Swedish experiences from wastewater irrigation on large-scale Short-Rotation Willow Coppice

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SLU

Umeå

- Faculty of Forest Sciences

Uppsala

- Faculty of Natural Resources and Agricultural Sciences
- Faculty of Veterinary Medicine and Animal Science

Alnarp

- Faculty of Landscape Planning, Horticulture and Agricultural Science

SLU

- Staff 3200
- Annual turnover 235 M Euro
- 202 Professors
- 830 PhD students
- 3340 full-time students

Dep. of Crop Production Ecology

- Based in Uppsala, central Sweden
- Belongs to the Faculty of Natural Resources and Agricultural Sciences
- Research and teaching for all crops with economical interest in Sweden (food, fodder, energy)

Dep. of Crop Production Ecology

Section of Short-Rotation Forestry

-Mainly *Salix* but also *Populus*
-Ecological characterisation
-Stand dynamics
-Management
-Economy
-Multifunctional environmetal uses of *SRF*

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Short-Rotation Willow Coppice for energy in Sweden

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Mechanised planting with approx. 12 000 cuttings/ha

20 Sep-05

Harvest in winter after 3 years

CLAAS
9/3/2000

Short Rotation Willow Coppice

- Ca. 16 000 ha are currently cultivated in Sweden for energy
- Predictions for increase to 30 000 ha (Ministry of Agriculture, 2006)
- Grown on agricultural land
- Double-row system, fertilisation, weed control
- Average production: 6-10 t DM/ha/yr

Multifunctional uses of SRWC in Sweden

- Vegetation filter systems
- Phytoremediation
- Recreation (Game shelter and hunting, bird watching etc.)

SRWC as vegetation filters

- Need for nutrients and retention ability of SRWC for other compounds is combined with biomass for energy
- Approximately 10 facilities with wastewater irrigation of 5 – 75-ha willow plantations
- Residues applied: Municipal wastewater, landfill leachate, log-yard runoff, sewage sludge and wood-ash

Municipality of Enköping

- 50% nitrogen reduction required
- Reduced load of the WWTP through:

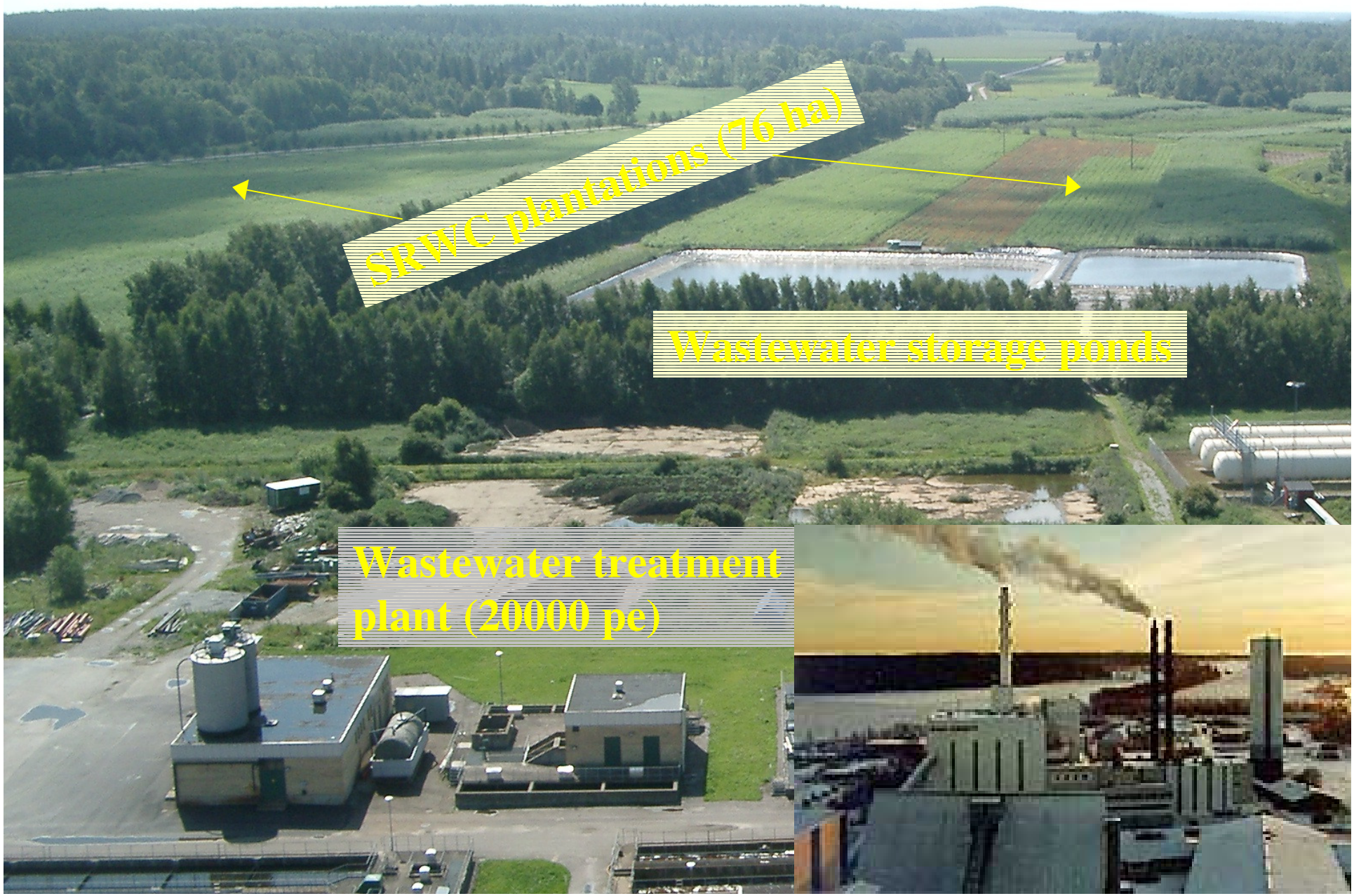
1. Septic-tank sludge to rural storage ponds

2. Diversion of wastewater from dewatering of sewage sludge….

Municipality of Enköping

…and irrigation of willows with “wet sludge” and treated wastewater

Wastewater treatment in Enköping


SRWC plantations (76 ha)
Wastewater storage ponds
Wastewater treatment plant (20000 pe)

Lined ponds for winter storage

300 km drip irrigation tubes

Wastewater treatment in Enköping

Wastewater	N-tot (mg/l)	N-NH_4 (mg/l)	P (mg/l)
Treated water	35	32	0.22
From dewatered sludge after sedimentation	925	639	21
From dewatered sludge after centrifuge	801	475	10.4

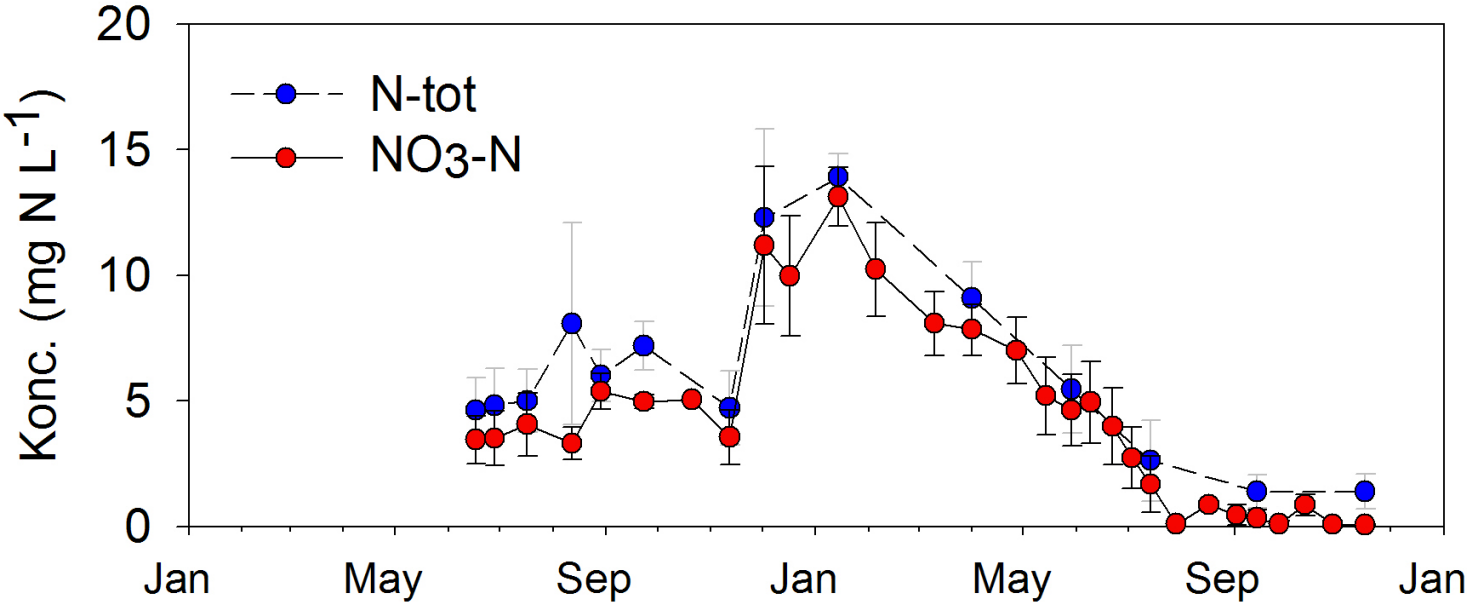
Wastewater treatment in Enköping

- Irrigation with around 2.5 mm per day for around 120 days on 76-ha SRWC
- Ca 150 kg N/ha yr
- N-rich wastewater is diluted by 75% with conventionally treated wastewater
- 11 t N and 0.2 t P are treated after irrigation with 20 000 m^3 N-rich water after sludge dewatering, total irrigation: 200 000 m^3

Potential environmental hazards

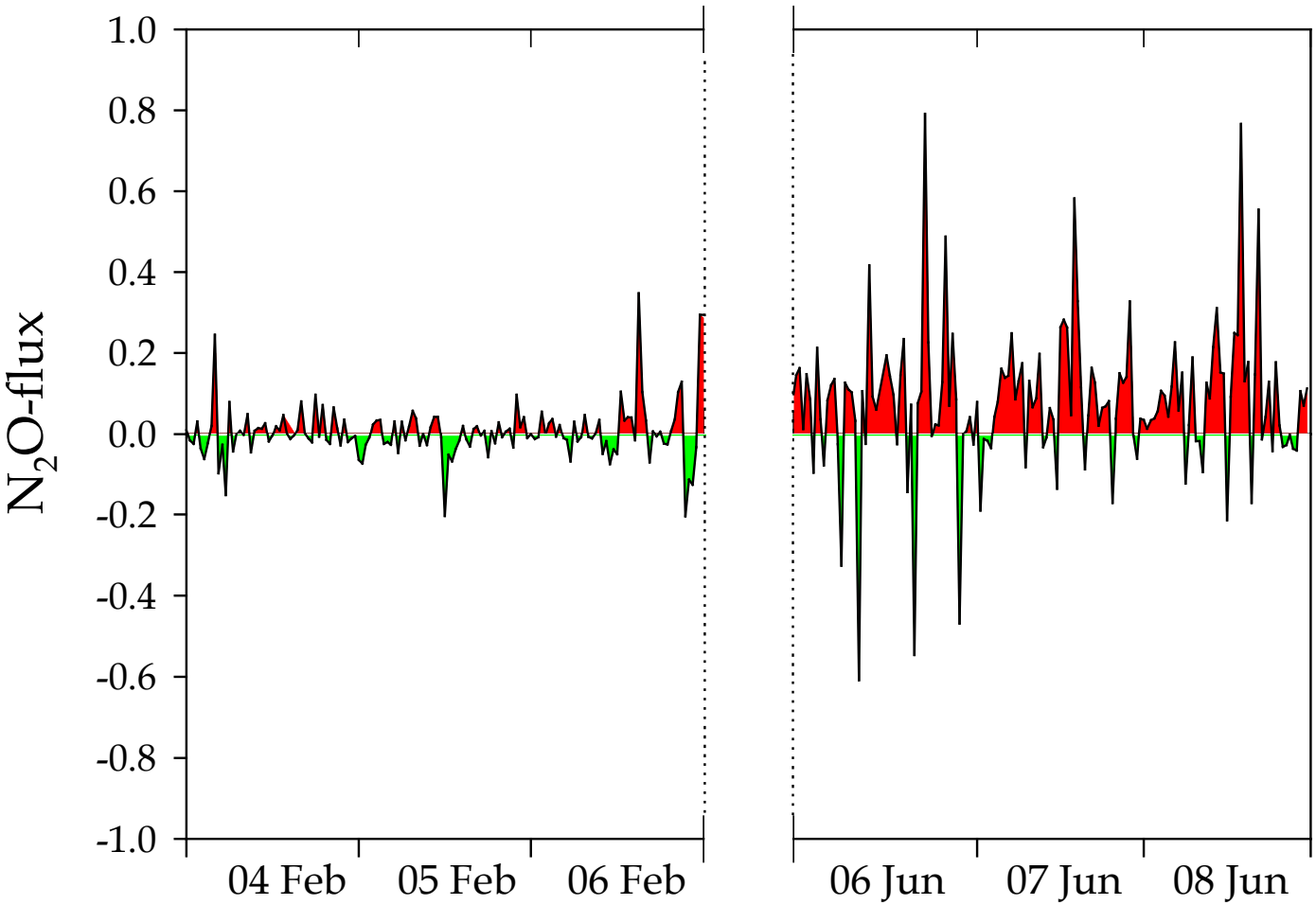
- N-leaching to the groundwater
- Toxicity effects on SRWC (lower biomass production)
- Greenhouse gas losses (mainly N_2O) to the atmosphere

NO_3-N in the groundwater in Enköping



Supply: 150 kg N/ha y

AGA
Flytande
BXG 358



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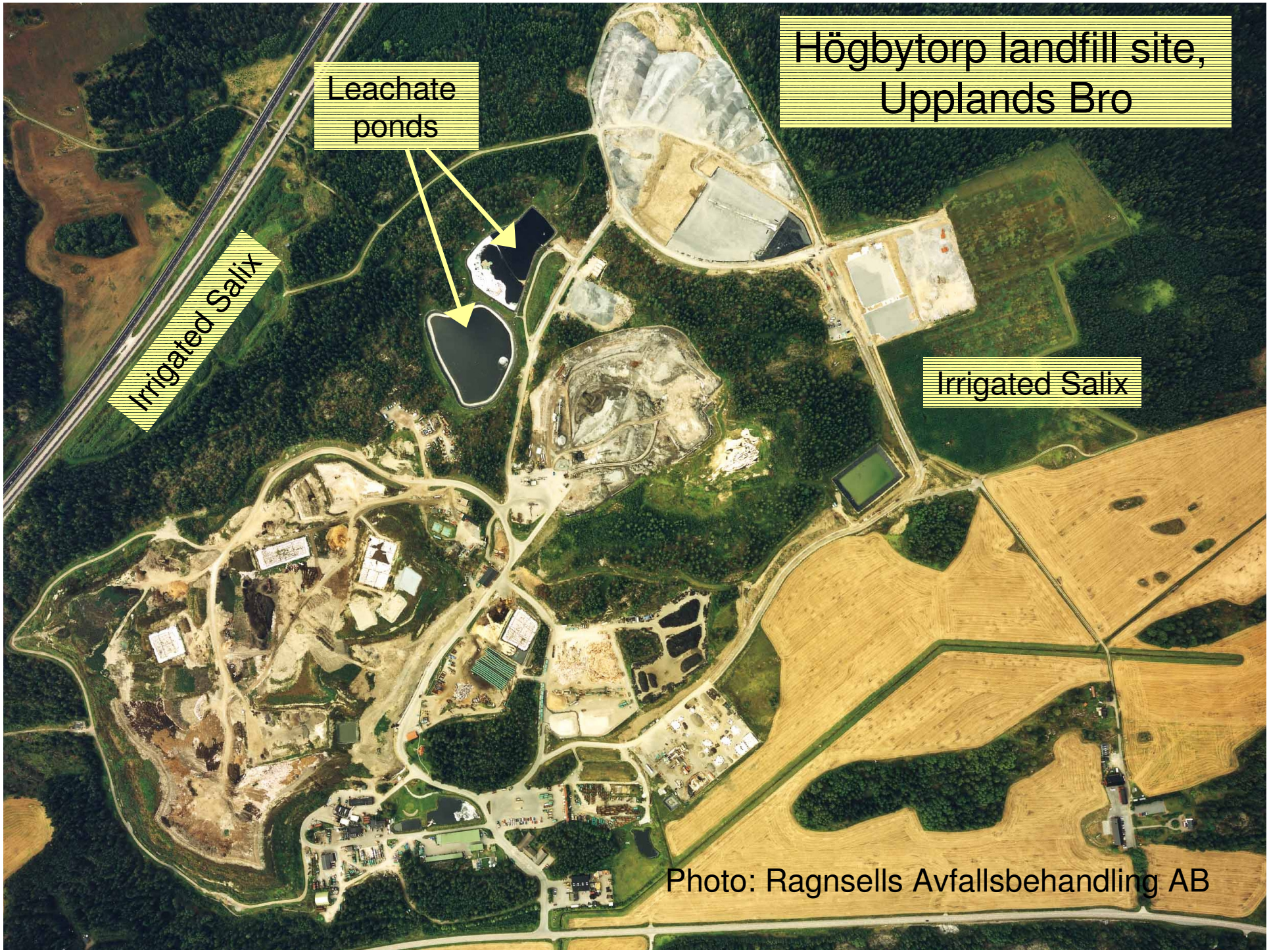
Research results

- N-leaching: negligible after the establishment year of SRWC
- High irrigation rates (10 mm per day) with N-rich water result in some leaching but no toxicity effects (due to e.g. NH_3 volatilisation) on plants are mentioned
- N_2O emissions to the atmosphere occur, vary within a year but are low (10 kg ha^{-1} yr^{-1}, Aronsson, unpublished data)


Högbytorp landfill site,
Upplands Bro
Leachate
ponds
Irrigated Salix
Irrigated Salix
Photo: Ragnsells Avfallsbehandling AB

Energiskog
Snabbväxande energiskog planteras för att ta upp näringsämnen
från lakvattnet. Träden avverkas och blir energi genom att bl a
eldas som flis i pannor.
RAGN-SELLS

Some willow clones suffered from toxicity, probably due to the high ionic strength of the leachate **(photo taken autumn 2001)**

Decision with Ragn Sells AB for experiments in 2005

- Field experiment at Upplands Bro with 2 different clones (Tora, Gudrun), 3 irrigation regimes + control, and 4 replicates
- Similar lysimeter experiment with Salix grown in clay for validation of field results

Irrigation in lysimeters

- Automatic irrigation system installed
- Irrigation rates based on the average water deficit (WD) for willows in Upplands Bro (precipitation - evapotranspiration)

			Irrigation amounts (mm)	
	Start	End	**Trtm 1**	**Trtm 3**
2005	20 July	27 Sept.	33	99
2006	1 June	21 Sept.	164	492

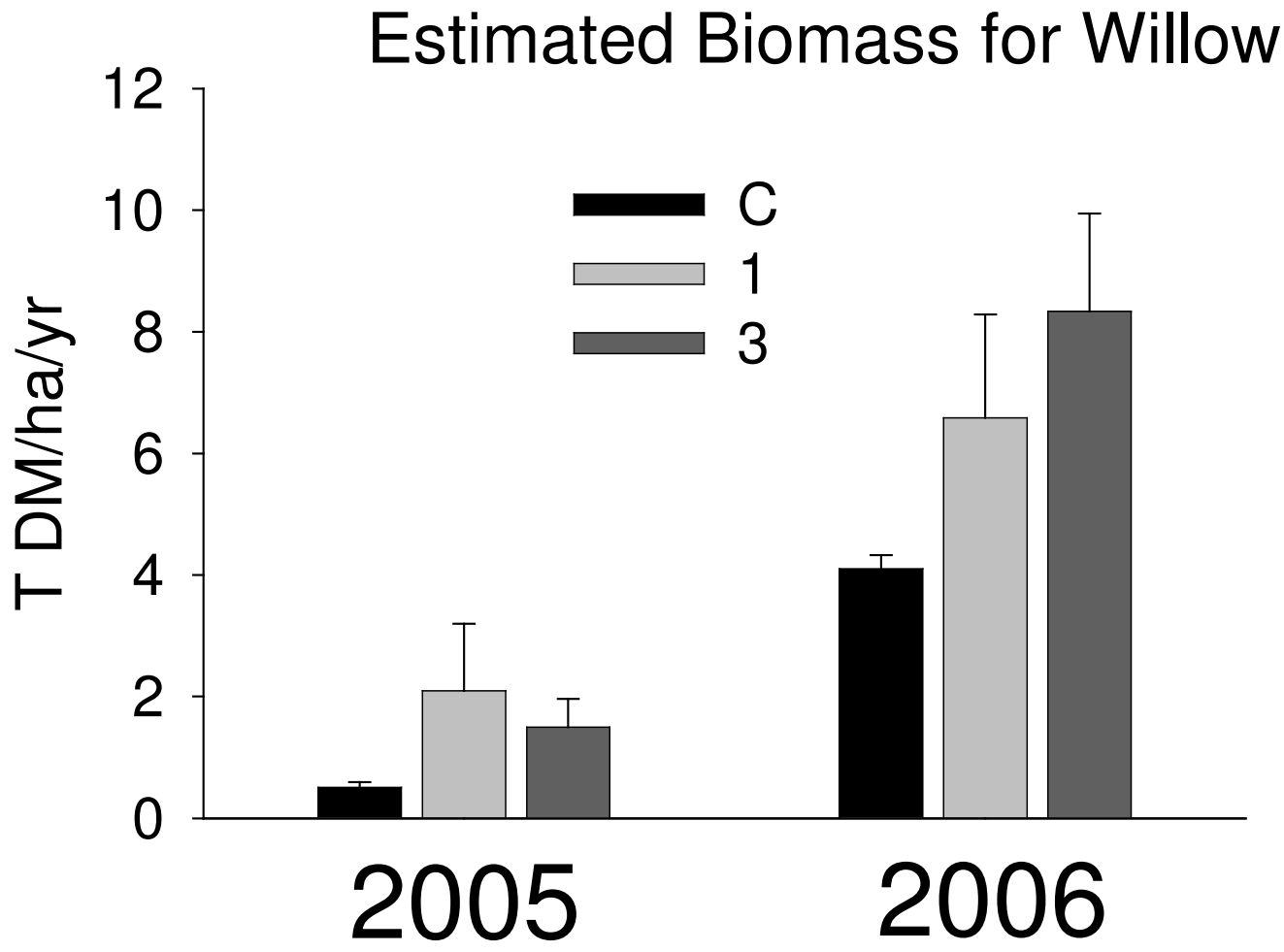
	Trtm 1 (mm)	Trtm 3 (mm)
2005	0.5	1.5
2006	2	6

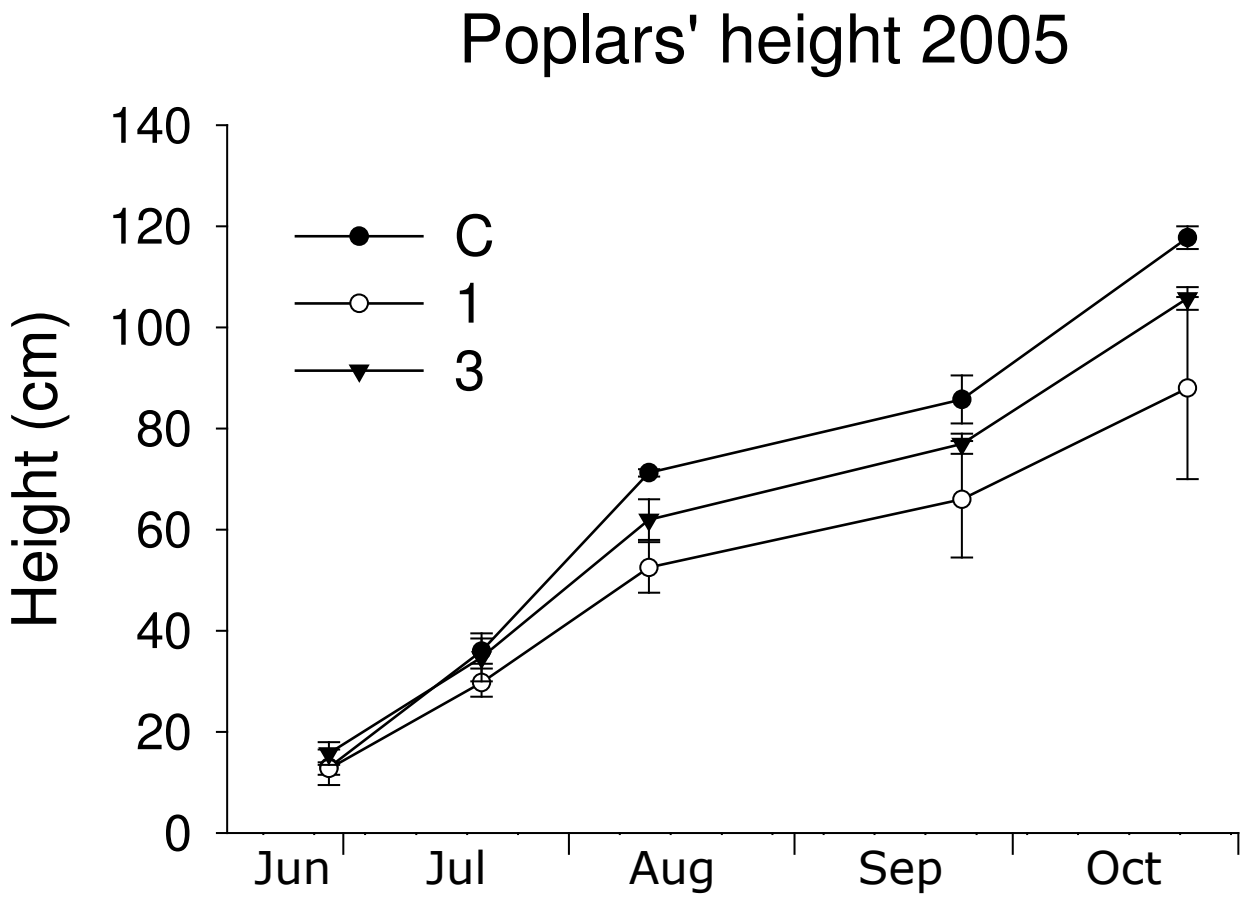
Concentrations in landfill leachate (mg/l)

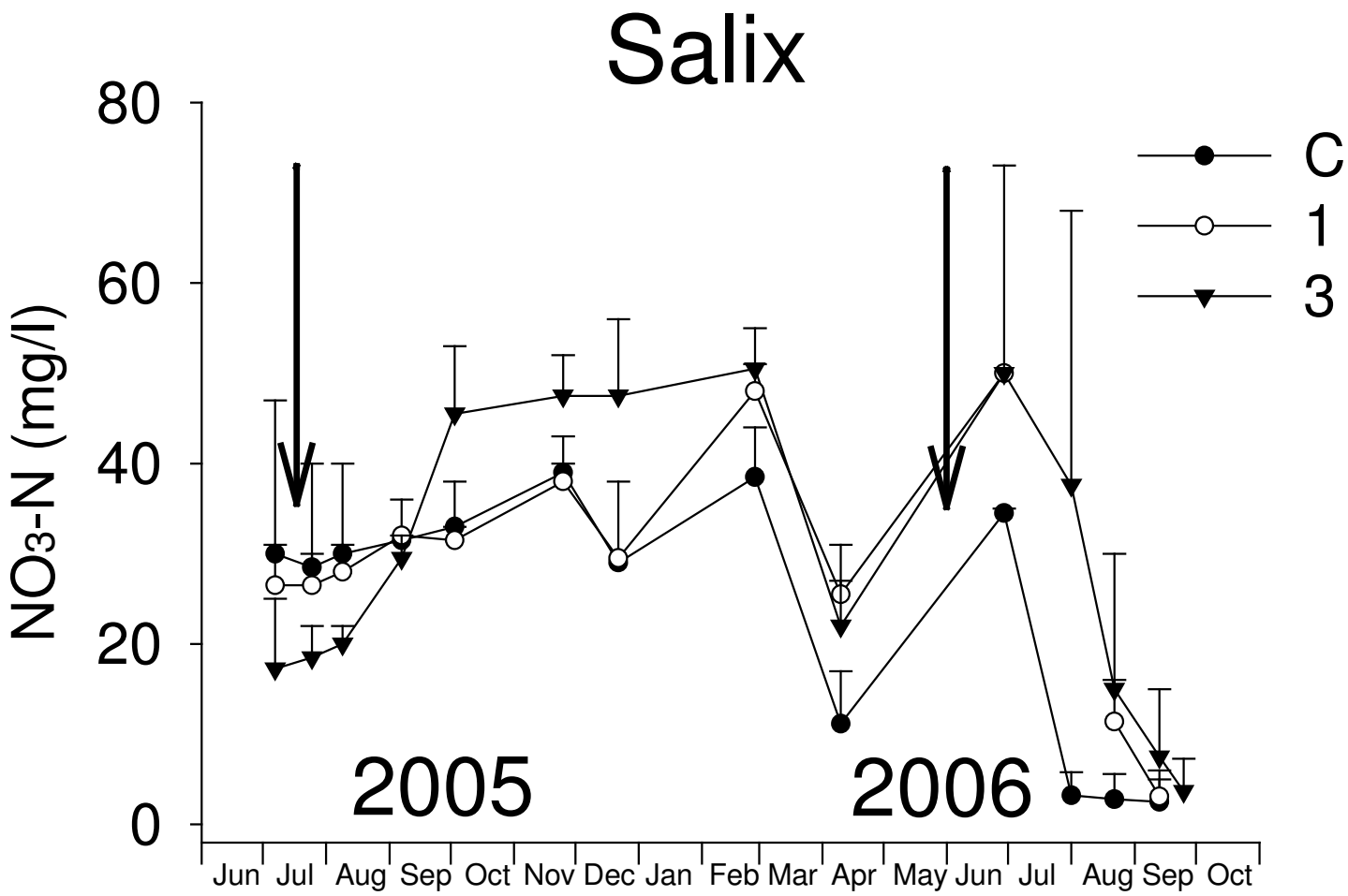
	NO_3-N	NH_4-N	Tot. N	P	Cl	TOC
2005	2.56	205	242	1.49	1086	565
2006	7.5	17.1	55.5	2.95	1350	313

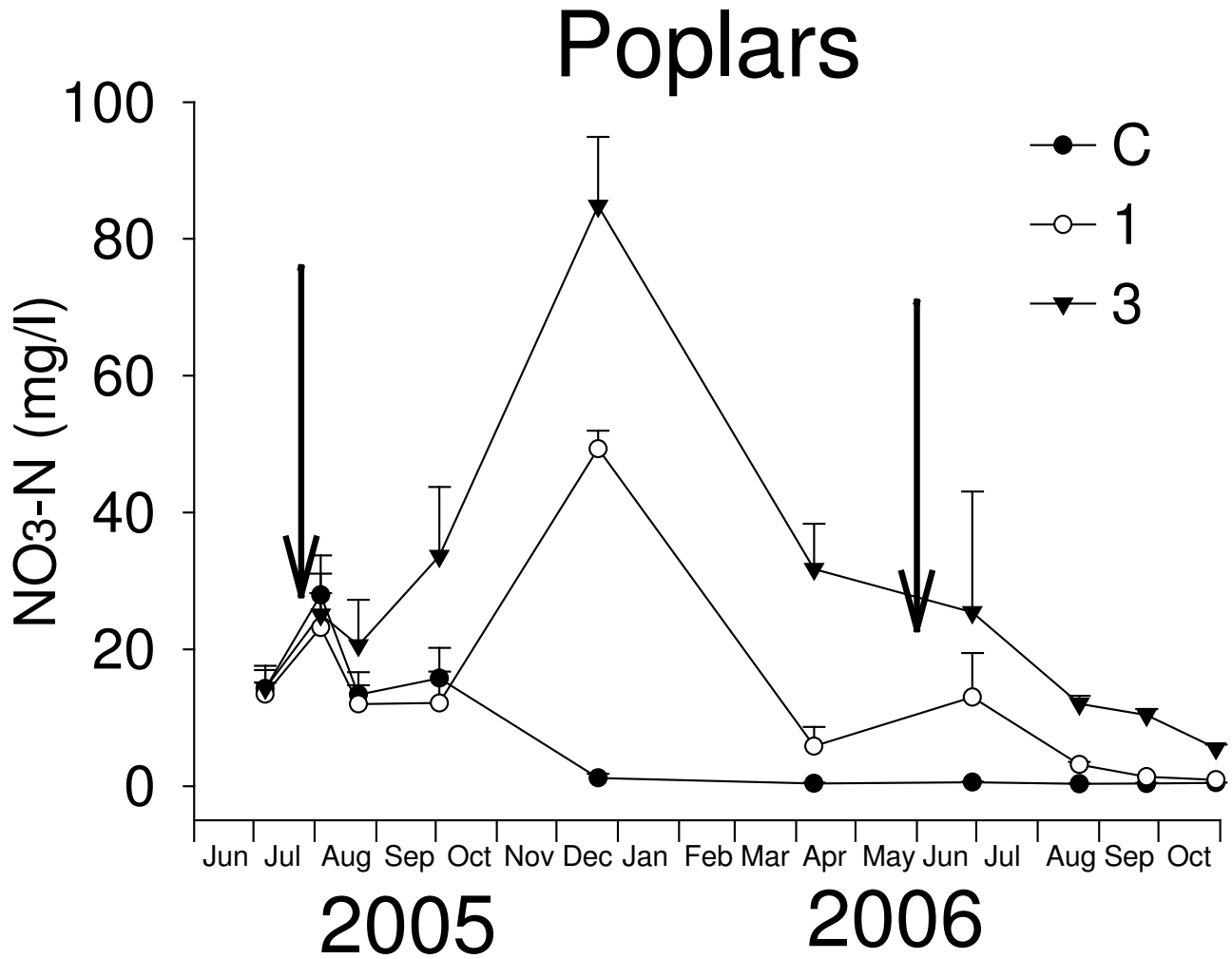
Supply of compounds with LL irrigation

		Control (kg/ha)	Trtm 1 (kg/ha)	Trtm 3 (kg/ha)
NO_3-N	2005	0	1.18	3.56
	2006	2.79	11.7	35.1
NH_4-N	2005	0	73.6	221
	2006	0.05	29.3	88
Org. N	2005	0	12	36
	2006	0	50.5	152
Tot. P	2005	0	0.54	1.61
	2006	0	4.7	14.6
Cl	2005	0	392	1178
	2006	37.7	2210	6630
TOC	2005	0	174	523
	2006	7.2	513	1539

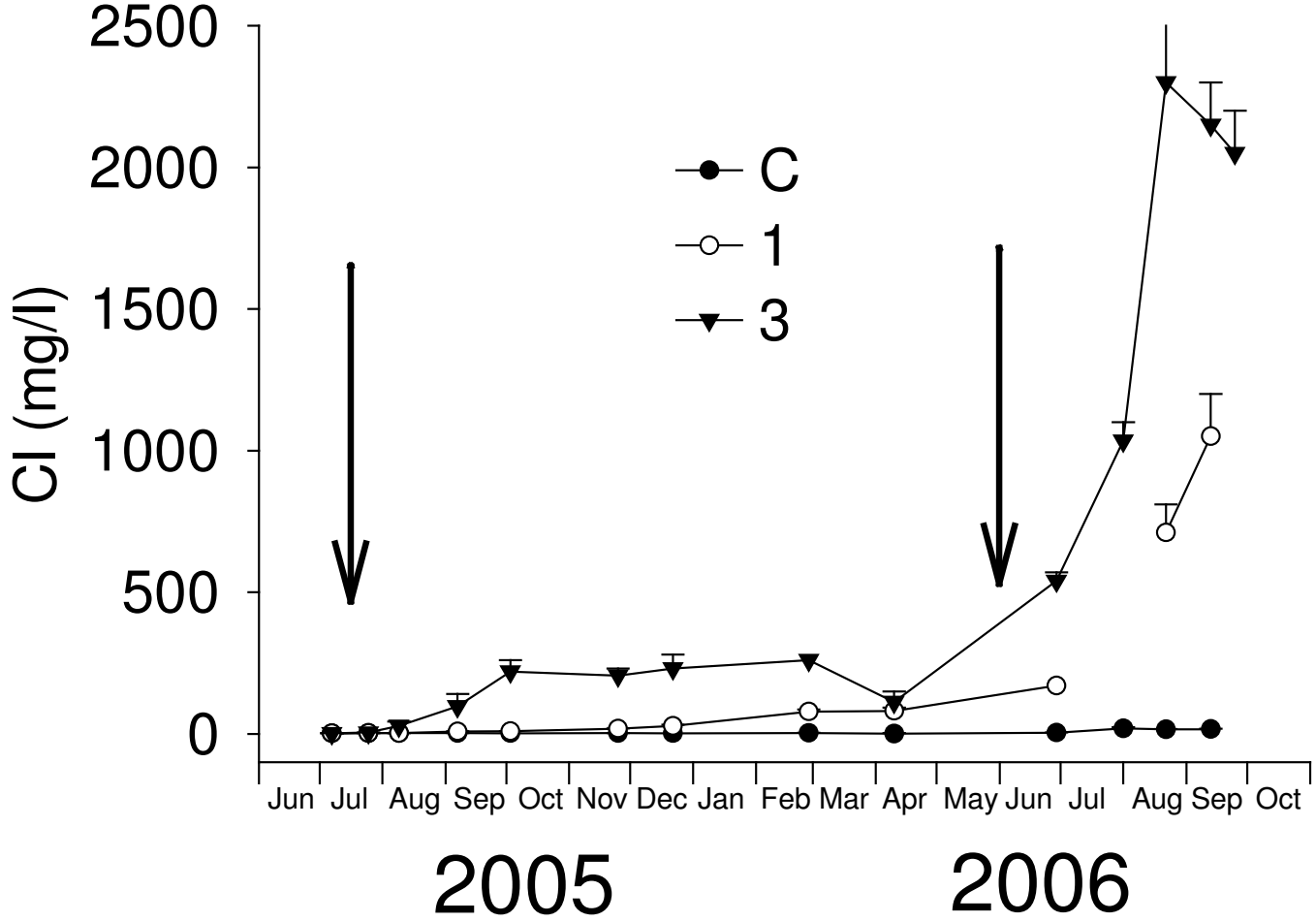

Estimated Biomass for Willow
T DM/ha/yr
12
10
8
6
4
2
0
C
1
3
2005
2006


Poplars' height 2005
Height (cm)
140
120
100
80
60
40
20
0
C
1
3
Jun
Jul
Aug
Sep
Oct


Salix
80
60
40
20
0
NO3-N (mg/l)
C
1
3
2005
2006
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct


Poplars
100
80
60
40
20
0
NO3-N (mg/l)
C
1
3
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2005
2006

Salix



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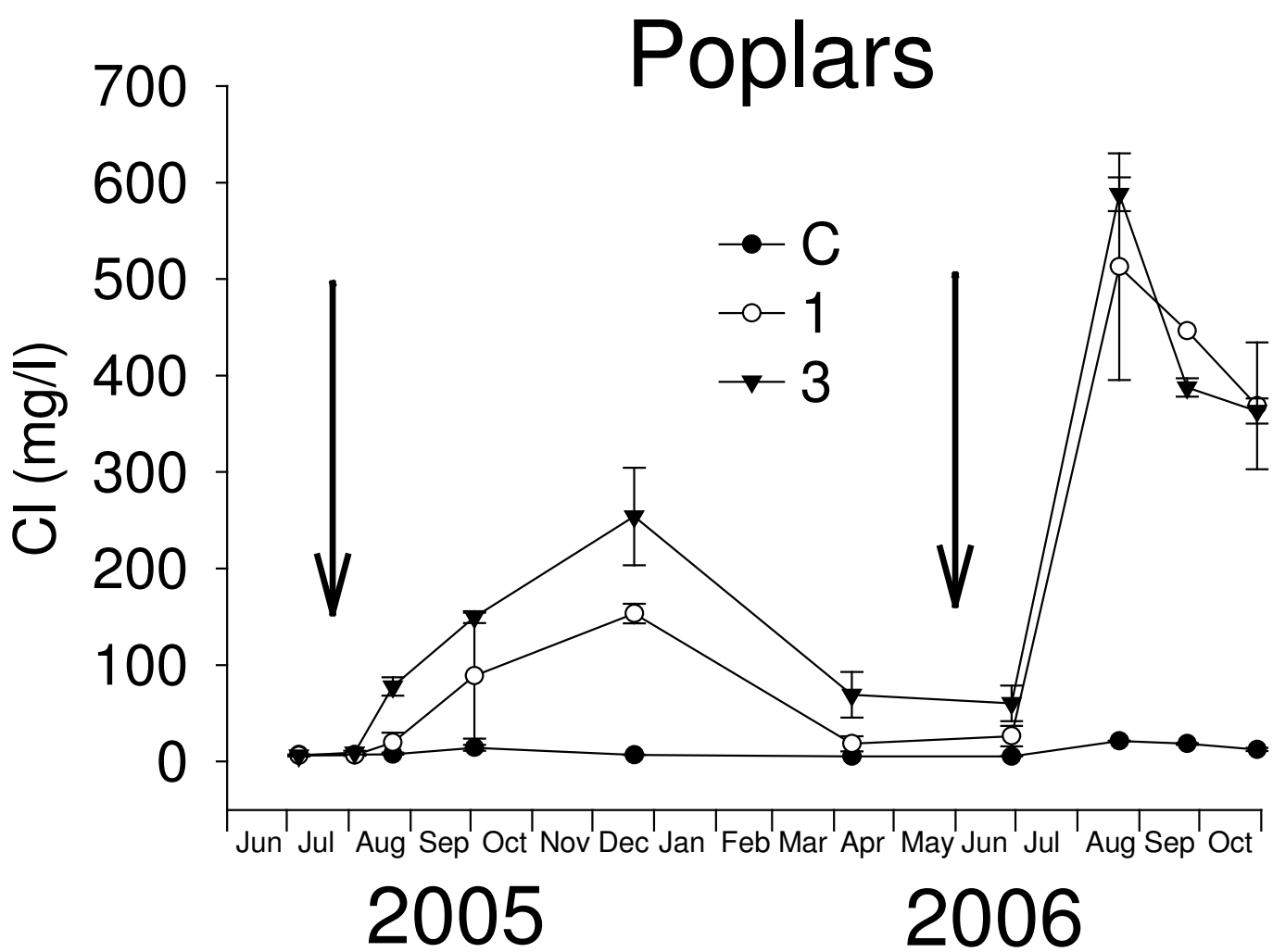
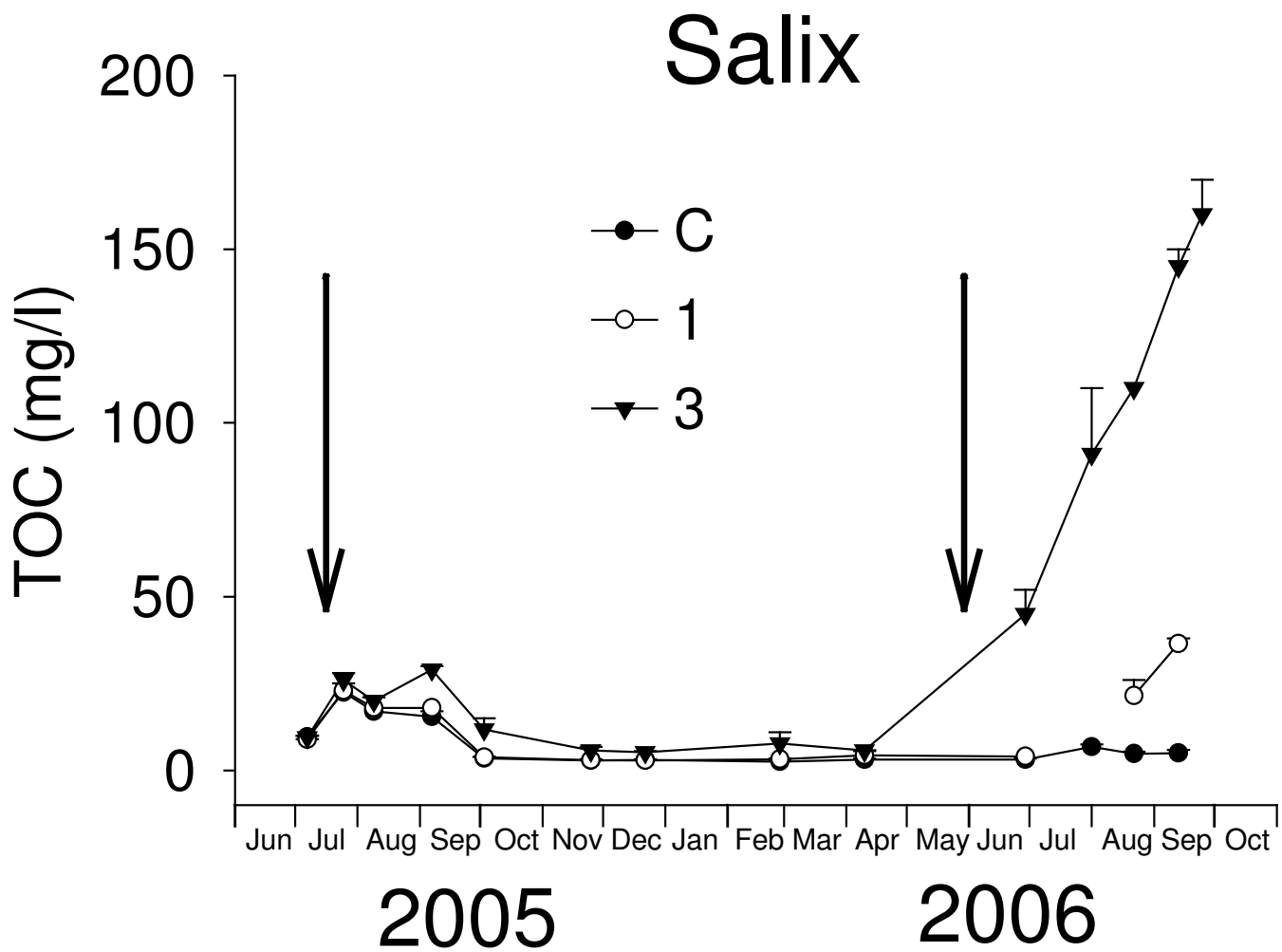
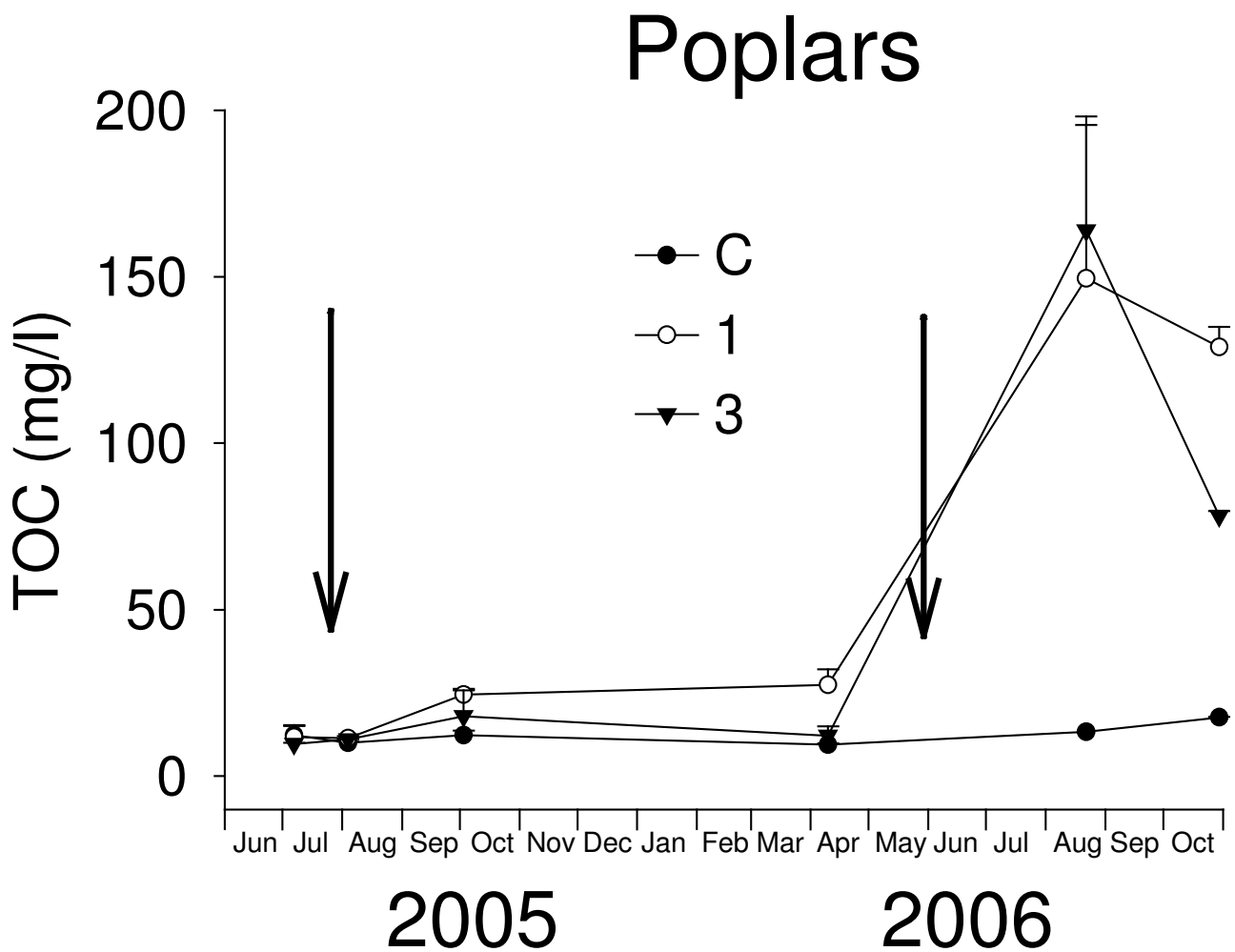

Poplars
Cl (mg/l)
700
600
500
400
300
200
100
0
C
1
3
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2005
2006


Salix
TOC (mg/l)
200
150
100
50
0
C
1
3
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2005
2006


Poplars
TOC (mg/l)
200
150
100
50
0
C
1
3
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
2005
2006

Retention (supply - transport) of compounds in soil-plant system (Willows)

		Control (kg/ha)	Trtm 1 (kg/ha)	Trtm 3 (kg/ha)
NO_3-N	Season 1	-76.7	-86.3	-101
	Season 2	6.8	1.5	-2.8
NH_4-N	Season 1	-0.10	73.6	221
	Season 2	-0.15	29.1	87.6
Org. N	Season 1	-0.8	11.9	35.9
	Season 2	-0.7	45.2	90
Tot. P	Season 1	-0.04	0.53	1.56
	Season 2	-0.02	4.82	14
Cl	Season 1	-5.5	272	765
	Season 2	-14.1	-785	-1768
TOC	Season 1	-26.5	145	473
	Season 2	-9.3	409	926

Retention of compounds in soil-plant system (Poplars)

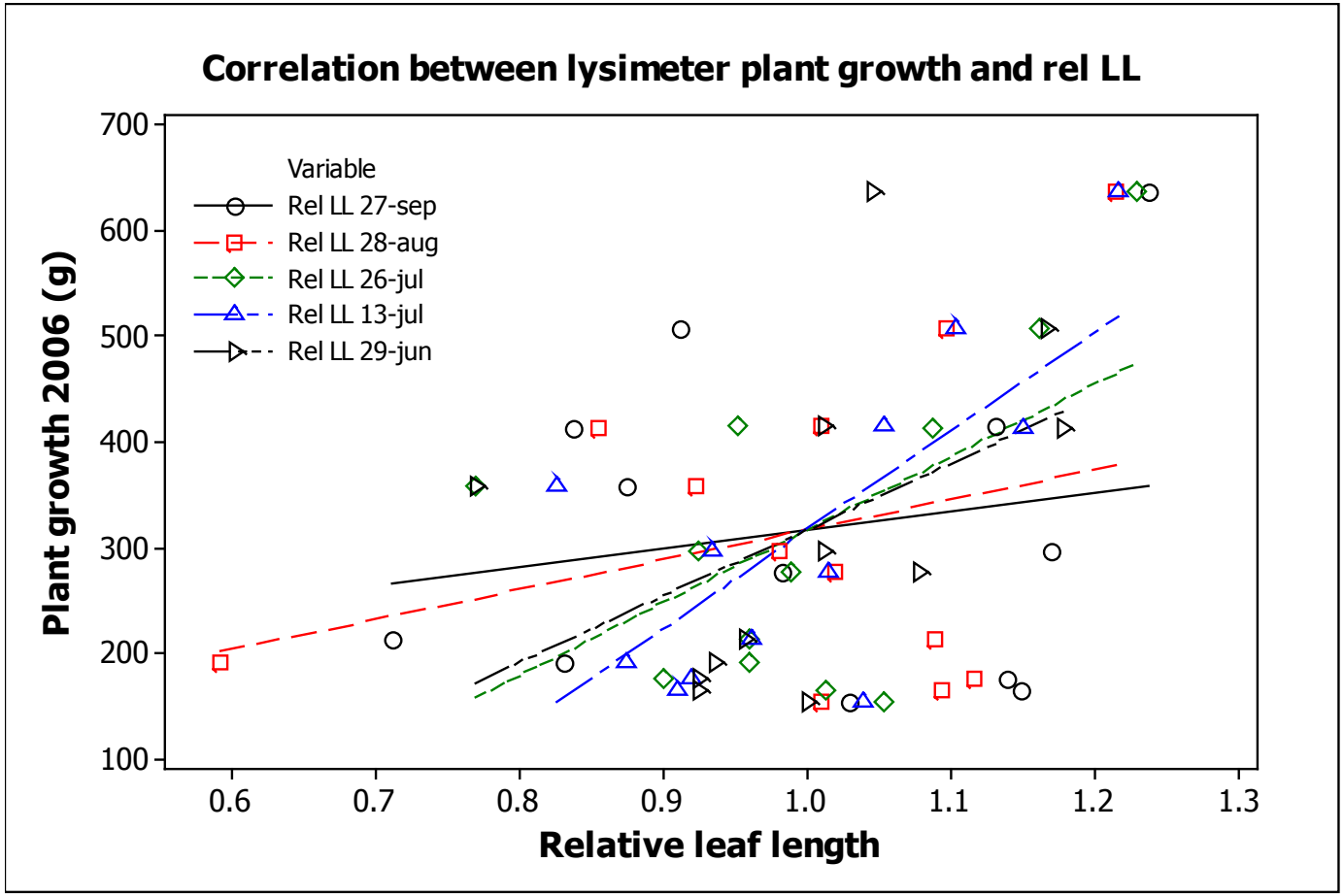
		Control (kg/ha)	Trtm 1 (kg/ha)	Trtm 3 (kg/ha)
NO_3-N	Season 1	-27	-52	-111.5
	Season 2	2.5	10.4	7.5
NH_4-N	Season 1	-1.13	72.5	218.6
	Season 2	-0.47	28.9	87.2
Org. N	Season 1	-8.4	0.6	19.4
	Season 2	-3.33	42.8	94
Tot. P	Season 1	-1.04	0.79	-0.01
	Season 2	-0.09	4.7	14.6
Cl	Season 1	-18.8	278	875
	Season 2	19.6	1943	5502
TOC	Season 1	-29.3	137.2	447
	Season 2	-7.9	452.8	1217

Observations in balances

- Supply of org. N and TOC was high for trtm. 3, season 2, but up to 65% of org. N and TOC was treated
- Poplar lysimeters (sand) were slightly more effective in treating N and TOC
- P treatment reached almost 100%
- Cl in sand lysimeters was not leached in the drainage water but remained mostly in the soil

Stress indicators for Salix

- Measurements of chlorophyll fluorescence in leaves were difficult to interpret/no significant differences between treatments were observed
- Relative leaf length was not correlated to growth (estimated) in the first season
- In the second season, a weak correlation of relative leaf length to estimated growth was observed


Correlation between lysimeter plant growth and rel LL
Variable
Rel LL 27-sep
Rel LL 28-aug
Rel LL 26-jul
Rel LL 13-jul
Rel LL 29-jun
Plant growth 2006 (g)
700
600
500
400
300
200
100
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
Relative leaf length

Spreading of sewage sludge in SRWC is very common in Sweden

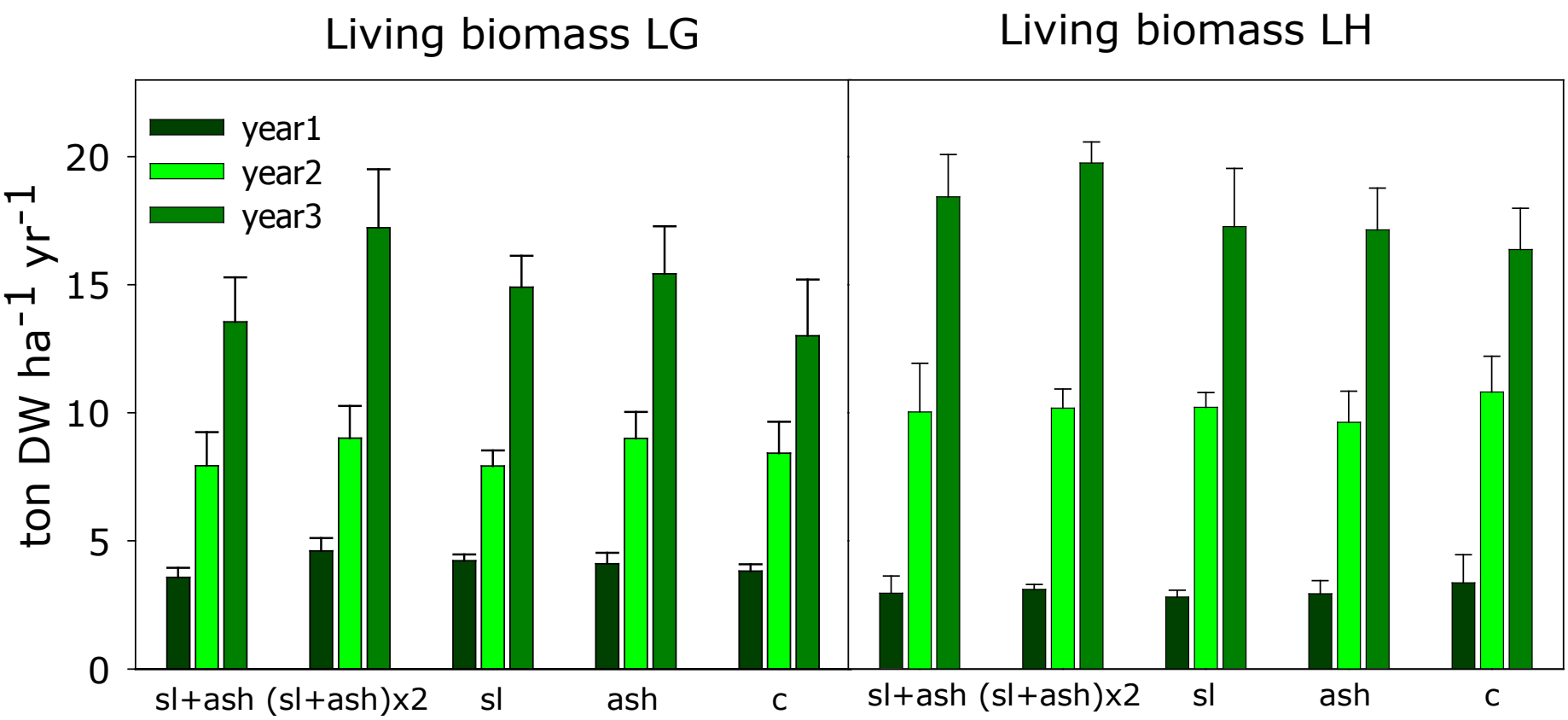
Photo: Ragnsells Avfallsbehandling AB

Sewage sludge application on SRWC

- Today 80% of the total SRWC plantations (ca. 10 000 ha) are fertilised after harvest with sludge (mixed with wood-ash where available)
- 22 kg P ha^{-1} yr^{-1} for a cutting cycle
- Willow is reported to efficiently take up metals, mainly Cd (ca. 10 g/ha/yr)

		Treatments									
		sl+ash		**(sl+ash)x2**		**sl**		**ash**		**control**	
	Harvest interval (yrs)	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**	**1**	**3**
	Supply	*1.2*		*2.5*		*1.2*		*1.3*		*0*	
Cd	Potential output	5.6	5.2	8.9	7	8	5.7	6.9	7	6.7	5.2
	Change	**–4.4**	**–4**	**–6.4**	**–4.5**	**–6.8**	**–4.5**	**–5.6**	**–5.7**	**–6.7**	**–5.2**
	Supply	*303*		*606*		*500*		*106*		*0*	
Cu	Potential output	28	14	48	18	34	14	39	14	30	12
	Change	**275**	**289**	**558**	**588**	**466**	**486**	**67**	**92**	**–30**	**–12**
	Supply	*18*		*38*		*13*		*25*		*0*	
Ni	Potential output	12	7	15	6	12	5	11	5	10	6
	Change	**6**	**11**	**23**	**32**	**1**	**8**	**14**	**20**	**–10**	**–6**
	Supply	*449*		*899*		*569*		*330*		*0*	
Zn	Potential output	243	245	359	330	308	284	258	273	240	213
	Change	**206**	**204**	**540**	**569**	**261**	**285**	**72**	**57**	**–240**	**–213**

Table. Balance between supply via sludge–ash application and potential output via willow plantation harvest (in g ha^{-1} yr^{-1}), for the various treatments, if a potential harvest occurred annually or every three years. The potential output with a stem harvest was calculated for a 30:70 bark:wood ratio for year 1 and a 25:75 bark:wood ratio for year 3. Changes indicate potential changes in the soil pool


Living biomass LG
Living biomass LH
year1
year2
year3
ton DW ha-1 yr-1
0
5
10
15
20
sl+ash
(sl+ash)x2
sl
ash
c
sl+ash
(sl+ash)x2
sl
ash
c