This parameter needs to be better adapted in the future to find the best compromise between good yield and plant survival.

6 Soybean (UNapoli)

6.1 Experimental Layout

6.1.1 Measuring Plan

Plant development

Weekly assessment for 2 plants per double gully

- plant height
- number of lateral shoots
- number of leaves, leaf area estimation

Plant physiological parameters

- leaf gas exchanges: net photosynthesis and transpiration rate (WALZ HCM 1000)
- stomatal conductance: leaf porometer (AP4, Delta T Devices, Cambridge)
- chlorophyll content: analytical method (extraction in acetone and spectrophotometer lecture)

Destructive measurements

- fresh weight (FW), dry weight (DW), percentage of dry matter (DM) and DM partitioning in the different organs
- plant leaf area: leaf area meter (LI-COR 3000, LI-COR, Lincoln, NE, USA)

Nutrient solution

- EC and pH manual control and adjustment every 2 days
- water depletion measurement every 2 days to keep constant the solution volume
- cumulative crop water usage
- week analyses of main macronutrients (NO3-, PO43-, K+) by spectrophotometer
- periodic detailed analyses (NO3-, PO43-, K+, Cl-, Ca2+, Mg2+, SO42-, B3+), at the start (fresh solution), at the end of vegetative phase (approximately after 7 weeks) and at the harvest.

6.1.2 Setup

The layout of the chamber can accommodate 12 independent double gullies 1m length. The 4 selected cultivars were ‘PR91M10’, ‘Cresir’, ‘Regir’, ‘Atlantic’.

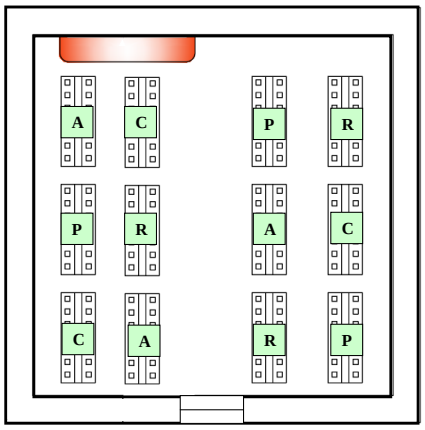


Fig. 101 UNapoli - Setup

6.2 Growth environment follow-up

6.2.1 Settings

Tab. 40 UNapoli - Settings

Photoperiod	12-h Long Day
Light intensity	350 µmol m^{-2} s^{-1}
Room temperature Humidity	20/26 °C (Night/Day) 65-75% (set point 70%)

The T and humidity measurements resolve around the set points.

6.2.2 Chamber T/RH evolution

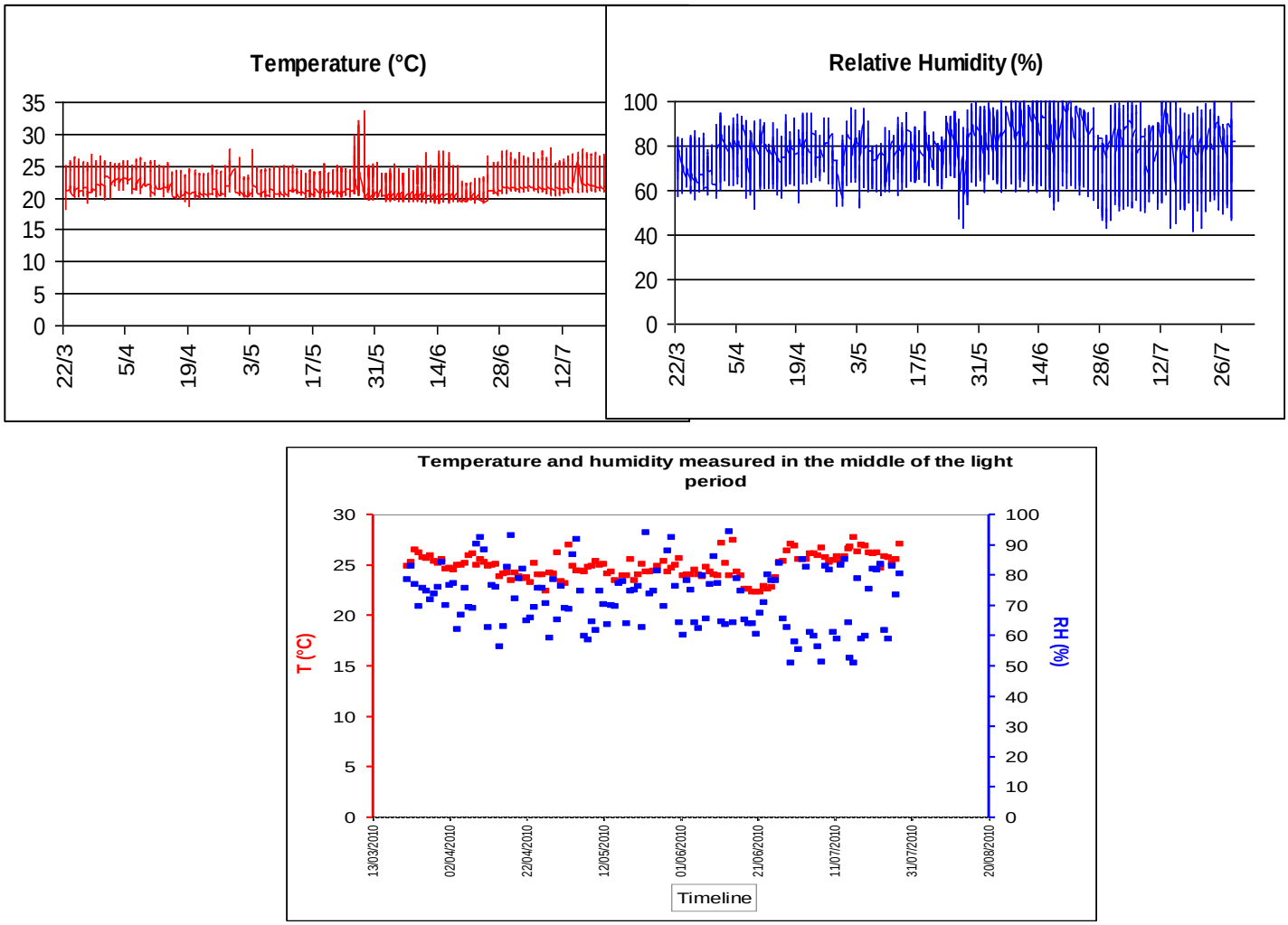


Fig. 102 UNapoli - Chamber T/RH

Note: RH level was reduced during the last month of the growing cycle to improve the desiccation of soybean pods.

6.2.3 Chamber CO_2 level

Ambient level, profiles in the daytime were monitored during the gas exchange measurements.

6.2.4 Nutrient Solution Environment

Gully inclination: 1%
Nutrient solution flow rate: 2.4 l/min.

6.2.5 pH and EC evolution

The data points indicate the values before adjustment to the set-points pH 5.8 and EC 2000 µS/cm.

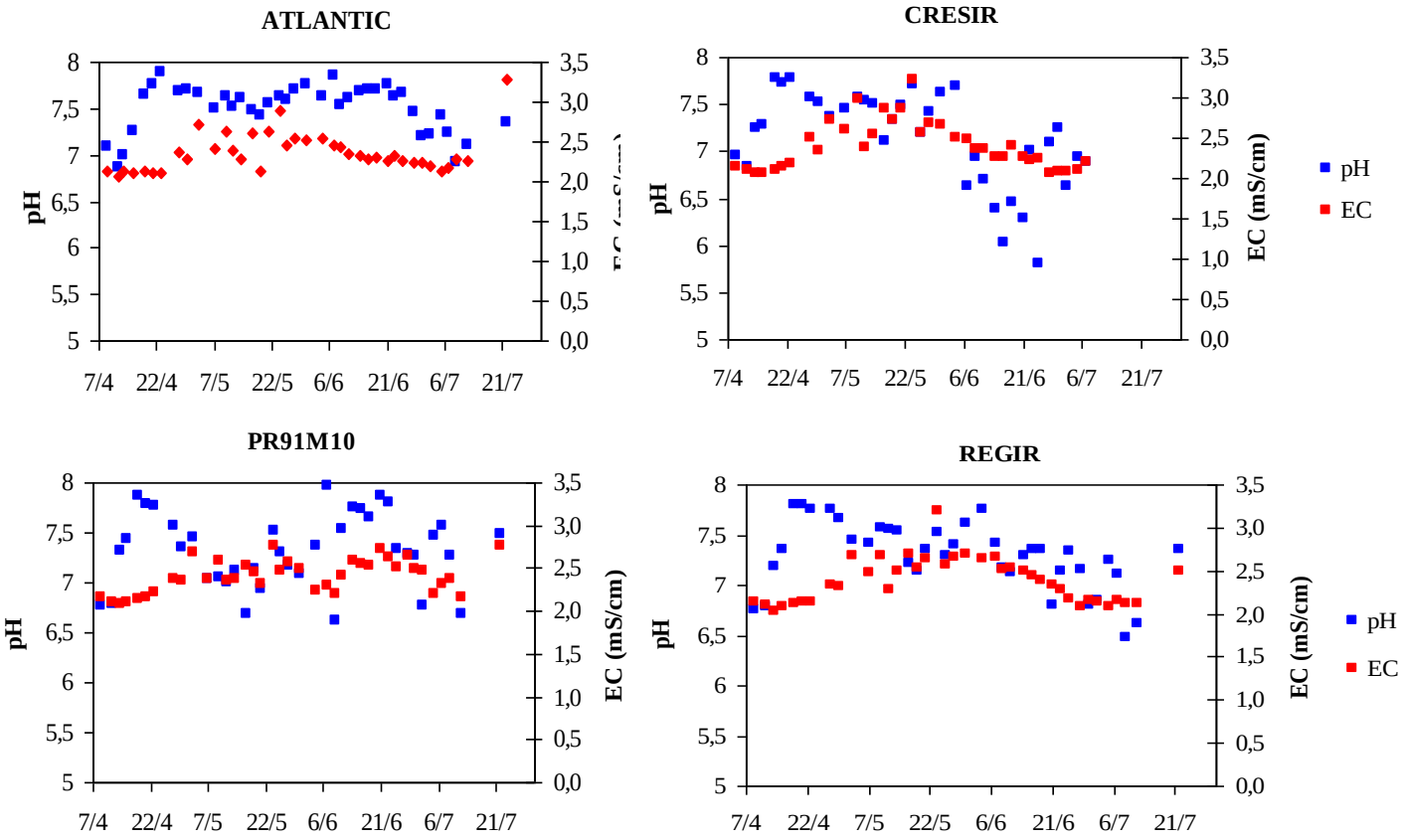


Fig. 103 UNapoli - pH/EC evolution before adjustments to set-points

pH and EC values of nutrient solution after the adjustment to the set-points pH 5.8 and EC 2000 µS/cm (B).

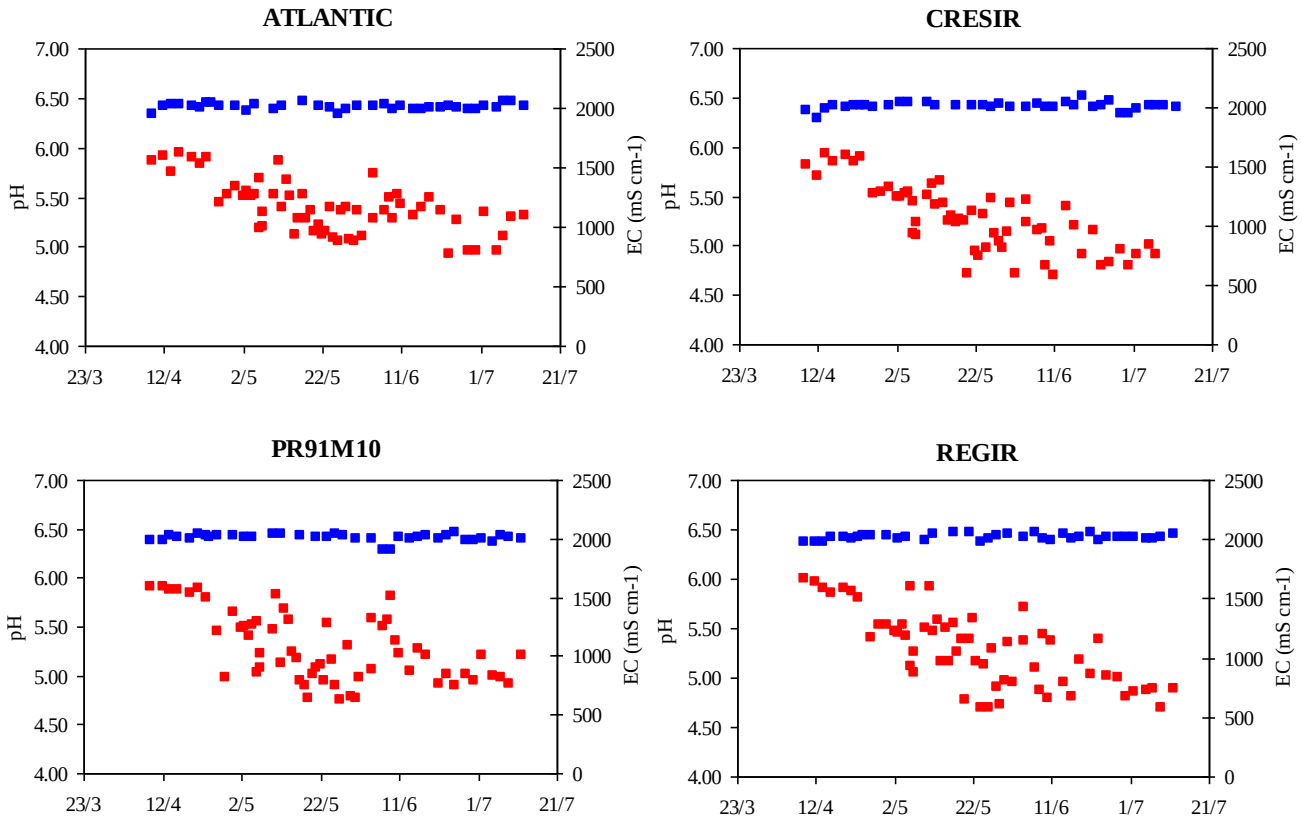


Fig. 104 UNapoli - pH/EC evolution after adjustment to set-points

Tab. 41 Cumulative consumption of Nitric acid for pH correction (ml/ double gully)

	Nitric Acid Volume (ml/double gully)
Atlantic	23.87
Cresir	17.94
Pr91m10	18.25
Regir	20.68

6.2.6 Plant Water Usage

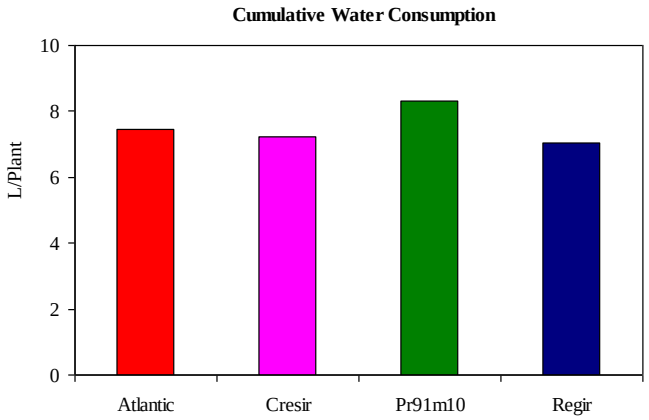


Fig. 105 UNapoli - Water consumption

6.2.7 Nutrient solution T

18°C (day) and 22°C (night).

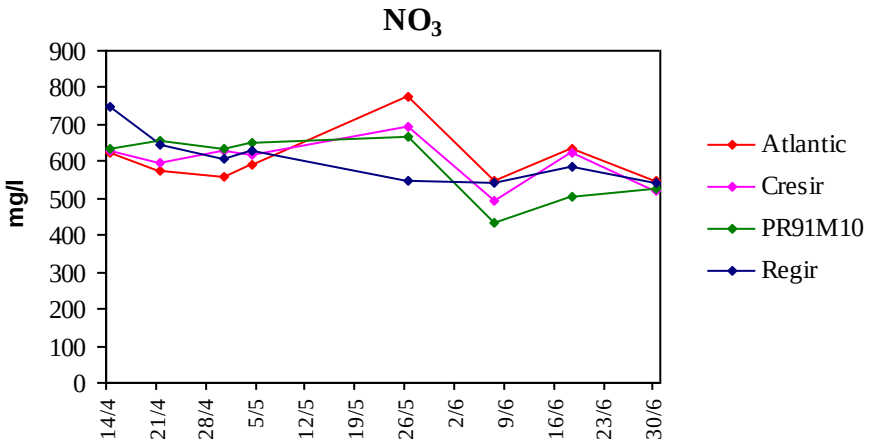


Fig. 106 UNapoli - NO_3 evolution in the nutrion solution

6.2.8 Nutrient solution analysis

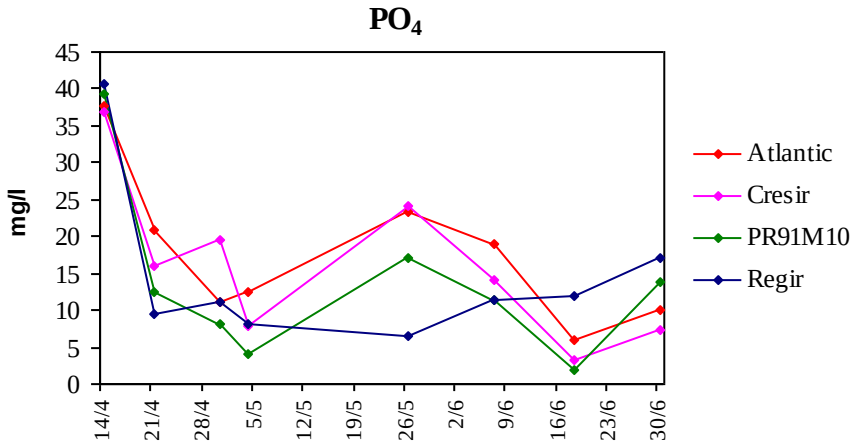


Fig. 107 UNapoli - PO4 evolution in the nutrient solution

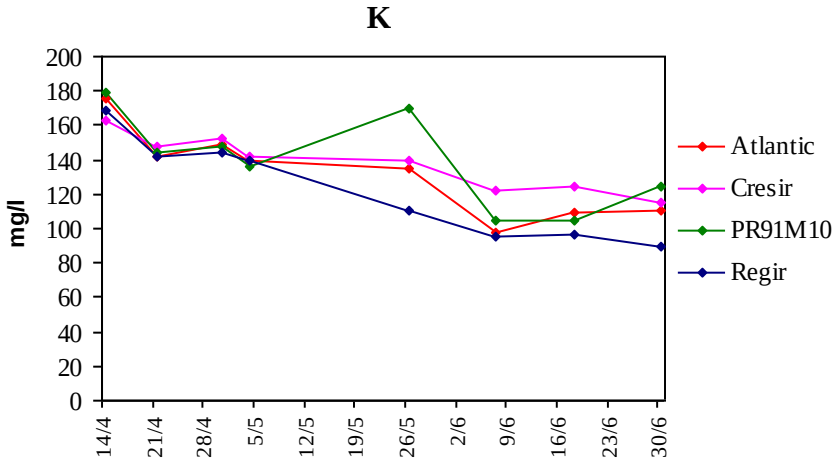


Fig. 108 UNapoli - K evolution in the nutrient solution

Tab. 42 UNapoli - Nutrient solution analysis

	NO_3^-	$P\text{-}PO_4^{--}$	K^+	Ca	Mg	B	SO_4
Atlantic	589.6	12.6	139	138	19	0.2	360
Cresir	620.4	7.8	142	82	40	0.3	370
PR91M10	651.2	4	136	123	61	0.1	350
Regir	629.2	8	140	94	41	0.2	350

Nutrient solution detailed analyses in the middle of the cycle (7^{th} week).

6.3 Monitoring of plant development

The growing cycle, from the sowing to the harvest, lasted from 114 days, in the earliest cultivar (Cresir) to 133 days on average in the other ones.

Plant samples collected during the 7th week of the growing cycle.

Tab. 43 UNapoli - Plants FW and DW

	Total FW	Total DW	DM	DM partitioning (%)			
	(g)	(g)	(%)	Stem	Leaves	Pods	Flowers
Atlantic	25,45 ± 2,51	5,16 ± 0,62	63,01 ± 2,96	36,40 ± 0,57	60,96 ± 0,71	1,25 ± 0,33	1,39 ± 0,06
Cresir	27,14 ± 2,39	5,11 ± 0,40	65,87 ± 2,27	33,38 ± 0,42	61,50 ± 0,41	3,94 ± 0,78	1,19 ± 0,10
PR91M10	21,94 ± 1,89	3,85 ± 0,25	77,08 ± 2,05	26,29 ± 1,15	69,98 ± 0,9	1,53 ± 0,57	2,20 ± 0,21
Regir	19,66 ± 3,62	4,03 ± 0,87	61,75 ± 5,83	37,25 ± 0,86	58,48 ± 1,17	2,03 ± 0,39	2,24 ± 0,16

6.3.1 Photographic follow-up

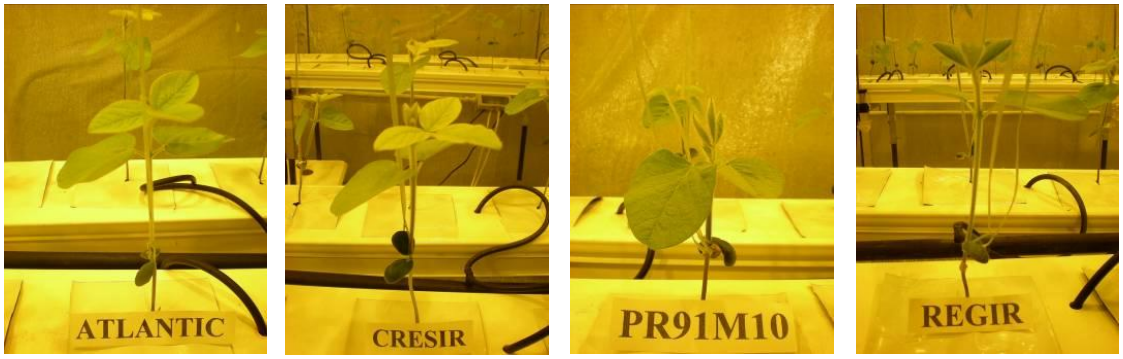


Fig. 109 April, 7 – 21 days after sowing

Fig. 110 April, 23 – 37 days after sowing

ATLANTI

CRESIR

PR91M10

REGIR

Fig. 111 May, 7 – 51 days after sowing

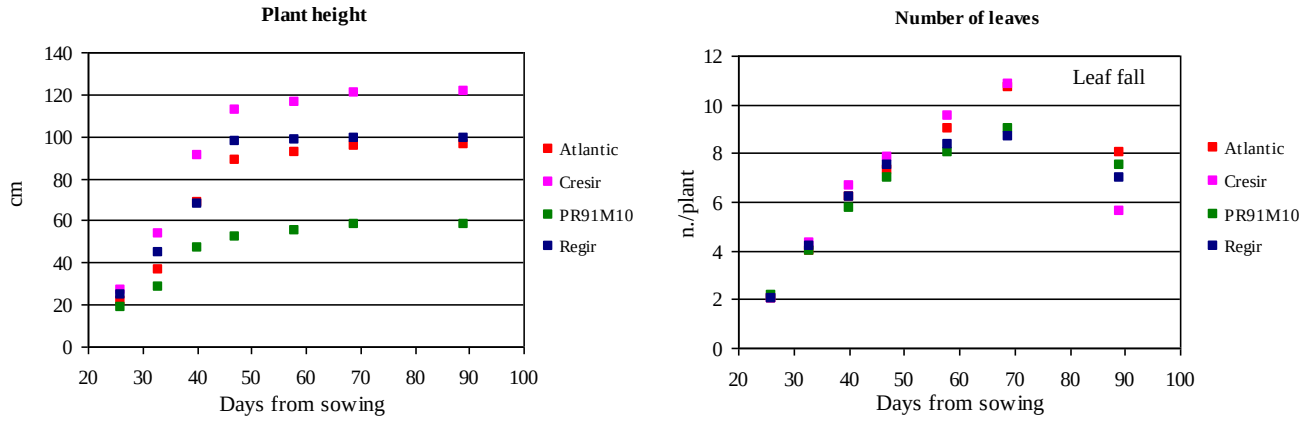
Fig. 112 May, 31 – 75 days after sowing

6.3.2 Detailed observation

Leaf fall was observed starting from the 13th week, when the pods were completely developed.

6.3.3 Growth assessment

The height of 6 plants per cultivar was measured, as well as the number of sprouts and leaves per plant (indicative of branching). Leaf area was estimated based on a published method (Wiersma and Bailey 1975; Lieth *et al*., 1986).



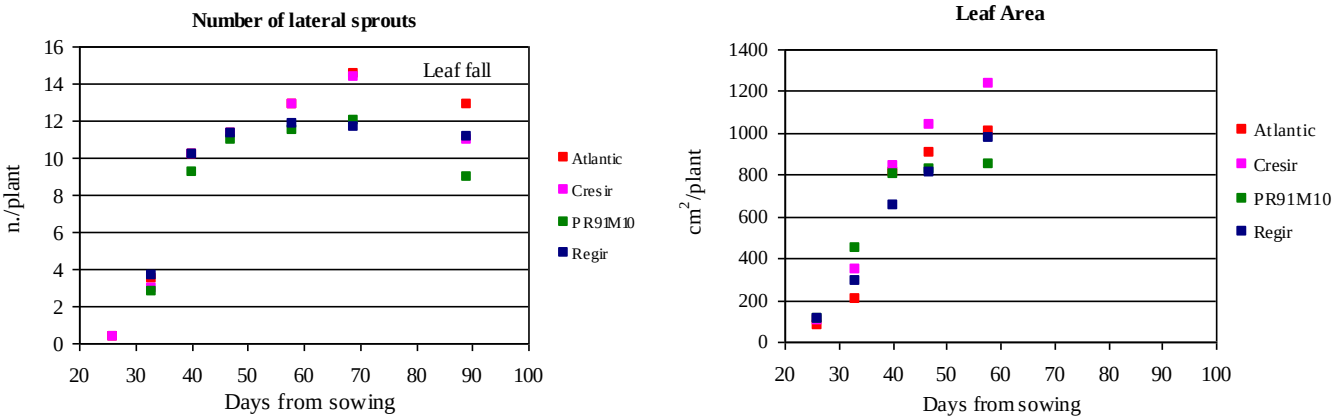


Fig. 113 UNapoli - Growth assessment

6.3.4 Gas exchange data

Measurements of photosynthesis, transpiration rate and stomatal conductance did not show relevant differences in physiological behaviour in the 4 soybean cultivars.
The table shows the average values of single measurements performed on the 9th week from sowing (2 leaves per plant; 3 plants per cultivar).

Tab. 44 Stomatal conductance (Gs), transpiration rate (Tr) and net photosynthesis (NP) in the four selected cultivars of soybean, grown in hydroponics in growth chamber.

	Gs (cm/s)	Tr (mmol/m^2 s)	NP (µmol/m^2 s)
Atlantic	1.02 ± 0.15	1.80 ± 0.27	12.16 ± 1.82
Cresir	0.96 ± 0.14	1.55 ± 0.25	11.65 ± 1.73
Pr91m10	0.91 ± 0.18	1.45 ± 0.29	10.57 ± 2.11
Regir	0.85 ± 0.13	1.77 ± 0.26	11.78 ± 1.77

6.3.5 Nutritional and Chemical composition of soybean

Tab. 45 Chemical composition of soybean stems and leaves at the beginning of pods formation (48 DAS) and at harvest.

	N (%)		P (%)		K (%)		NO3/Ntot	
	48 DAS	harvest	48 DAS	harvest	48 DAS	harvest	48 DAS	harvest
Atlantic	3.7	2.4	0.4	0.3	2.9	2.4	3.7	4.3
Cresir	3.4	1.9	0.4	0.2	2.6	2.4	4.6	6.2
Pr91m10	3.7	2.6	0.4	0.3	2.5	1.9	6.8	7.7
Regir	3.8	2.6	0.3	0.2	2.8	2.1	8.2	7.1
stem	2.9	2.2	0.5	0.3	2.3	2.3	8.9	8.4
leaves	4.3	2.5	0.3	0.2	3.0	2.1	2.7	4.2

Tab. 46 Chemical composition of soybean stems and leaves at the beginning of pods formation (48 DAS) and at harvest.

	Ca (%)		Mg (%)		S (%)		Cl (%)	
	48 DAS	harvest	48 DAS	harvest	48 DAS	harvest	48 DAS	harvest
Atlantic	0.8	1.4	0.4	0.5	0.2	0.2	0.4	0.9
Cresir	0.9	1.3	0.5	0.5	0.2	0.2	0.4	1.0
Pr91m10	0.8	0.7	0.4	0.5	0.2	0.2	0.3	0.8
Regir	0.9	1.0	0.4	0.4	0.2	0.2	0.5	1.0
stem	0.5	0.6	0.4	0.4	0.2	0.3	0.2	0.5
leaves	1.2	1.6	0.5	0.5	0.1	0.2	0.5	1.3

Tab. 47 Proximate composition of soybean seeds (Mean values; ns = not significant; * = significant at P≤0.05) ([1] lsd).

	DM (%)	Protein (%)	Fat (%)	Fibre (%)
Atlantic	88.1 b	33.8 b	22.1	27.5 b
Cresir	89.1 a	34.1 b	22.1	27.4 b
Pr91m10	88.1 b	35.6 a	21.2	27.6 b
Regir	88.8 ab	32.0 c	22.5	31.5 a
Significance	* (0.75[1])	* (0.31)	n.s.	* (1.48)

6.4 Harvest results

Soybean pods of the 4 cultivars were harvested twice a week, from the third week of June to the end of July and, at each harvest, yield data (number of pods and seeds, fresh weight, dry weight and dry matter percentage) were determined for single plant.
During the harvest period, the fallen leaves were collected and, at the end of the harvests, all the plants were cut in order to determine the edible and non-edible biomass and the total dry mass production in the different cultivars.
The harvests of soybean pods started from the third to the fourth week of June, in the different 4 cultivars, and lasted until the end of July. Cresir and Regir were the earliest and the most productive cultivars (450 g of seeds on average), followed by Atlantic (about 420 g) and PR91M10 (about 320 g).

6.5 References

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7 Summary

Bread wheat

During BT2, the four bread wheat cultivars were grown in four independent hydroponic systems. The density was 100 plants / m^2 (60 plants / $0.6m^2$) instead of 200 plants / m^2 for BT1. The plant development and the environmental conditions were characterised as in BT1. But, in BT2 the pH of the nutrient solution was compensated with acids and the concentration of macro and micronutrients was step-wise decreased after flowering. The amount of kernels collected in BT2 was higher for the 4 cultivars than in BT1. For all cultivars, the harvest index was also higher in BT2 than in BT1. These two results were most likely related to the change in the nutrient solution concentration and the lower density of the plants. The generation time of Greina and CH Rubli was shortened in BT2 while it was extended for Fiorina.

Durum wheat

Durum wheat results show higher yields in the Eurostar and Strongfield cultivars, however conclusions regarding the best candidate for closed environment production cannot be made on a single case study. Both of the highest yielding crops were grown in SEC2 chamber 2, indicating a possible chamber effect. The initial consideration for the discrepancy between the two chambers was the lower rate of leakage in chamber 1 when compared to chamber 2 (<1% vs. >5%), resulting in possible negative effects from higher concentrations of oxygen and ethylene. Biweekly venting was employed in an effort to mitigate this effect in the next trials, however the highest yield was still observed in chamber 2. One of the additional variables that differs between the two chambers is air velocity. Chamber 2 air speed is higher than that of chamber 1, which may allow improved gas exchange in the dense durum wheat canopy. Faster air velocity may also explain the large differences in evapotranspiration that was noted between the two chambers.
All cultivars demonstrated a marked decrease in NCER during the first nutrient solution change, demonstrating the usefulness of this measurement in advanced life support research. Study of the cause of this decrease, and methods for improved nutrient delivery should be a priority for future research to increase yields beyond those observed here.

Potato

Yield at the two locations showed real improvement as it was more than doubled thanks to the optimization of Nitrogen availability.
Plants were still smaller than expected (with small leaves too) compared to the plants grown by our consultant HZPC. Abnormal pigmentation of leaves (anthocyanins) revealed stressful conditions, probably due to light quality (insufficient far red light).

After BT1 and BT2, the best performing cultivars are Annabelle and Bintje, the first one produces a unique good harvest in a short laps of time, the second one can produce several harvests in a longer laps of time (at least two good harvests).
In the future, focus should be put on finding the N-level needed after tuber set in order stimulate bulking and avoid tuber deformation and stolon second growth. A small daily addition of Nitrogen should be a good way to reach these results.

Soybean

Four cultivars of soybean were grown in growth chamber, in a recirculating NFT system: 'PR91M10', 'Cresir', 'Regir', 'Atlantic'. The growing cycle lasted from 114 to 133 day, depending on the cultivar. Cresir and Regir were the earliest and the most productive cultivars (450 g of seeds on average), followed by Atlantic (about 420 g) and PR91M10 (about 320 g).
The symptoms of nutrient deficiency observed during the BT1 were prevented by increasing the salt concentration of nutrient solution (EC from 1.2 to 2.0 mS/cm).