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

Marta Marmiroli¹, Brett Robinson², Nanthi Bolan³, Brent Clothier², Steve Green², Carlo van den Dijssel², Nelson Marmiroli¹.

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?

Atlanta, 2005
Agriculture is a starting point

Atlanta, 2005
Dairy effluent disposal: current practice

• Directly into waterways

• Onto pasture to improve growth
Dairy effluent in the environment

- NO₃ – 100 mg/kg – groundwater contamination
- NH₄ – 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

Atlanta, 2005
Increasing N-loading on waterways
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.

Atlanta, 2005
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

Evapotranspiration

Rainfall re-evaporated from leaves

Contaminant and water extraction

Plant uptake of groundwater

Contaminant degradation metal stabilisation

Atlanta, 2005
Other problems related to Agriculture and farming can span from...
...rough Bison in US

Atlanta, 2005
So it is important to train the cows when to urinate to disciplined cows in New Zealand.
effect of dairy effluent on growth

Atlanta, 2005
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
Effect of effluent on willow biomass

Atlanta, 2005
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

CONTAMINANT MOVEMENT
- soil distribution
- leaching
- plant uptake

CLIMATE

SUBSTATE

CONTAMINANT

PLANT

MANAGEMENT

ECONOMIC

Accuracy

PHYTO - DSS

Ease of use

CONTAMINANT

COSTS
- phytorem.
- alternative
- inaction

Atlanta, 2005
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

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<th>ETo</th>
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Rainfall

ETo

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

Atlanta, 2005
Parameterisation: substrate

File control
Current scenario
D:\Profiles\hpbh\Desktop\Delphi apps\Next Step\kopu.phy

Open  Save

Horizon No. 1
Type Sawdust
Max depth 100
Density 0.25
K(diff) 0.2
Wmi 43
W/fc 43
Wt 16
W/pwp 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) 130

Irrigation
Regime
- No irrigation
- To meet evapotranspiration
- Periodically

Contaminant addition
Regime
- No addition
- Periodically

Total (mm)
Amount (mm)
Perodisity (g)
From (DCY)
To (DOY)
Parameterisation: contaminants

Contaminant distribution

Contaminant solubility

Year of addition

Contaminant degradation

DS S

Atlanta, 2005
Parameterisation: plant properties

R.A.F. ≈ \( \text{plant [contaminant]} \times \text{plant biomass} \times \text{total water-use} \times \text{soil-solution [contaminant]} \)

Atlanta, 2005
Parameterisation: economic variables

<table>
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<th>Contaminant</th>
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<tbody>
<tr>
<td>Total (mg/kg)</td>
<td>35</td>
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<tr>
<td>Soil additive (mg/kg)</td>
<td>0</td>
</tr>
<tr>
<td>Half life (d)</td>
<td>0</td>
</tr>
<tr>
<td>MAV in soil (mg/kg)</td>
<td>1</td>
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<tr>
<td>Background (mg/kg)</td>
<td>0.001</td>
</tr>
<tr>
<td>Si-bound (mg/kg)</td>
<td>0</td>
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<tr>
<td>Soluble (mg/L)</td>
<td>3</td>
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<tr>
<td>Soluble+chelate (mg/L)</td>
<td>0.5</td>
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<tr>
<td>Chelate half life (d)</td>
<td>5</td>
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<tr>
<td>MAV groundwater (mg/L)</td>
<td>1.4</td>
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<tr>
<td>Plant max. (mg/kg)</td>
<td>1500</td>
</tr>
<tr>
<td>BioM.Thresh. (mg/kg)</td>
<td>1000</td>
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<tr>
<td>R.A.F.</td>
<td>0.3</td>
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<tr>
<td>R.A.F. Dec.Const.</td>
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<tr>
<td>Leaf/Stem Quo.</td>
<td>7</td>
</tr>
<tr>
<td>MAV in plant (mg/kg)</td>
<td>100</td>
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<tr>
<td>Value (US$/kg)</td>
<td>10000</td>
</tr>
<tr>
<td>Notes</td>
<td>No Chelate</td>
</tr>
</tbody>
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Substrate and management | Climate | Inputs | Outputs

### Phytoremediation
- Profit generation from:
  - leaves
  - stems
  - leaves and stems
  - metal
  - metal and biomass
  - none

<table>
<thead>
<tr>
<th>Plant use</th>
<th>fuel</th>
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<tr>
<td>Cost of site assessment ($000 US)</td>
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<tr>
<td>Gross biomass value ($US/t)</td>
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<tr>
<td>Cost of planting ($US/ha)</td>
<td>5000</td>
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<tr>
<td>Cost of production ($US/ha/yr)</td>
<td>1500</td>
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<tr>
<td>Cost of ashing ($US/t)</td>
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</tr>
<tr>
<td>Cost of recovery ($US/ton of ash)</td>
<td>0</td>
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<tr>
<td>Ash-Dry biomass (%)</td>
<td>10</td>
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</table>

### 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 |

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

<table>
<thead>
<tr>
<th>Clone numbers</th>
<th>Leaf cadmium concentration (µg/g)</th>
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<tr>
<td>14</td>
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<tr>
<td>11</td>
<td>2</td>
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<td>6</td>
<td>12</td>
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<tr>
<td>2</td>
<td>14</td>
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<tr>
<td>4</td>
<td>Soil Cd=0.3 µg/g</td>
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Atlanta, 2005
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.

Atlanta, 2005
Acknowledgements

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Atlanta, 2005