A Decade of Bioretention Mesocosm Experiments in Australia
Comparative Studies of Media and Plants Species to Improve Nutrient Retention

Margaret Greenway, Griffith University, Brisbane, AUSTRALIA
Background to Research Questions

Vegetation is an important component of bioretention systems for water quality improvement.

Benefits of plants in nutrient uptake are often under-rated because at high HLR the % removal is relatively small especially for phosphorus.

Media can enhance phosphorus adsorption in subsurface flow wetlands for wastewater and in bioretention systems for stormwater.

Carbon sequestration is an increasingly important attribute.
Background

- Plant species can vary in their ability for luxury uptake of phosphorus and storage of carbon.
- Phosphorous sorption capacity of media determines long term P removal & retention.
- After the sorption capacity is reached, P is no longer removed & desorption may occur, resulting in export of P.
- Media used in subsurface flow CW’s is typically gravel and/or sand (good hydraulic conductivity).
- Generally gravel and sand have poor adsorption capacity for phosphorus.
Aims of Research Project (commenced 2002)

1. To investigate the effect of different media on plant growth and nutrient retention.
2. To investigate the role of microorganisms in nutrient retention
3. To investigate the effect of media saturation on phosphorus retention.
4. To quantify nutrient uptake and carbon sequestration in different plant species.
Bioretention Mesocosm Experiments
Griffith University-Experimental Setup 240L Mesocosms

- 240L wheelie bin mesocosms
  Vegetated and barren.

- Stormwater or Recycled effluent loaded weekly 112L.

- Inflow distributed by a manifold system and regulated drippers.

- Outflows collected in 3m long chambers of 250mm pipes (135 L).

Thanks to Vinidex for the collection chambers!
Experiment 1—June 2003- March 2007

Acknowledgements- Courtney Henderson, Bill Lucas, Daya Gautum

30 mesocosms : 3 different media
gravel
sand (4% silt/clay)
loam (8% silt/clay)

NO TOPSOIL NOR COMPOST ADDED

Vegetated and Non-vegetated (barren) treatments

Shoot harvesting commenced after 2.5 years (Greenway)


All plants harvested after 4.5 years (Greenway –Gautum)
Experiment 1 Plants

Grass: *Pennisetum alopecuroides*
Lily: *Dianella brevipedunculata*
Shrubs: *Callistemon pachyphyllus; Banksia integrifolia*
Succulent creeper: *Carpobrotus glaucesens*
Retention in vegetated media > barren media

**Plant uptake only accounted for 11% TP & 13% PO4 load**

Retention in loam > sand > gravel

**After load of 100gPm-2 all media P saturated & loam clogged**
Expt 1 % P retention & TP plant uptake after load 105gP/m² - gravel, sand, loam

- Phosphorus Retention highest in loam (89% PO₄), then sand
- P retention exceeded plant uptake
- Chemical adsorption and microbial uptake important mechanisms
- Plant uptake highest in loam (43%) (better growth)
Retention in vegetated media > barren media

**Plant uptake accounted for 37% TN & 63% NOx load**

Retention in loam > sand > gravel

**Export of NOx in all barren media**
Expt 1 % nitrogen retention and plant uptake based on SW and effluent loading (4.5 years)

- Loam > Sand > Gravel
- Plant uptake exceeds inflow load
- N sources? microbial processes: nitrogen fixation? mineralisation?
• Callistemon and Pennisetum had the highest biomass
• Total plant biomass was highest in the loam media
Annual N & P plant uptake

Callistemon: 15g N, 4.4g P  mean annual uptake 33.4gN, 10.7gP
Pennisetum: 13g N, 5.0g P  max annual uptake 40g N, 11.1g P
Dianella: 3g N, 0.5g P
Banksia: 1g N, 0.1g P
Carpobrotus: 1.4g N, 0.7g P
Expt 1 Sand & Loam Media : Total Phosphorous

Original media g/m2 P (2003): sand 25g; loam 130g

After stormwater loading (3.7gP/m2) 2003 -2006:
sand 28g, sand vegetated 18g **LOSS**- plant uptake?
loam 134g, loam vegetated 147g **GAIN**- adsorption?

After recycled effluent loading (102gP/m2) 2006 -2007:
sand 60g, sand vegetated 80g; loam 154g, loam vegetated 197g
Greater P retention in both vegetated sand and loam
After 12 months effluent loading (102gP/m²)

- Sand 60g, Vegetated Sand 72g; difference 12g/m²
- Loam 154g, Vegetated Loam 185g; difference 31g/m²

Greater P retention in both vegetated sand and loam
Higher in *vegetated* than *barren*

Soil OM higher in loam than sand

Within mesocosms no sig difference down profile
SOM increases over time in vegetated media
Higher OM in top 10cm overtime due to leaf litter (only significant for sand)
Overall no significant change in soil profile
Slightly higher OM at 60-70cm
Experiment 2 (Bill Lucas) – commenced in January 2007

27 mesocosms 240 L wheelie bins : -9 treatments ( 3 replicates)

SAND PLUS Media Amendments:

- **Krasnozem soils**: Red clay soils derived from weathering of ancient basalt
- **Red Mud**: By-product of refining bauxite into aluminium. Mostly clay/silt with fractions of Al & Fe oxides
- **Water Treatment Residuals**: Al-WTR ‘sludge’ residues from water treatment processes dominated by aluminium hydroxides, plus clay & organic matter.
Media treatments formulated for phosphorus retention:

- **Sand (60-80%)**
  - Sand plus **Krasnozem** (K) - 3 treatments: (20%, 30%, 40%)
  - Sand plus **Red Mud** (RM) - 2 treatments: 6% and 10%
  - Sand plus **Water Treatment Residuals** (WTR) - 30%
  - Sand plus Water Treatment Residuals 10% + Krasnozem 20% (WTR-K)

All media plus 12% by volume **coir peat**
## Expt 2: % SOM Original Media

<table>
<thead>
<tr>
<th>Sample</th>
<th>% SOM in original media</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM6</td>
<td>1</td>
</tr>
<tr>
<td>K20</td>
<td>2</td>
</tr>
<tr>
<td>RM 10</td>
<td>3</td>
</tr>
<tr>
<td>WTR+K</td>
<td>4</td>
</tr>
<tr>
<td>WTR30</td>
<td>5</td>
</tr>
<tr>
<td>Krasnozem</td>
<td>8</td>
</tr>
</tbody>
</table>
Experiment 2 Plants

Grass: *Pennisetum alopecuroides*
Sedges: *Carex appressa; Isolepis nodosa*
Shrubs: *Callistemon pachyphyllus; Melaleuca thymifolia*
Expt 2 % phosphorus retention & TP plant uptake (mass load– 200gP/m2)

- All media excellent P retention (85-96%) - no indication of P saturation even after total inflow loads of 300gP/m2
- Retention far exceeded plant uptake (note lower % due to higher load)
- Media adsorption primary P removal process
Expt 2 % nitrogen retention and plant uptake based on effluent loading (2 years)

- Maximum TN retention 58% WTR+K; least 41% RM06
- Plant uptake exceeds inflow load in K30,RM06,RM10
- N sources ? microbial processes: fixation? mineralisation?
- Retention exceeds plant uptake in K10-30-microbial uptake
Pennisetum and Carex had the highest biomass.
Root biomass lowest for Isolepis.
Expt 2 Shoot/Root Biomass after 3 years

- **Pennisetum** had the highest biomass (cropping of shoots)
- **Isolepis** had poorest root biomass - ‘wiry’ morphology / competition?
Expt 2: Comparison of Total Shoot/Root Biomass after 2 & 3 years

- K20 had the highest biomass after 2 y and RM10 after 3 y
- All media had similar root biomass
- No incremental root biomass after 2 years - *pot bound?*
Annual P & N accumulation in plant biomass in media with Krasnozems and Red Mud

Expt 2.1 Annual Plant Uptake P & N g/m²/y

Annual P uptake 12-15 g/m²/y
Annual N uptake 48-58 g/m²/y

NOTE irrigated with tertiary treated sewage effluent
Annual P & N accumulation in plant biomass in media with WTR and Krasnozems

Annual Plant Uptake P & N g/m2

- WTR+K: 60 g/m2 (2.2 years)
- WTR+K: 50 g/m2 (3.5 years)
- WTR30: 40 g/m2 (4.2 years)

Annual P uptake 10g-12/m2
Annual N uptake max 62 g/m2

Annual N & P accumulation varied over time as different plant species dominated and some became pot bound.
Annual carbon accumulation ranged from 2800g (K20) to 2600g (K40) m²/y.
Annual carbon accumulation up to 3000 g/m²/y (WTR 30)
Expt 2: % SOM Original media & after 3 years

Changes in SOM were not consistent in all media:
- K20 & WTR+K - % SOM increased
- RM10 & WTR 30 - %SOM decreased (possibly initial leaching? Or high rates of microbial mineralisation)
Changes in % SOM over 4 years

WTR-K

- % SOM fluctuations over time
- WTR-K - % SOM decreased – then increased
Experiment 3 2009-present

Commenced in May 2009. 12 mesocosms.
- Mesocosms with sandy media (80%) amended with Water Treatment Residuals for P retention
- 4 mesocosms loaded with recycled effluent
- 8 mesocosms loaded with tap water or synthetic stormwater

Funded by SEQWater interested in use of WTR for P removal
Grasses: *Pennisetum alopecuroides; Vetiveria z Ianoides*
Lily: *Lomandra hystrix*
Shrubs: *Callistemon pachyphyllus; Melaleuca quinquenervia*
Expt 3 Shoot Biomass after 12 months

- Pennisetum > Vetiveria > Lomandra
- Shoot biomass significantly higher with effluent loading
• Annual P uptake around 1.5 g/m in controls irrigated with tap water/stormwater compared to 8g/m2 in effluent irrigated mesocosms

• Annual N uptake 7g/m2 in controls compared to 45 g/m2 in effluent
Expt 3: Comparison of P and N accumulation in plant sp in Control and Effluent mesocosms

All species showed enhanced growth when irrigated with effluent. Pennisetum had the highest P and N accumulation.
Expt 3: Temporal changes in % SOM
(no significant difference between effluent and controls)
Comparison of N and P between all plant species
Annual P & N accumulation in plant species biomass after 2 years

Phosphorus & Nitrogen in biomass g/m²/y
Annual Carbon accumulation in plant species biomass after 2 years

- **Pennisetum**
- **Vetiver**
- **Paspalum**
- **Carex**
- **Isolepis**
- **Lomandra**
- **Dianella**
- **Callistemon p**
- **Callistemon s**
- **Melaleuca**

**g C/y for different species**

<table>
<thead>
<tr>
<th>Species</th>
<th>g C/m²/y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennisetum</td>
<td>900</td>
</tr>
<tr>
<td>Vetiver</td>
<td>800</td>
</tr>
<tr>
<td>Paspalum</td>
<td>500</td>
</tr>
<tr>
<td>Carex</td>
<td>700</td>
</tr>
<tr>
<td>Isolepis</td>
<td>400</td>
</tr>
<tr>
<td>Lomandra</td>
<td>200</td>
</tr>
<tr>
<td>Dianella</td>
<td>300</td>
</tr>
<tr>
<td>Callistemon p</td>
<td>600</td>
</tr>
<tr>
<td>Callistemon s</td>
<td>700</td>
</tr>
<tr>
<td>Melaleuca</td>
<td>800</td>
</tr>
</tbody>
</table>

**Categories:**
- **GRASSES**
- **SEDGES**
- **LILIES**
- **SHRUBS**
Conclusions - Media

In Expt 1 loam was highly effective for P retention but clogged

In Expt 2 mesocosms with sandy media amended with Krasnozem soils, Red Mud, and Water Treatment Residuals ALL demonstrated excellent P retention from wastewater effluent. (Bill to expand)

In Expt 2 & 3 Sand amended with Water Treatment Residuals was the most effective treatment - 99% retention, and showed no sign of saturation even after the application of 3000kgP/ha

Thus all amended sand media demonstrated long term capacity for P sorption and retention.
Conclusions - Plants

- **Pennisetum** and **Carex** yielded the highest biomass of the herbaceous plants.

- Harvesting of the shoots increased yield – but this requires maintenance.

- **Callistemon** and **Melaleuca** yielded the highest biomass of the woody plants.

- All plants trialed grew equally well in the different media.

- In Expt 1 all plants grew well without added organic matter.

- Plants can be effective in **Phosphorus & Nitrogen** uptake.

- Plants also **sequester Carbon**.

Thus the selection of suitable plant species is paramount for long term sustainability of bioretention systems.
Thank You

Green tree frog finds a home in the wheelie bin mesocosm
Brown honeyeater extracts nectar from Callistemon in the wheelie bin mesocosm.