

A Decision Support System for the phyto – treatment of dairy effluent



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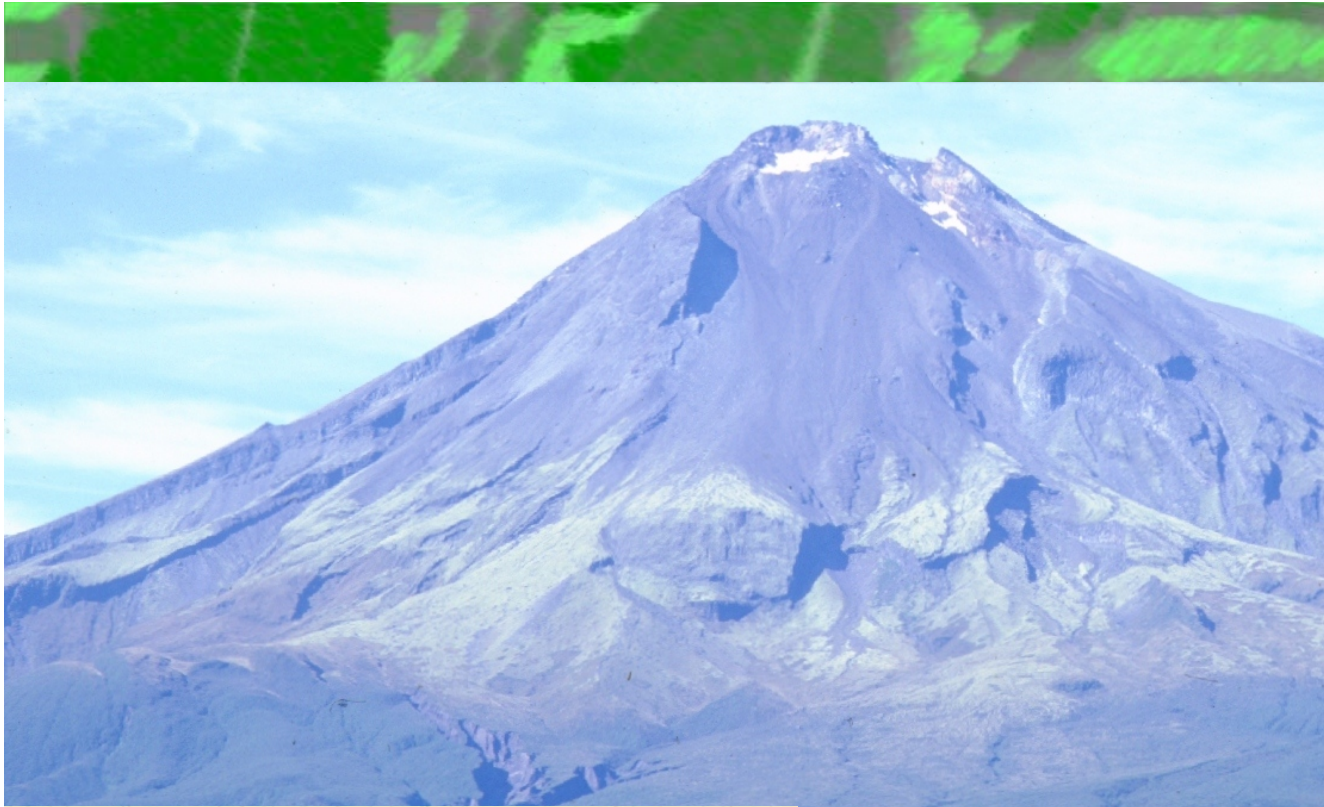
1-HortResearch & 3-Massey University, Palmerston North, New Zealand
2-University of Parma, Parma, Italy

Phytoremediation as a form of “Phytoprevention”

Phytoremediation can come handy to solve pollution problems already existing. Is there a way it can help to prevent these problems to show up?

A background image of various green leaves, including ferns and broad-leafed plants, creating a dense, natural texture.

Agriculture is a starting point



Atlanta, 2005





Atlanta, 2005



Atlanta, 2005

Dairy effluent disposal: current practice

- Directly into waterways
- Onto pasture to improve growth

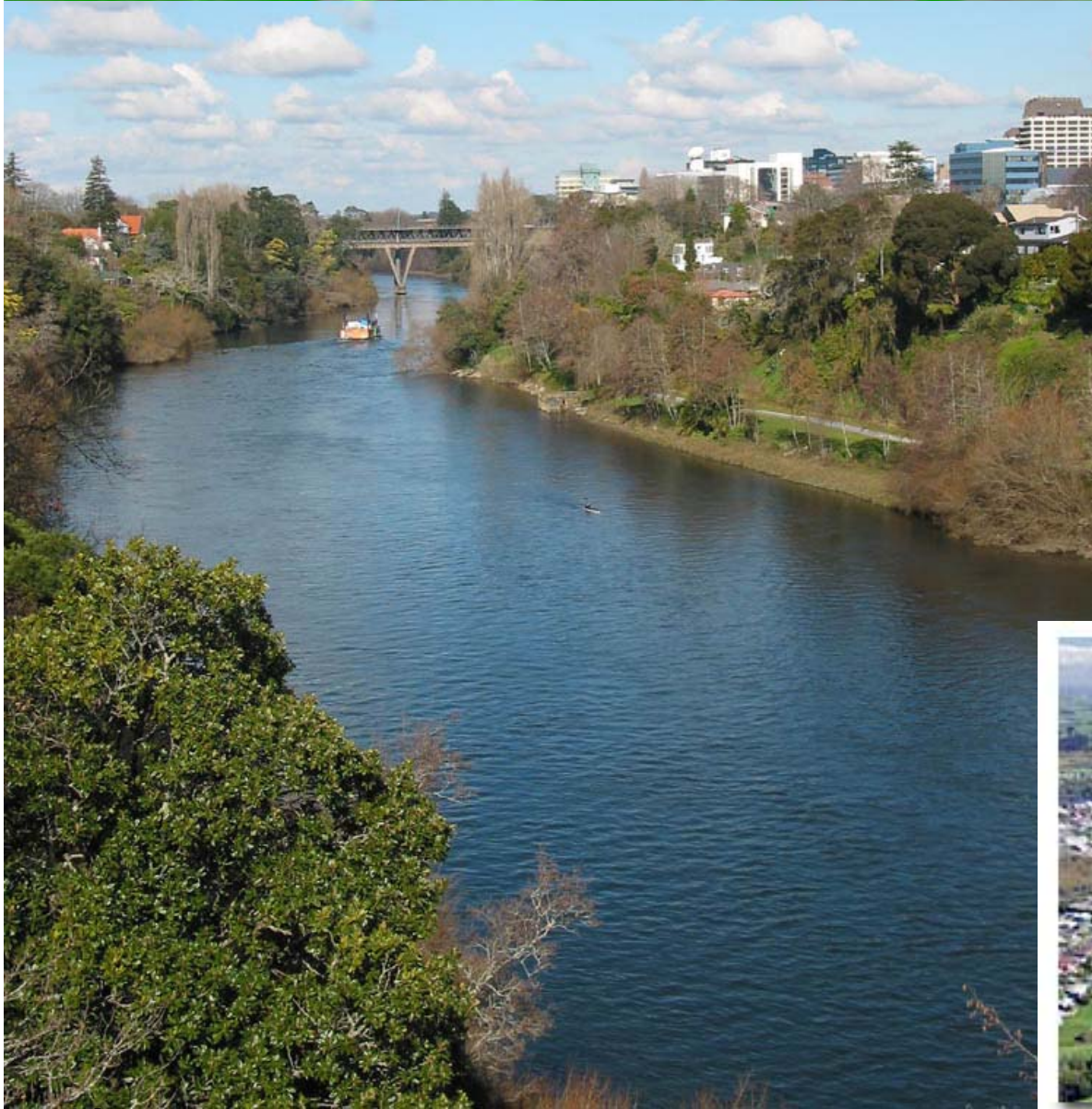


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Dairy effluent in the environment

- NO_3 – 100 mg/kg – groundwater contamination
- NH_4 – 50 mg/kg – surface runoff
- K – 200 mg/kg – induced Mg deficiencies
- Pb, Cu, Zn traces – accumulation in soils and/or crops
- DOC – 100 mg/kg – facilitate metal leaching

Increasing N-loading on waterways



Atlanta, 2005



John Greenwood Blue-green algal bloom, Lake Hakanoa

Financial incentives for sustainable effluent disposal

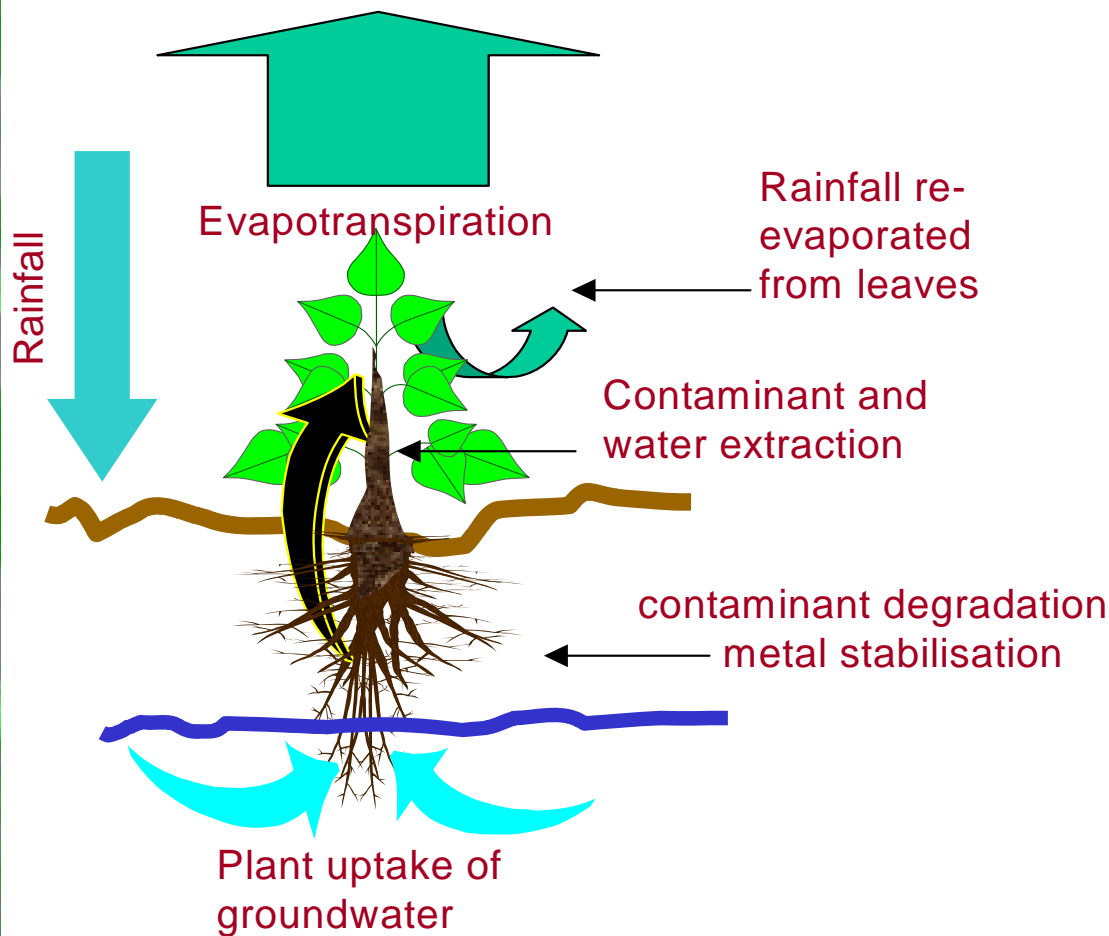
The Resource Management Act (1991)

Purpose – (1) The purpose of this Act is to promote the sustainable management of natural and physical resources

(2) In this Act, “sustainable management” means managing the use, development, and protection of natural and physical resources ... while

(c) Avoiding, remedying, or mitigating any adverse effects of activities on the environment.

Could fast-growing tree species be used?



- **Tolerant to local conditions**
- **Rapid growth**
- **High water use**
- **Extract or enhance the degradation of the target contaminant**



Atlanta, 2005



Atlanta, 2005

*Other problems related to
Agriculture and farming
can span from...*

...rough Bison in US

HortResearch



Atlanta, 2005

to disciplined cows in New Zealand

So it is important to train the cows when to urinate

Celestial Lagoon

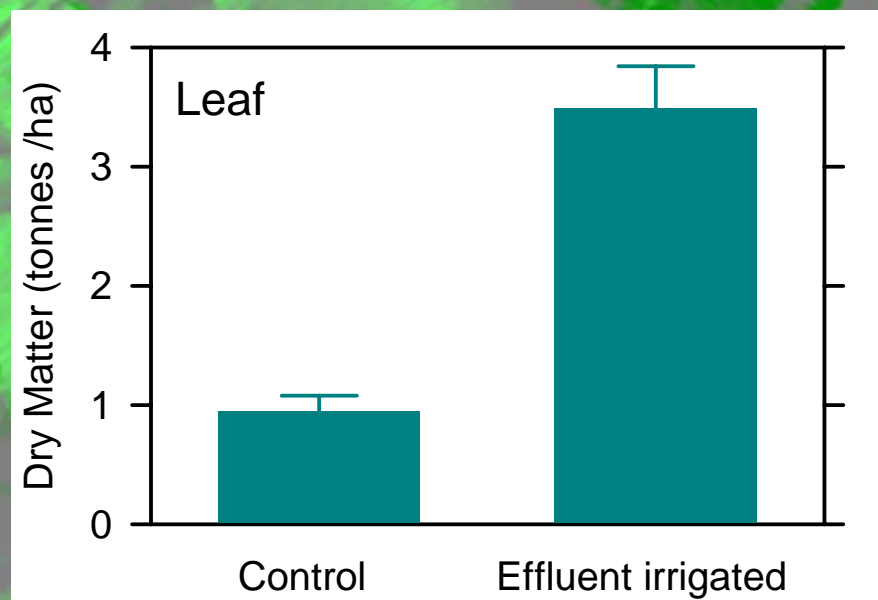
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effect of dairy effluent on growth



Atlanta, 2005





Mmhuu!

**Salix
branches
and
leaves are
palatable
fodder for
cows.
They also
supply
minerals
as Mg and
Ca**

Green house experiment

- 18 lysimeters
- 12 planted with *Salix kanayunagy* clones (a species very resistant to pathogens)
- 6 control non planted lysimeters
- Treatments: 2L effluent a day=T1, 1L effluent a day=T2, 0,5L of effluent a day=T3, only water=T0; three replicates for each treatment
- Effluent collected from Massey dairy farm N°4, Palmerston North, NZ

Green house experiment

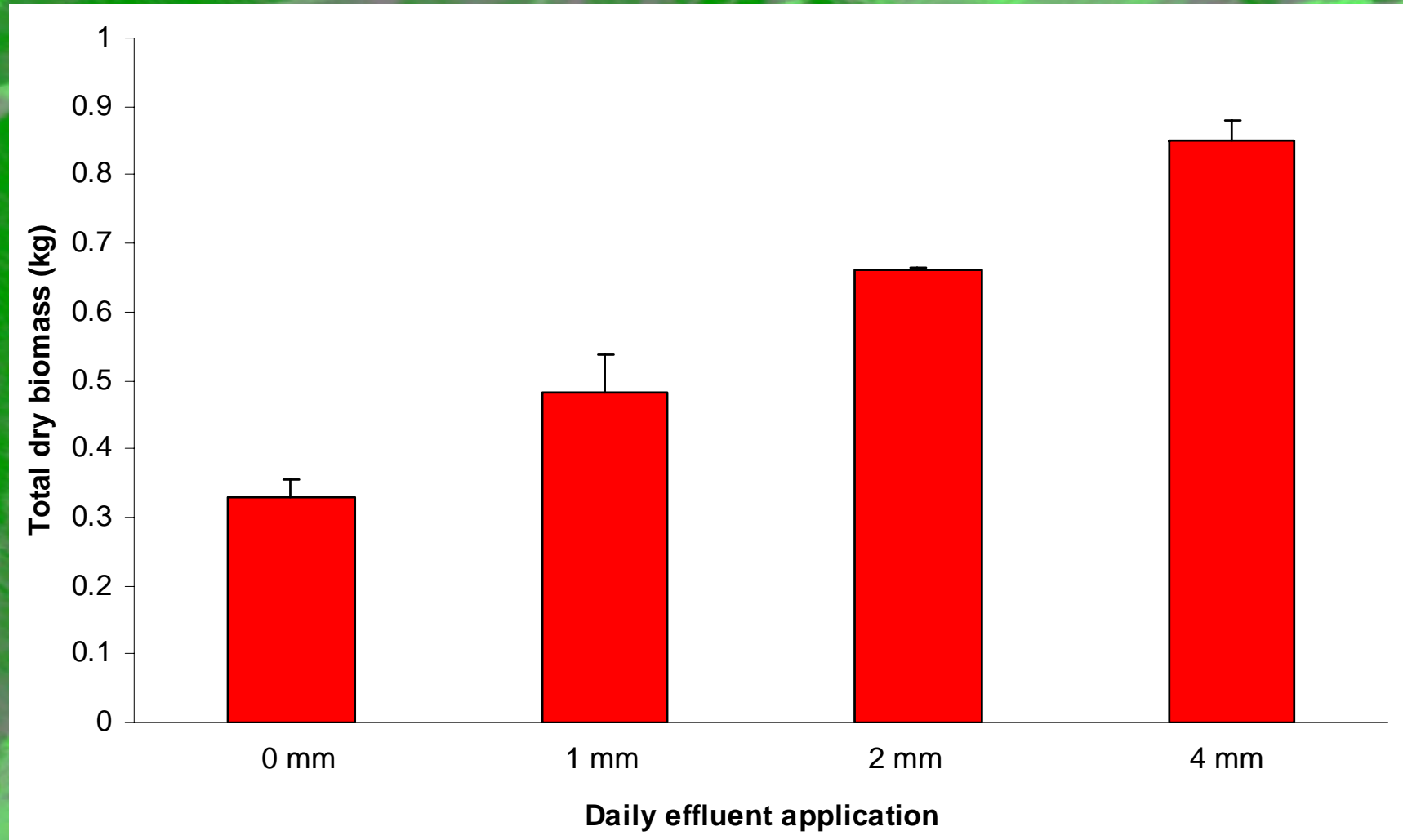
- Water for irrigation was supplied according to the seasonal and growth needs.
- Effluent was applied for 100 days, after leaving the plants stand for 35 days in the buckets for acclimation
- Weekly activities: collect leachates, measure shoot length, count leaves, collect leaves samples
- Destructive final sample: 14 Feb. 2005



Atlanta, 2005

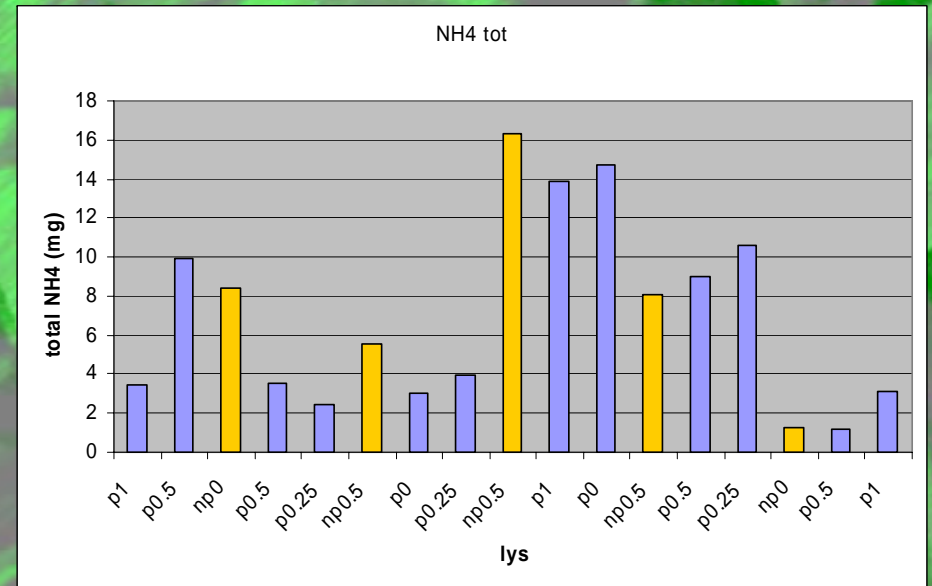
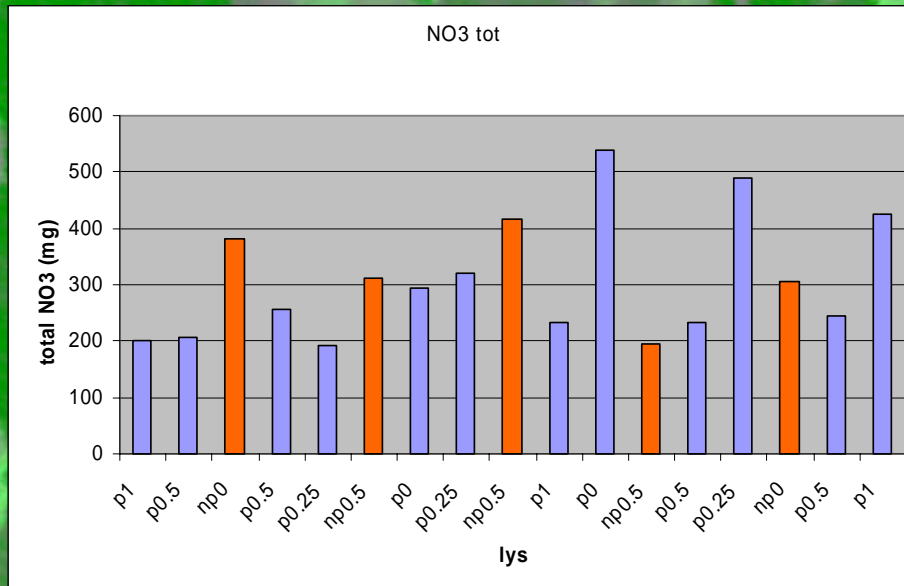
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Effect of effluent on willow biomass



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NO₃ and NH₄ from lysimeter lecheates after 100 days of effluent application



Total NO₃ is almost 100 times higher than total NH₄

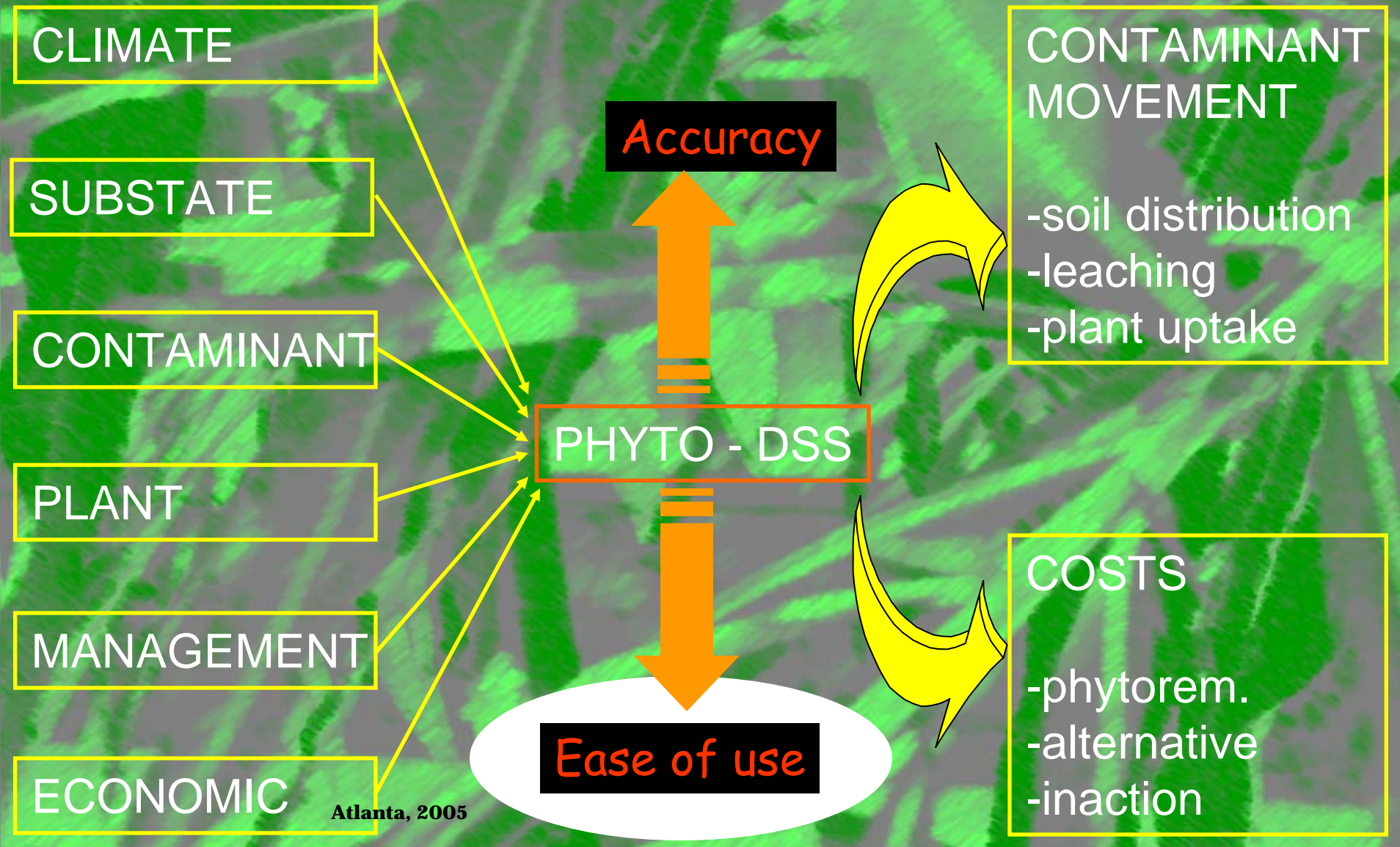
Critical questions

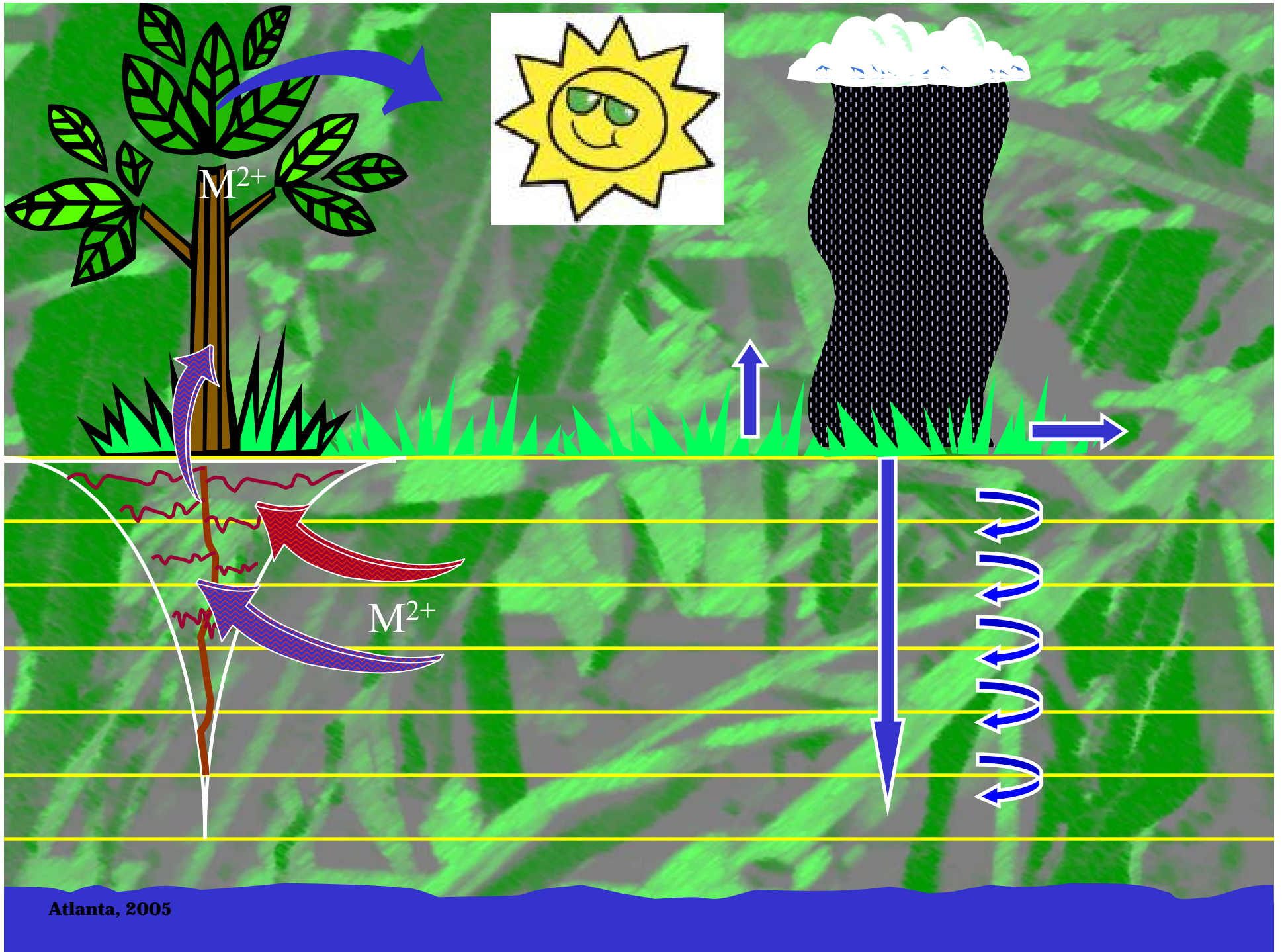
- Poplar and willow (phreatophytes) are palatable forage species that have a positive growth response to dairy effluent.
- What area of trees is needed to dispose of the effluent?
- How do the costs compare to pasture disposal?
- What are the likely long-term effects?

Decision Support System

- **Supple technical program that works for gold, and works just as well for wastewaters: how to dispose of “something” (metal, nutrient, ecc..) and have back a revenue**
- **For dairy shed effluent we can just say “pecunia non olent”**

DSS design

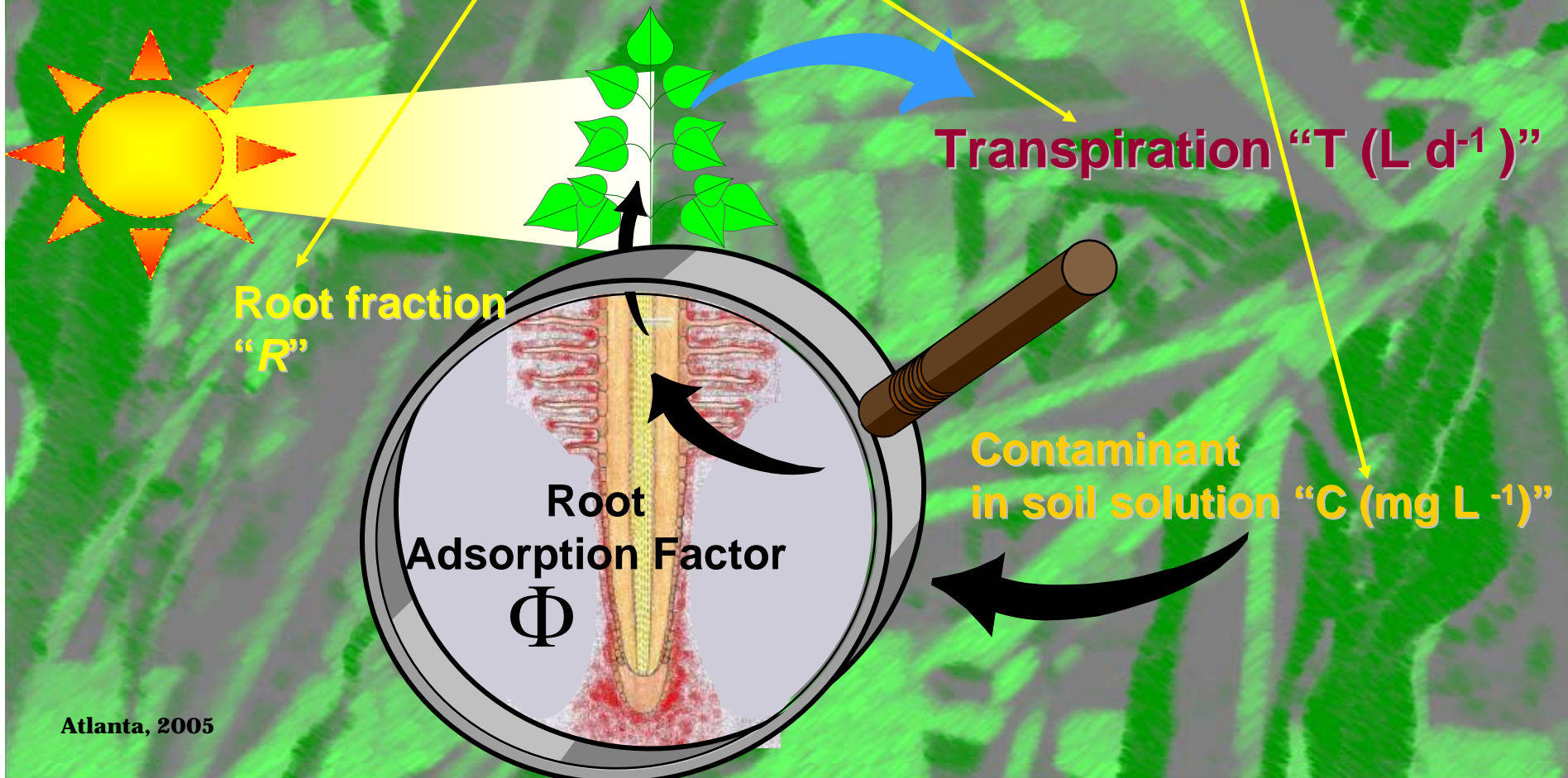




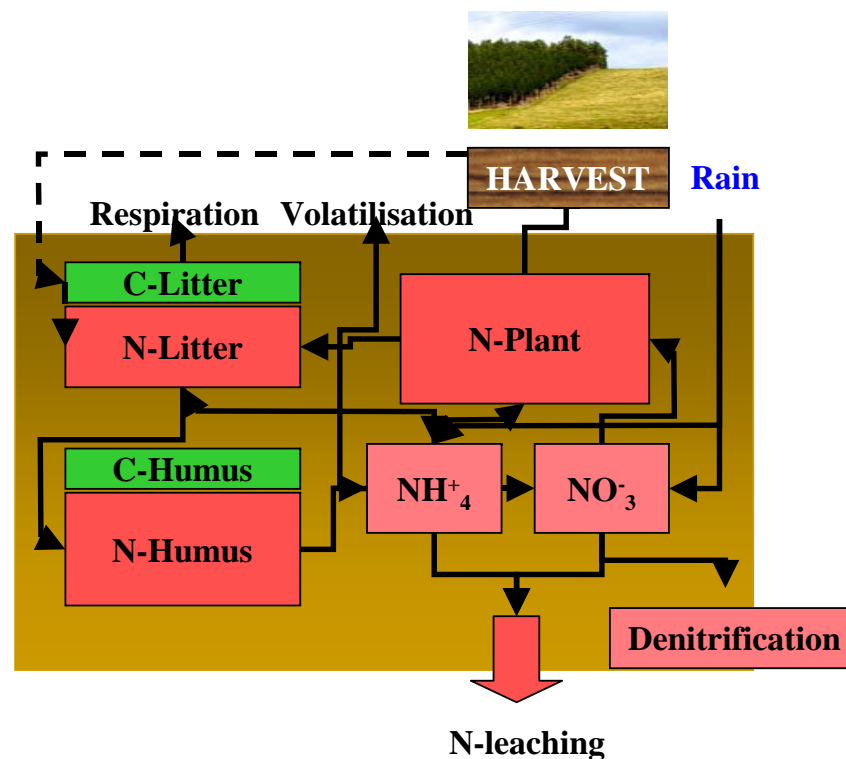
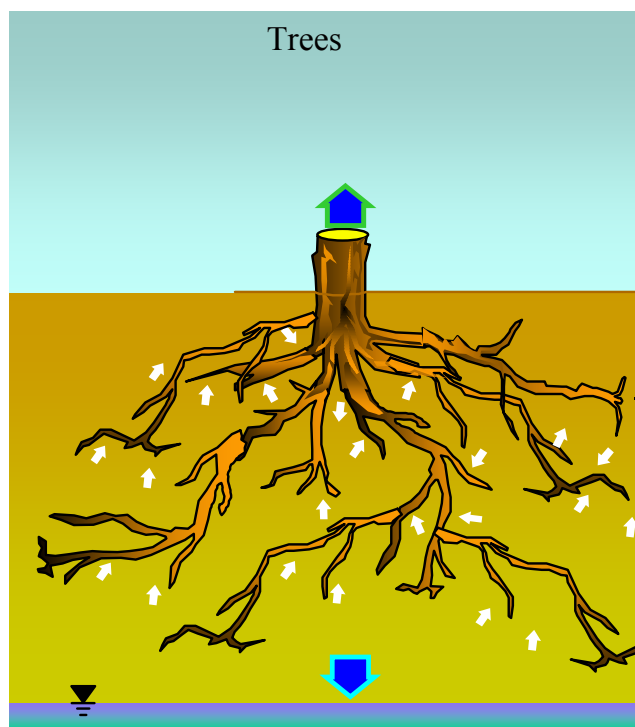
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The process of phytoextraction

$$M(t) = \int_0^{z_R} \int_0^t R(t', z) T(t') C(t'z) \phi(C(t'z)) dt dz$$



Nitrogen in soil is affected by plants roots, microbes, humic substances, DOC and climate



Parameterisation: climate

Substrate and management | **Climate** | Inputs | Outputs Copy screen to clipboard

Date	Rainfall	ETo
1982001	0	4.6
1982002	0	5.0
1982003	15.6	4.8
1982004	0	5.0
1982005	1.3	4.6
1982006	9.4	4.3
1982007	4.2	4.4
1982008	0	5.9
1982009	0	5.1
1982010	0	5.7
1982011	0	6.0
1982012	0	5.4
1982013	0	6.2
1982014	1.1	3.1
1982015	0	6.4
1982016	0	4.3
1982017	0	5.4
1982018	0.6	5.9
1982019	0.1	4.6
1982020	0	5.9
1982021	0	5.1
1982022	0	4.1
1982023	4.8	4.0
1982024	1.4	3.8

Rainfall

ETo

Load Climate

Launch Climate Simulator

Climate data

Climate data file	KopuMetData82-02.pm	Total number of days	7665
Average annual rainfall (mm)	1169	Total Rainfall (mm)	24933
Average annual ETo (mm)	856	Total ETo (mm)	18278

Parameterisation: substrate

Substrate and management | Climate | Inputs | Outputs | Copy screen to clip-board

File control
Current scenario
D:\Profiles\hrpbhr\Desktop\Delphi apps\Next Step\Kopu.phy
Open **Save**


Horizon No.	1
Type	Sawdust
Max depth	100
Density	0.25
K(diff)	0.2
Wini	43
Wfc	43
Wr	16
Wpwp	12

Planting, harvesting and coppicing
Rotation period: 13
% crop removed: 100
Coppicing:
No Rotation:
Day of planting: 260
Day of harvest: 100

Substrate properties
Macropore flow (%): 20
Avg. macropore len. (cm): 20
Rainfall infiltration (%): 100
No. of substrate horizons: 1
Max. substrate depth (cm): 120

Irrigation
Regime
 No irrigation
 To meet evapotranspiration
 Periodically
Total (mm): 0.0000
Amount (mm): 0.0000
Periodicity (d): 0.0000
From (DOY): 0.0000
To (DOY): 0.0000

Contaminant addition
Regime
 No addition
 Periodically



Parameterisation: contaminants

Substrate and management | Climate | Inputs | Outputs | Copy screen to clip-board

Contaminant | Plant properties | Economic and Site management

Contaminant distribution

Concentration profile

Soluble contaminant

Soluble contaminant

Maximum 0%: 0

Minimum 100%: 1

Maximum 100%: 5

Minimum 0%: 30

Contaminant solubility: [dropdown]

Contamination:

- Surface contamination
- Contamination at depth
- Uniform (contamination)
- Uniform (background only)

Year of addition: 1,995

Day: 300

Solubilising agent added

Number of soil contaminants: 4

Contaminant degradation

Contaminant	B	Cu
Total (mg/kg)	35	200
Soil additive (mg/kg)	0	0
Half life (d)	0	0
MAV in soil (mg/kg)	5	300
Background (mg/kg)	1	0.1
Si-bound (mg/kg)	0	0
Soluble (mg/L)	3	0.15
Soluble+chelate (mg/L)	3	0.5
Chelate half life (d)	100	100
MAV groundwater (mg)	1.4	0.03
Plant max. (mg/kg)	1500	150
BioM.Thresh. (mg/kg)	1000	75
R.A.F.	0.3	0.01
R.A.F. Dec.Const.	0.1	0
Leaf/Stem Quo.	7	7
MAV in plant (mg/kg)	100	100
Value (US\$/kg)	0	0
Notes	No chelate	no chelate

DS

S

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Parameterisation: plant properties

Substrate and management | Climate | Inputs | Outputs Copy screen to clipboard

Contaminant | **Plant properties** | Economic and Site management

Root distribution

Maximum pos. metal extracted

Maximum possible plant metal conc.

Contaminant	B	Cu
Total (mg/kg)	35	200
Soil additive (mg/kg)	0	0
Half life (d)	0	0
MAV in soil (mg/kg)	5	300
Background (mg/kg)	1	0.1
Si-bound (mg/kg)	0	0
Soluble (mg/L)	3	0.15
Soluble+chelate (mg/L)	3	0.5
Chelate half life (d)	100	100
MAV groundwater (mg)	1.4	0.03
Plant max. (mg/kg)	1500	150
Biom.Thresh. (mg/kg)	1000	75
R.A.F.	0.3	0.01
R.A.F. Dec.Const.	0.1	0
Leaf/Stem Quo.	7	7
MAV in plant (mg/kg)	100	100
Value (US\$/kg)	0	0
Notes	No chelate	no chelate

Biomass properties

Maximum root depth (cm)

Root distribution const.

% annual bioms. prod. in leaves

Decay Depth (cm)

BioM at canopy closure (kg/ha)

BioM at planting (kg/ha)

Initial growth conditions

Potential biomass production (t/ha)

Potential water use (mm)

Avg. init. Xtractable (soil+root profiles)

Initial plant metal conc. (mg/kg)

Initial metal extracted by crop (kg)

R.A.F. \approx $\frac{\text{plant [contaminant]} \times \text{plant biomass}}{\text{total water-use} \times \text{soil-solution [contaminant]}}$

Deciduous

Days when trees are bare (DOY)

From To

Crop coefficient [%]

No. of days from bud-burst to full leaf

Zero transpiration during winter

DSS

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Parameterisation: economic variables

Substrate and management | Climate | Inputs | Outputs | Copy screen to clipboard

Contaminant | Plant properties | Economic

Phytoremediation

Profit generation from:

- leaves
- stems
- leaves and stems
- metal
- metal and biomass
- none

Plant use: fuel

Cost of site assessment (\$000 US): 25

Gross biomass value (\$US/t): 0

Cost of planting (\$US/ha): 5000

Cost of production (\$US/ha/yr): 1500

Cost of ashing (\$US/t): 0

Cost of recovery (\$US/ton of ash): 0

Ash-Dry biomass (%): 10

Costs of inaction

Loss of productivity (\$US/ha/yr): 0

Reputation / Goodwill (\$000 US): 10

Legal / Litigation (\$000 US): 1,000

Future costs (\$000 US): 0

Interest Rates

In credit (%): 4 | In debt (%): 5

Best alternative technology

Technology type: Capping

Cost (\$000 US/ha): 140

Time needed (years): 1

Best alternative technology

Inaction

Contaminant	B
Total (mg/kg)	35
Soil additive (mg/kg)	0
Half life (d)	0
MAV in soil (mg/kg)	1
Background (mg/kg)	0.001
Si-bound (mg/kg)	0
Soluble (mg/L)	3
Soluble+chelate (mg/L)	0.5
Chelate half life (d)	5
MAV groundwater (mg)	1.4
Plant max. (mg/kg)	1500
BioM.Thresh. (mg/kg)	1000
R.A.F.	0.3
R.A.F. Dec.Const.	0.1
Leaf/Stem Quo.	7
MAV in plant (mg/kg)	100
Value (US\$/kg)	10000
Notes	No Chelate

DS
S

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PhytoDSS - outputs

Substrate and management | Climate | Inputs | **Outputs**

Mass balance

Contaminant (kg) **Water (mm)**

Initial

Added to substrate **0.0000** **12472**
 Initial soil loading **175.0** **860.0**

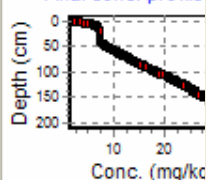
Final

Removed in crop(s) **1.706** **6704**
 Remaining in substr. **93.85** **686.9**
 Leached **79.44** **5941**
 Decayed **0.0000**

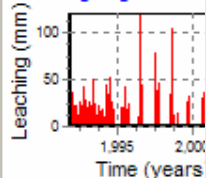
Initial - Final

Balance **0.0000** **0.000**

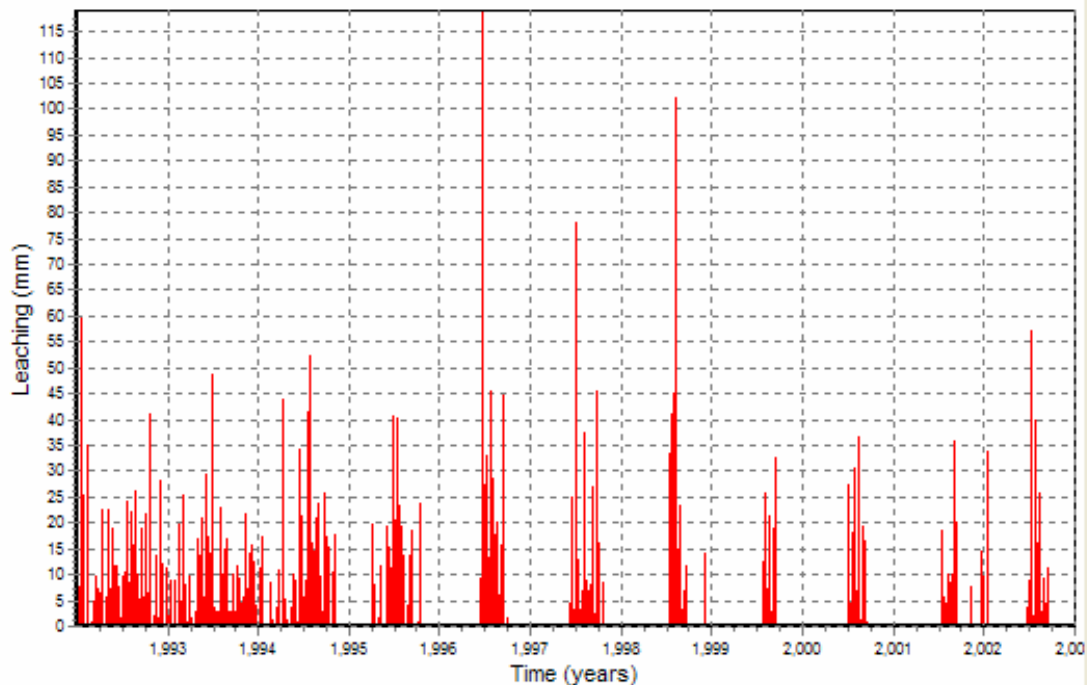
Final conc. profile



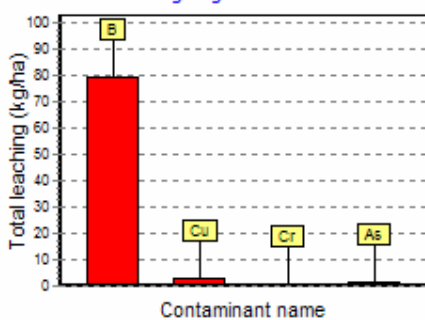
Leaching to groundwater



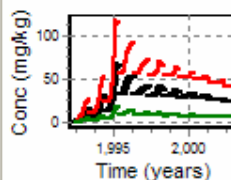
Leaching to groundwater



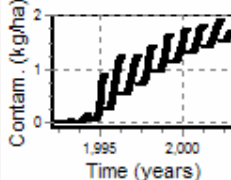
Leaching to groundwater



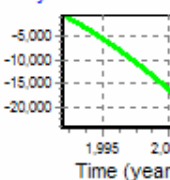
Plant contaminant conc.



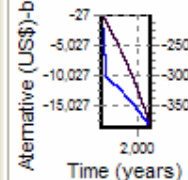
Total contam. extracted



Phytoremediation



Alternatives



Calculate

B

- Show permissible limits
- Simulate without crop

General data

Area name Kopu

Land area (ha) 5

Simulation dates

From (year,DOY) 1,992 1

To (year,DOY) 2,002 365

Economics calculated on a

- Per hectare basis
- Total area basis

Progress

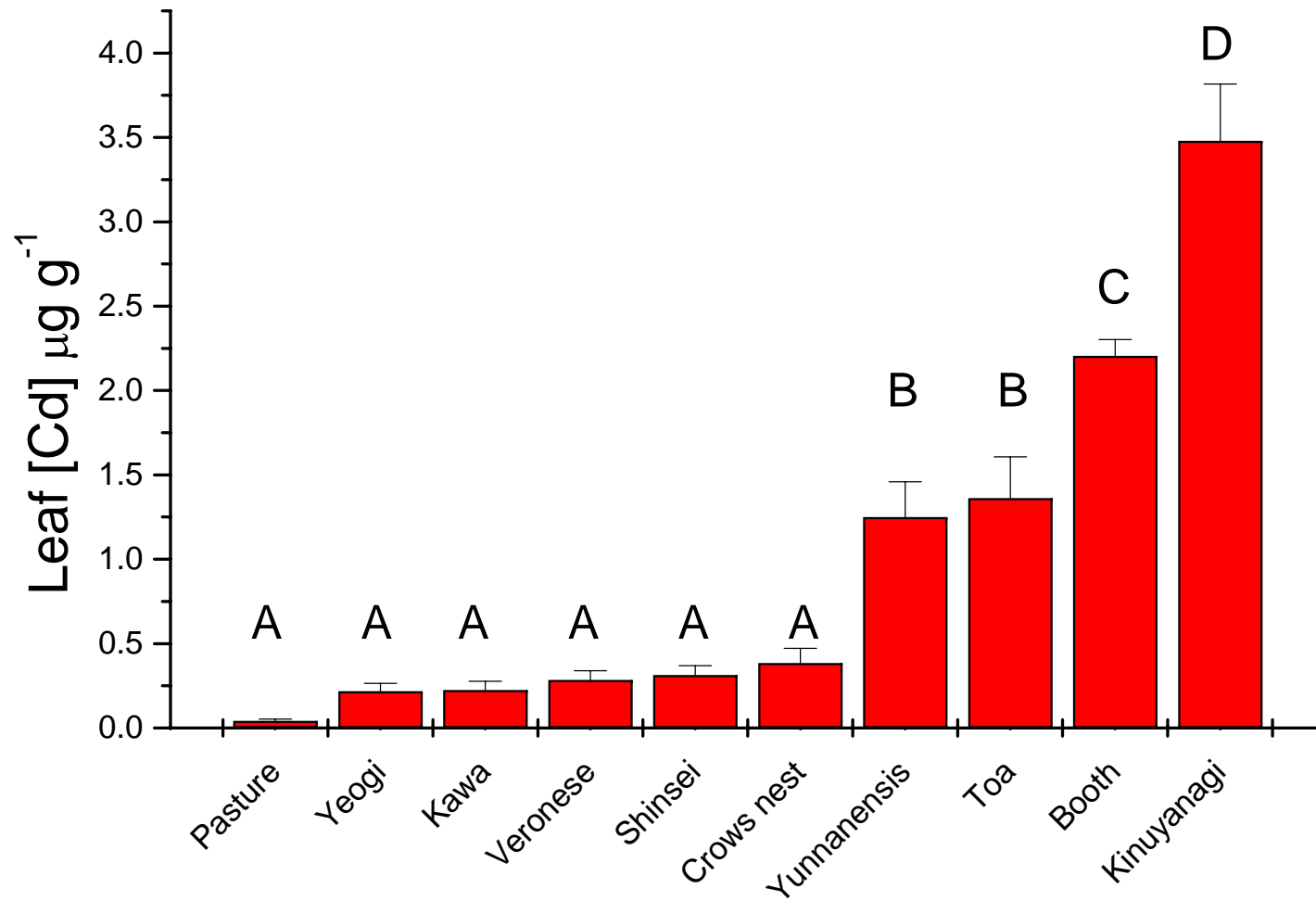
Save results to spreadsheet

Atlanta, 2005

Conclusions

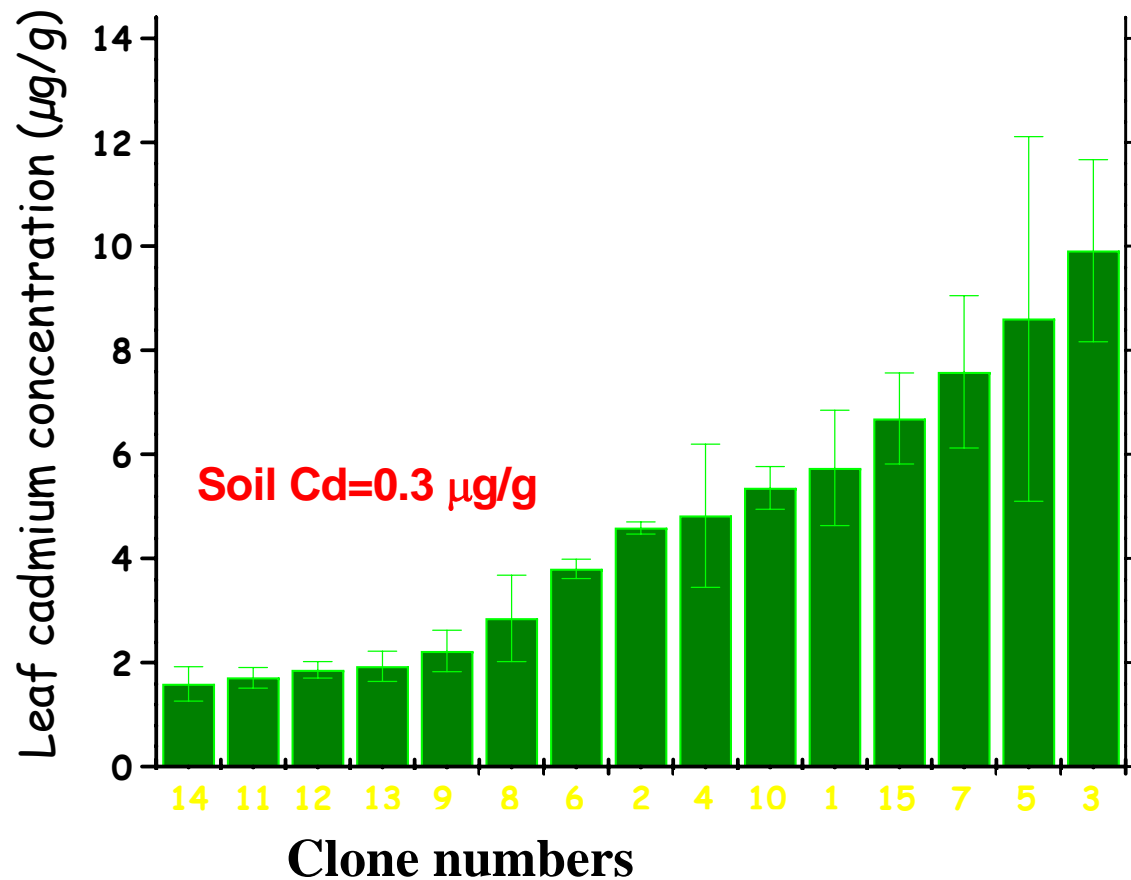
- Each farm is unique in the characteristics of soil, agronomical practice and climate
- The DSS is a mechanistic model that takes into consideration the main variable affecting Nitrogen and metal leaching into soil and water due to wastewater disposal onto agricultural land
- Existing models may not be suitable for dairy effluents because they do not consider DOC and N
- There may also be concerns for metals transport from soil to groundwater

Willows may provide an exposure pathway for Cd

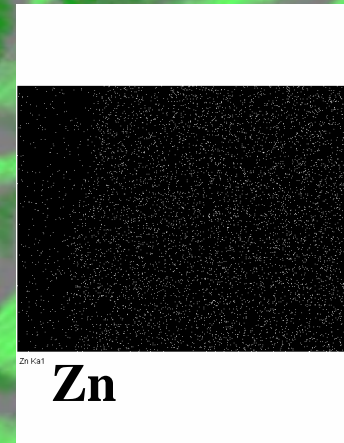
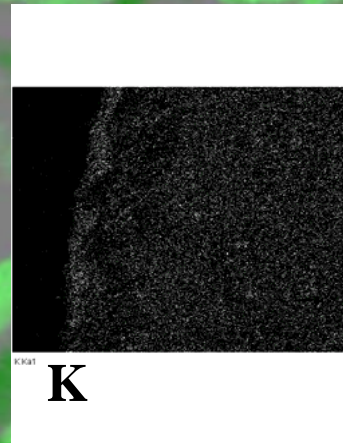
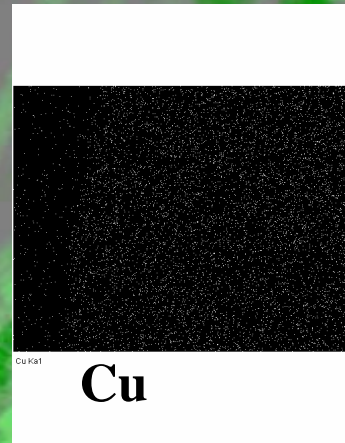
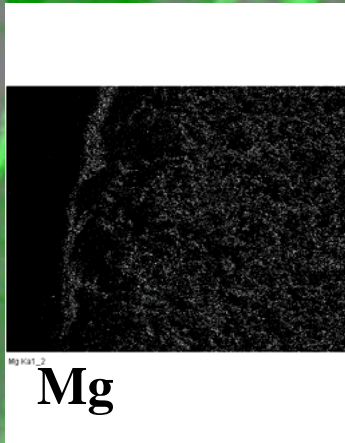
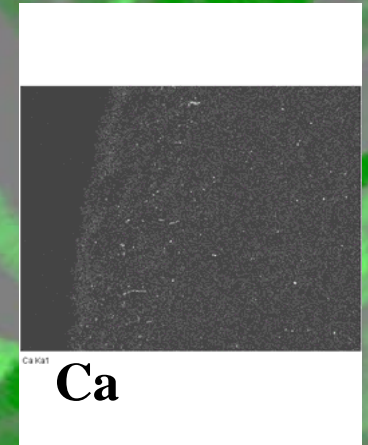
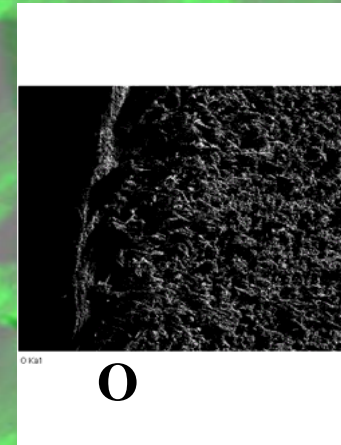
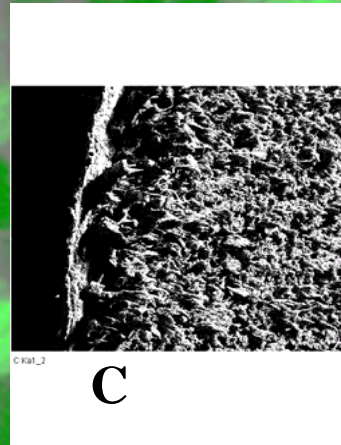
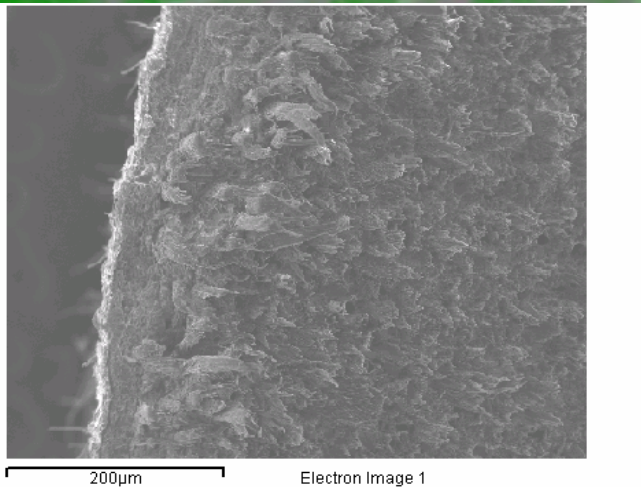


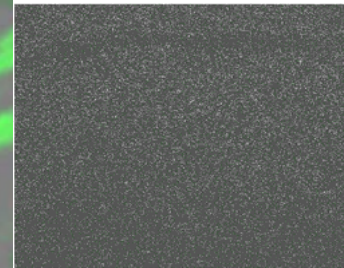
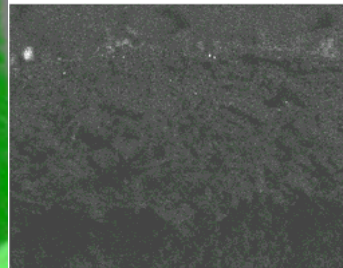
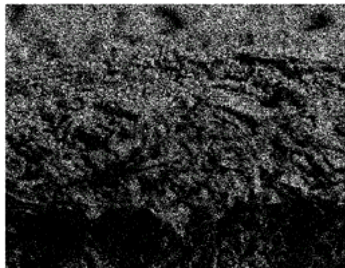
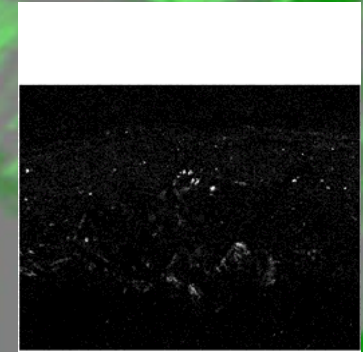
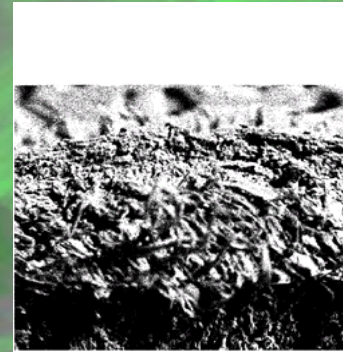
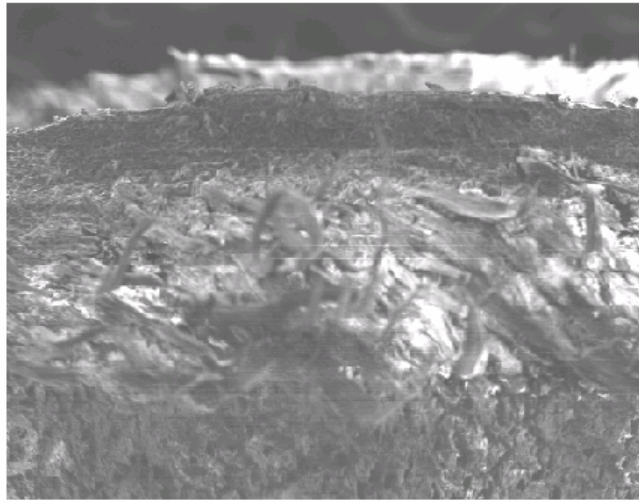
Future challenges: determining nutrients and metal contents of plant used for wastewater disposal

Leaf cadmium concentrations in 15 willow clones



Preliminary SEM/EDX screening of sections from willow branches





Take home message

- Dairy farms are getting larger and the problem of disposing of wastewaters is becoming urgent
- Green-house lysimeters experiment with willow stands can simulate leaching and plant growth under dairy shed effluent irrigation
- Data from green-house experiment are instrumental to shape a suitable DSS to help farmers to follow an environmental sound and cost effective disposal of wastewaters

Acknowledgements

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