Denitrifying Bioreactors:

A Synthesis of Removal Rates, Controls and Utility

Louis Schipper

University of Waikato

Hamilton, New Zealand

Workshop at the 2012 Land Grant and Sea Grant National Water Conference

May 23, 2012

Outline

- What the forms of bioreactors?
- Nitrate removal rates
- Controls on nitrate removal
  - Temperature
  - Nitrate concentration
  - Carbon source
- Longevity and costs
- Adverse effects?
- Conclude and gaps

The principle

Nitrate → Nitrogen gas

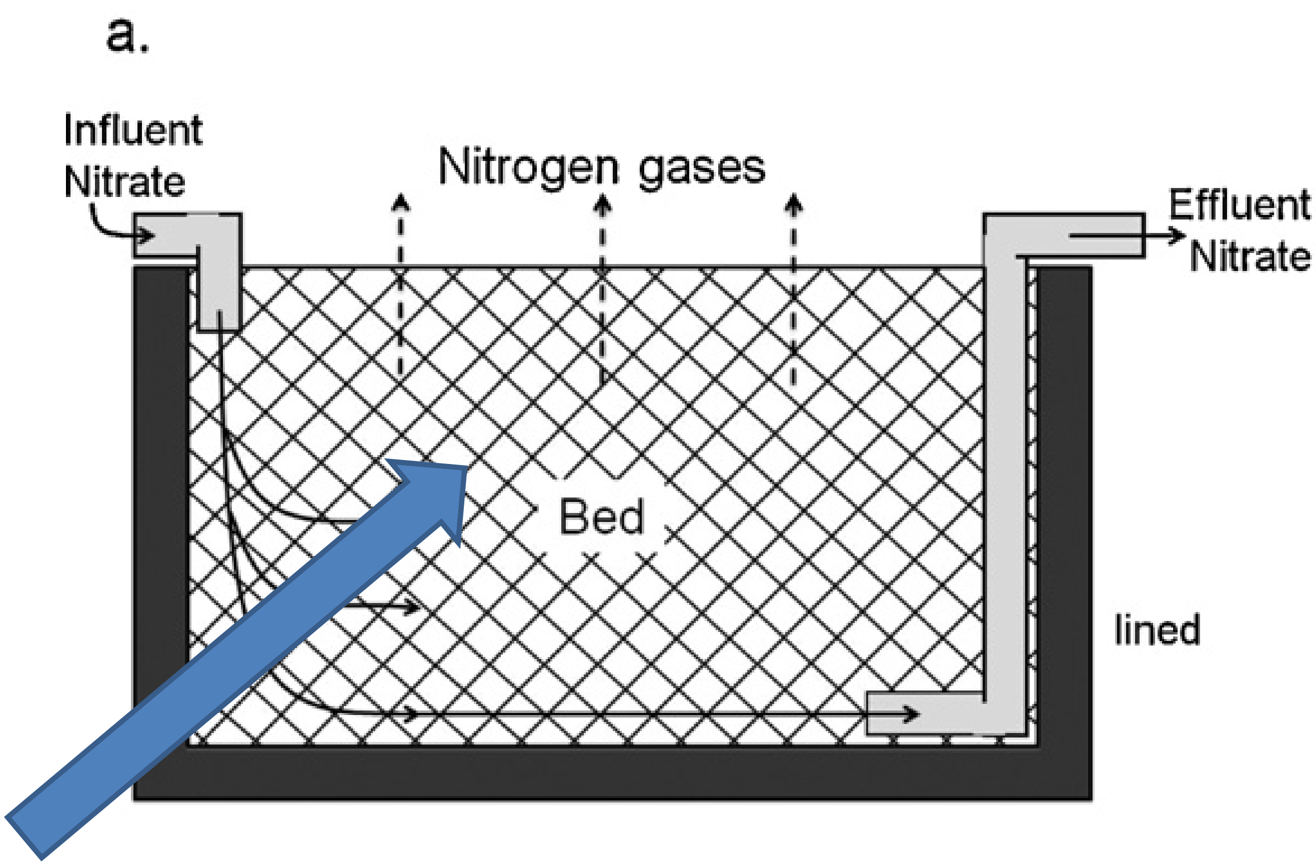
- By denitrifying microbes
- Requires carbon source for energy
- Absence of oxygen

- Common in water saturated environments such as wetlands and riparian zones but less so many agricultural ecosystems

Need a carbon source

And just add water … to make anaerobic
Add nitrate to promote denitrification

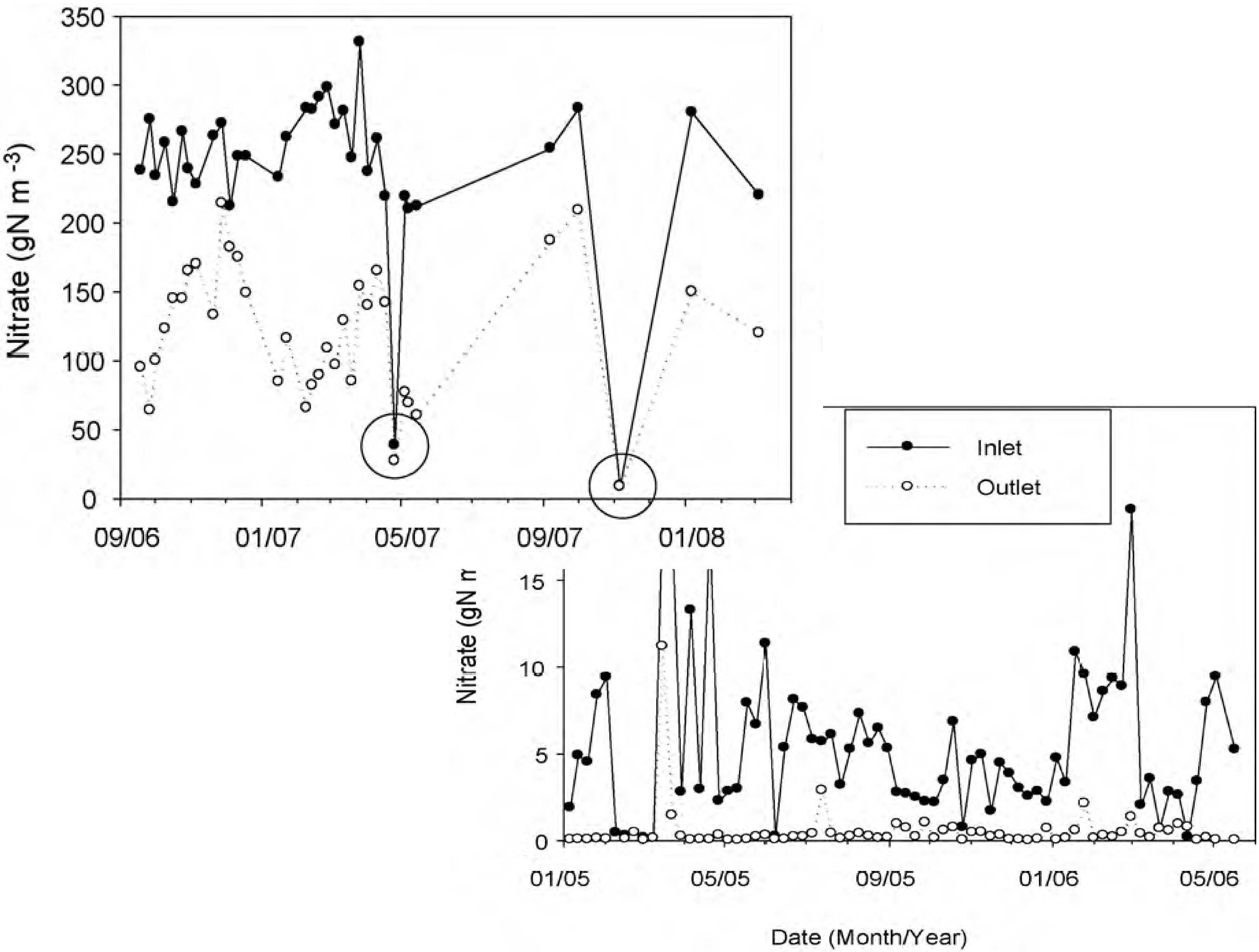
Simplest form – denitrification bed



Woodchips/sawdust/corn cobs

Wastewater

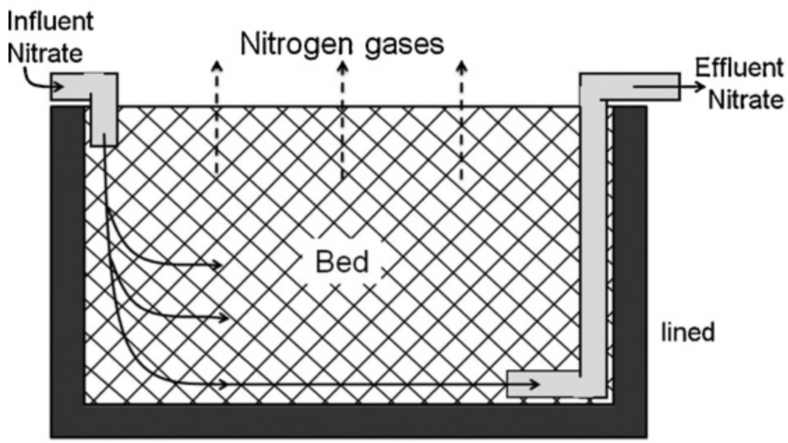
Harold Leverenz, UC Davis



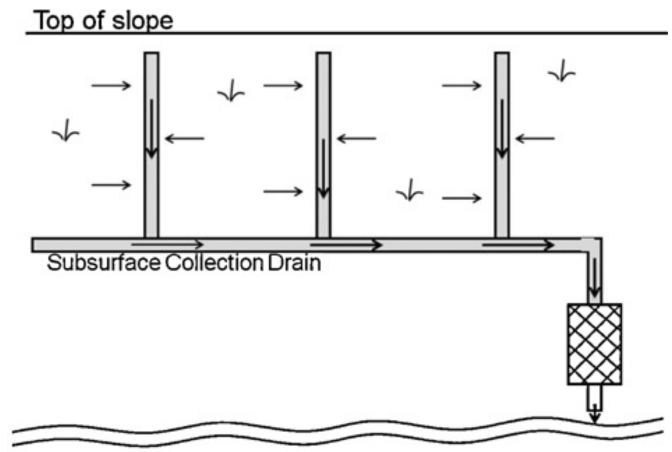
Nitrate (gN m -3)
350
300
250
200
150
100
50
0
09/06
01/07
05/07
09/07
01/08
Inlet
Outlet
Nitrate (gN m
15
10
5
0
01/05
05/05
09/05
01/06
05/06
Date (Month/Year)

Can be placed in different environments…

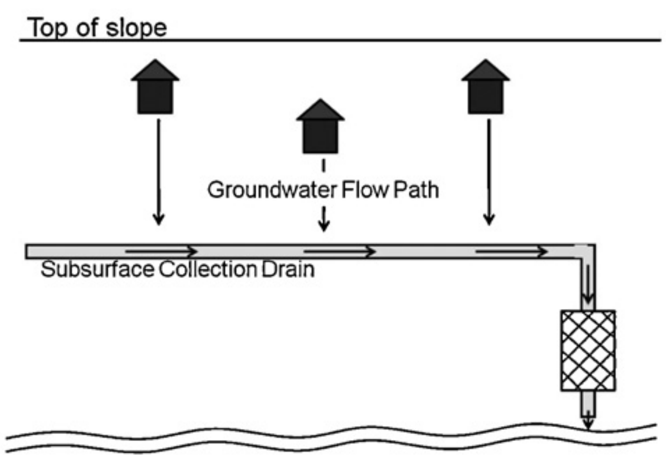
a.



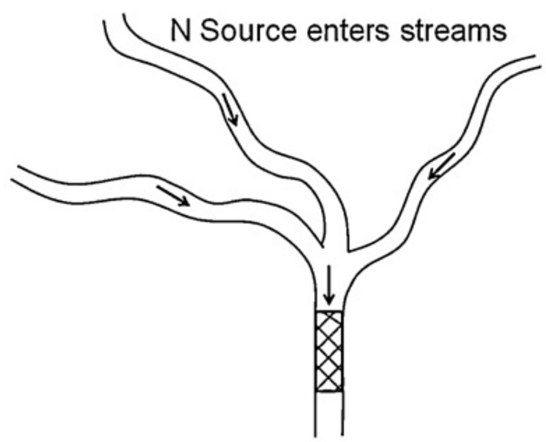
b.



c.



d.



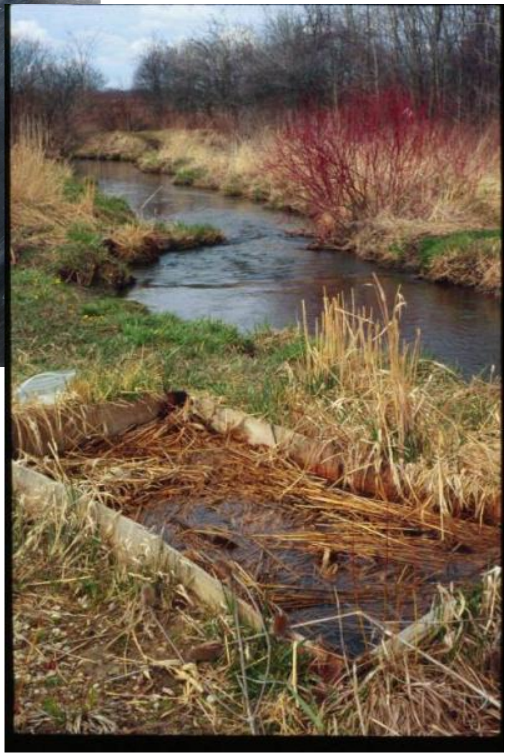
Tile Drainage

Wood chip bioreactor on a tile line draining 50 acres. Mark David

Iowa soybean growers – tile drains
Photo Stewart Cameron

Streams

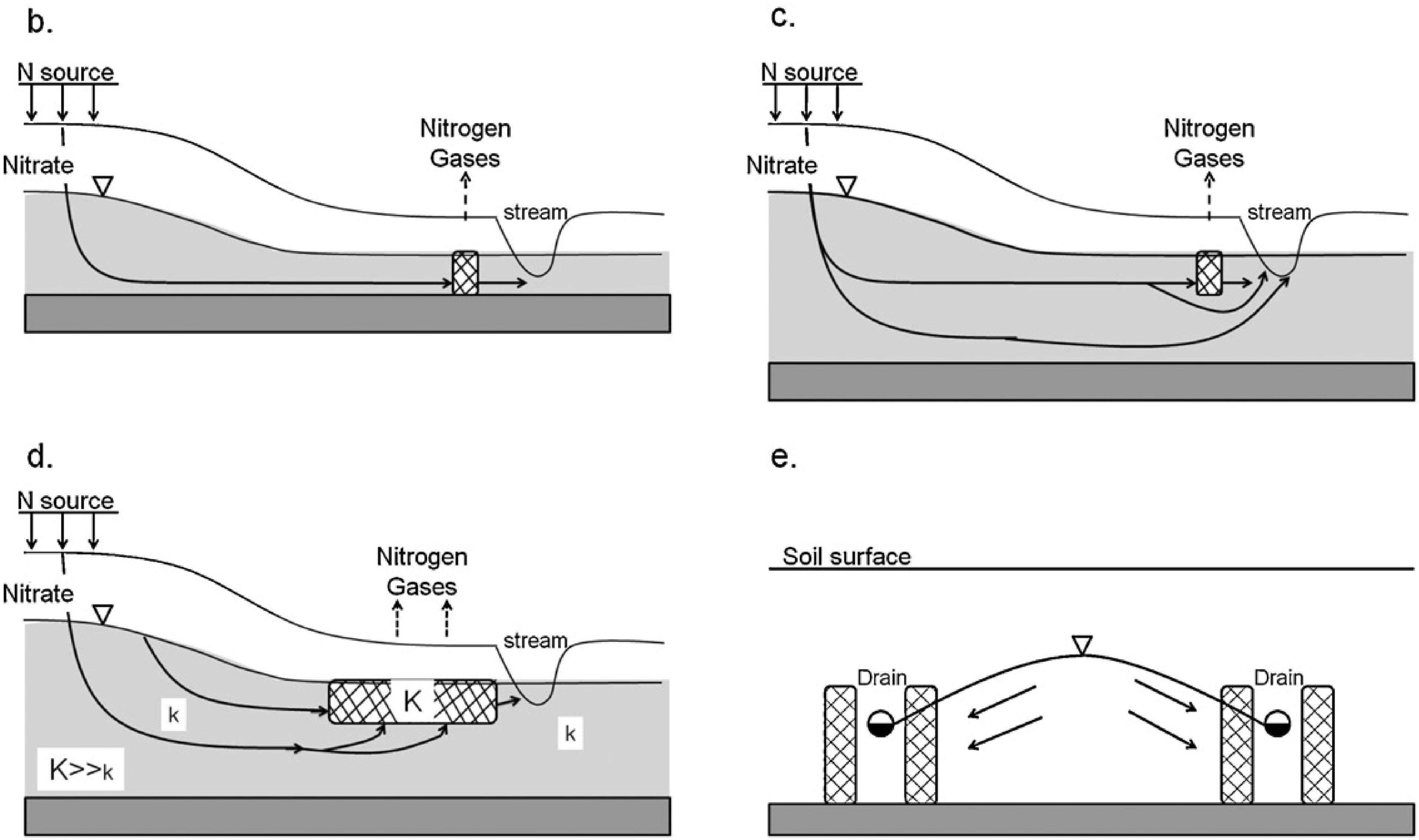
Tikitere a bioreactor
coupled to a stream

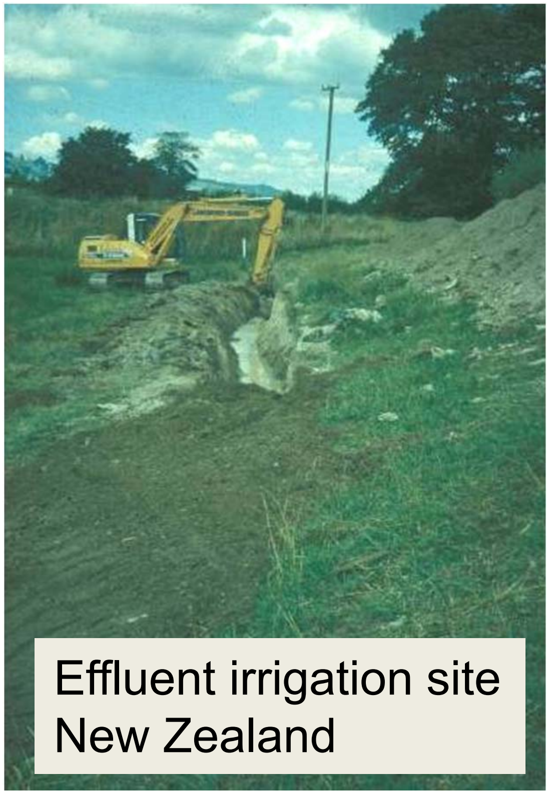


Will Robertson, Canada

Intercepting a stream entering
Lake Rotoehu, New Zealand.

Or restructured to intercept groundwater: Denitrification walls

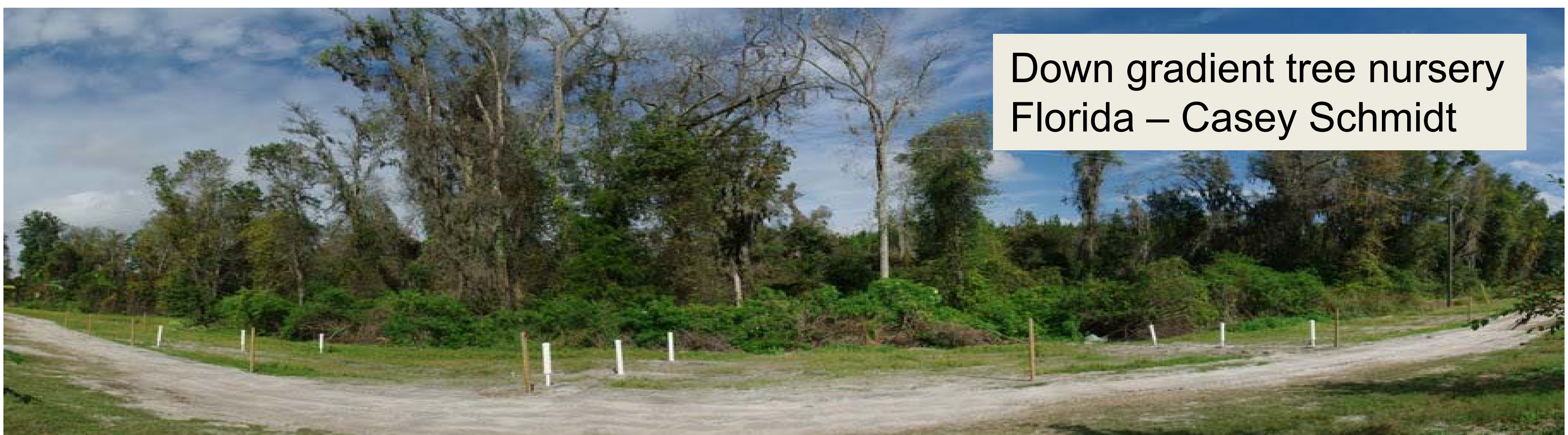




Effluent irrigation site
New Zealand

Tile drained corn
Iowa – Jaynes et al

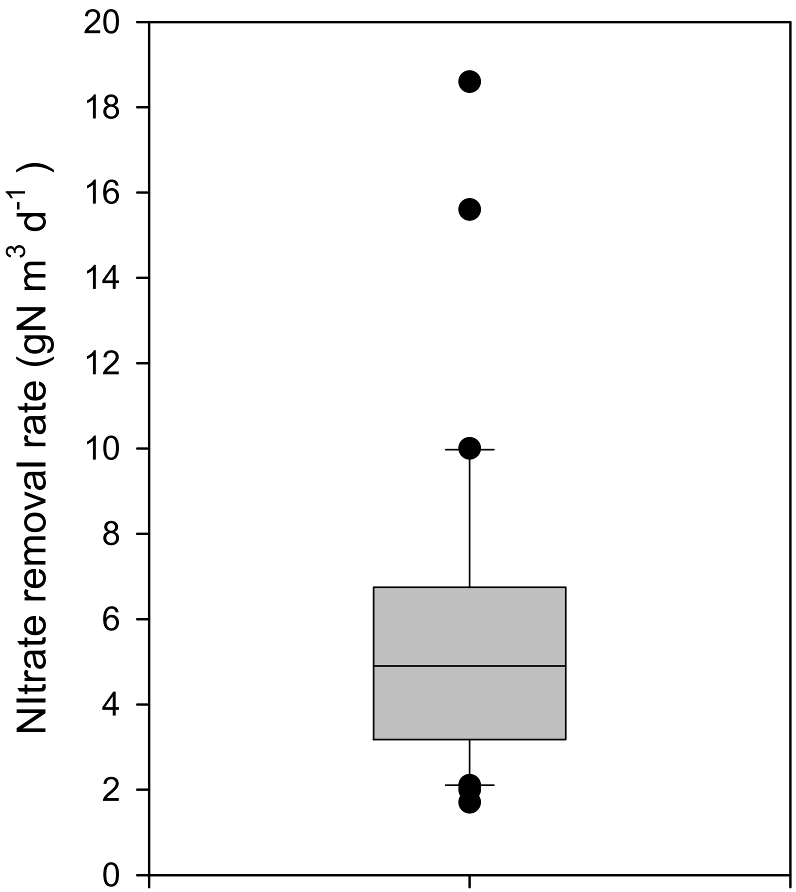
Fertilizer plume
New Zealand



Down gradient tree nursery
Florida – Casey Schmidt

Rates of N removal

- Geometric mean of 3.4 g m^{-3} d^{-1}
- Range probably due to range of nitrate concentrations, ages carbon stocks, and temperature



Adapted from Schipper et al 2010

Subsequent rates: N non-limiting

Author	Bed/wall	Size (m3)	Rate (g/m3/d)
Warneke et al 2011 Ecol Eng 37: 511-522	Bed NZ woodchip	1320	4.6 – 11.2 Mean = 7.6
Christianson et al 2011 Ag Water Manage 99:85-92	Bed NZ woodchip	0.5	6.7
Tanner et al 2012 Ecol Eng 42: 112-123	Bed, NZ woodchip	1.1	3 – 5.1
Schmidt and Clark 2012 Ecol Eng 42: 203-211	Wall, Florida	168	4.9 – 5.5
Average			5.9

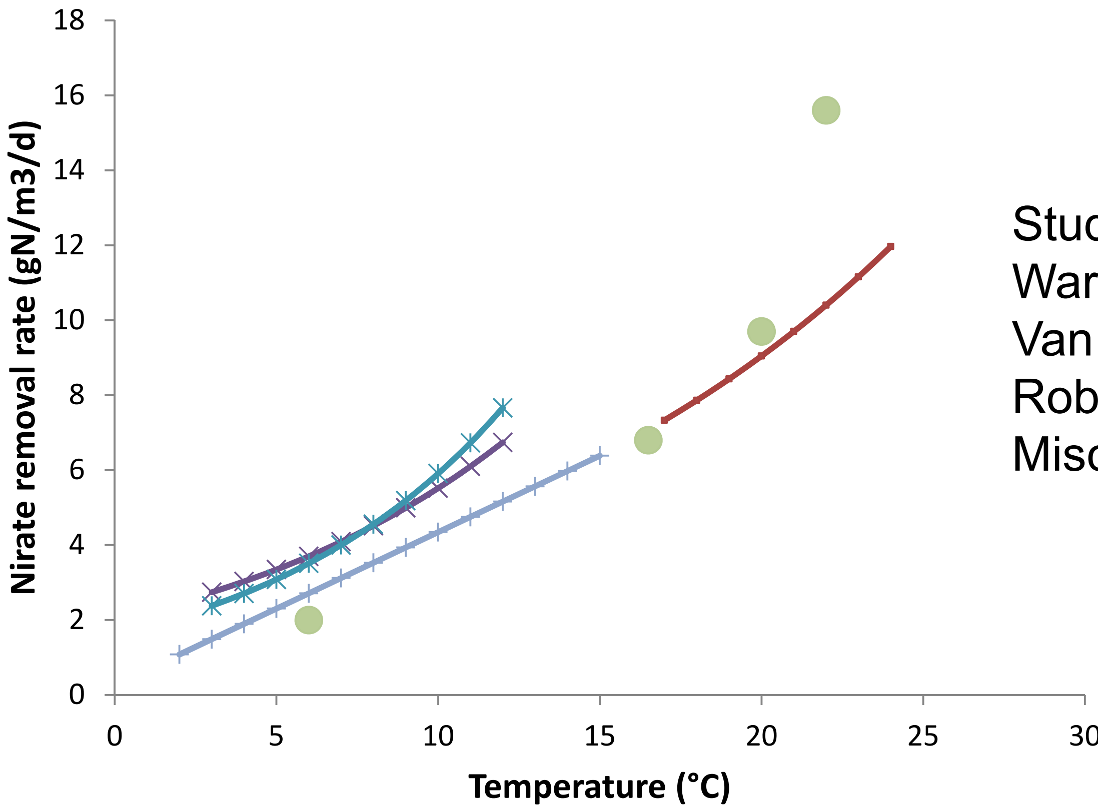
Factors controlling nitrate removal rates and denitrification

- Temperature
- Nitrate
- Carbon
- Absence of oxygen which inhibits denitrification

- But not microorganisms, which seem to be self-seeding

Temperature

Other factors non-limiting in field studies



Studies:
Warneke et al 2011
Van Driel et al 2006
Robertson and Merkley 2009
Misc point studies

Roughly, as temperature increases by 10 °C rate increases 2 fold

Nitrate concentration

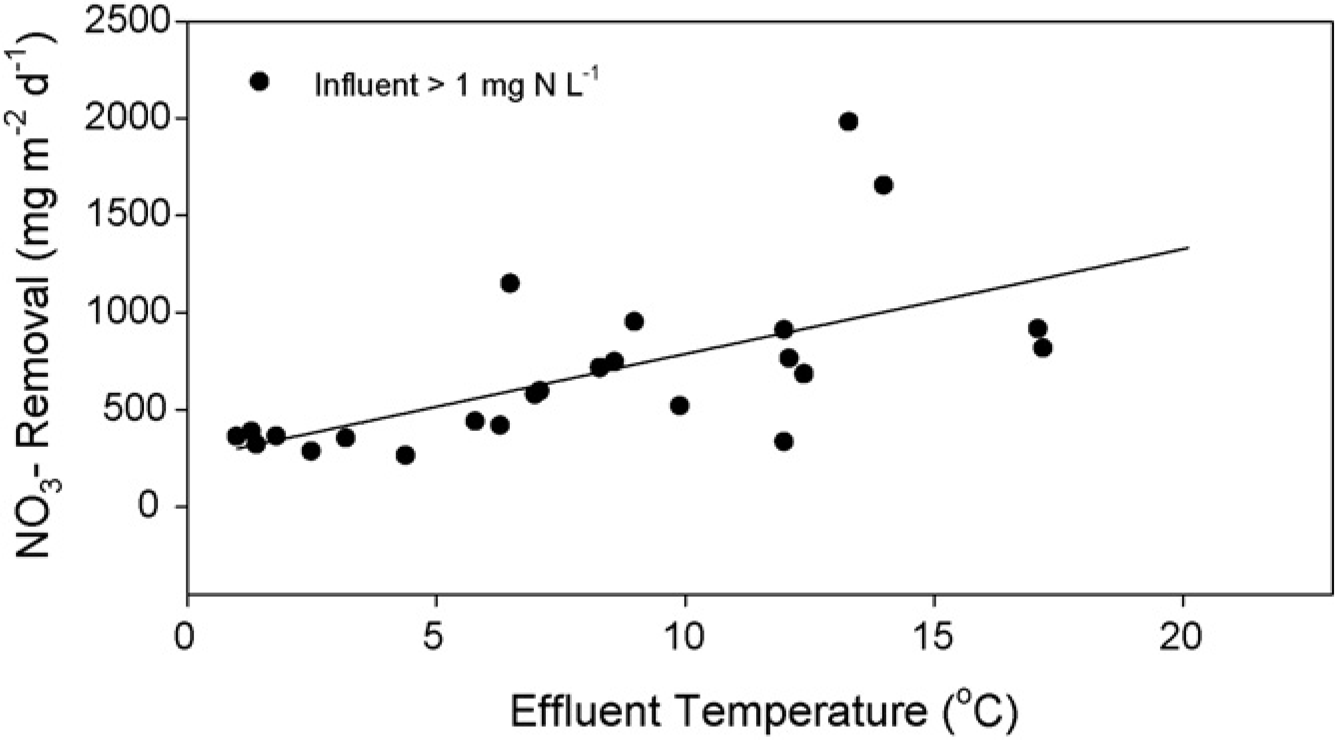
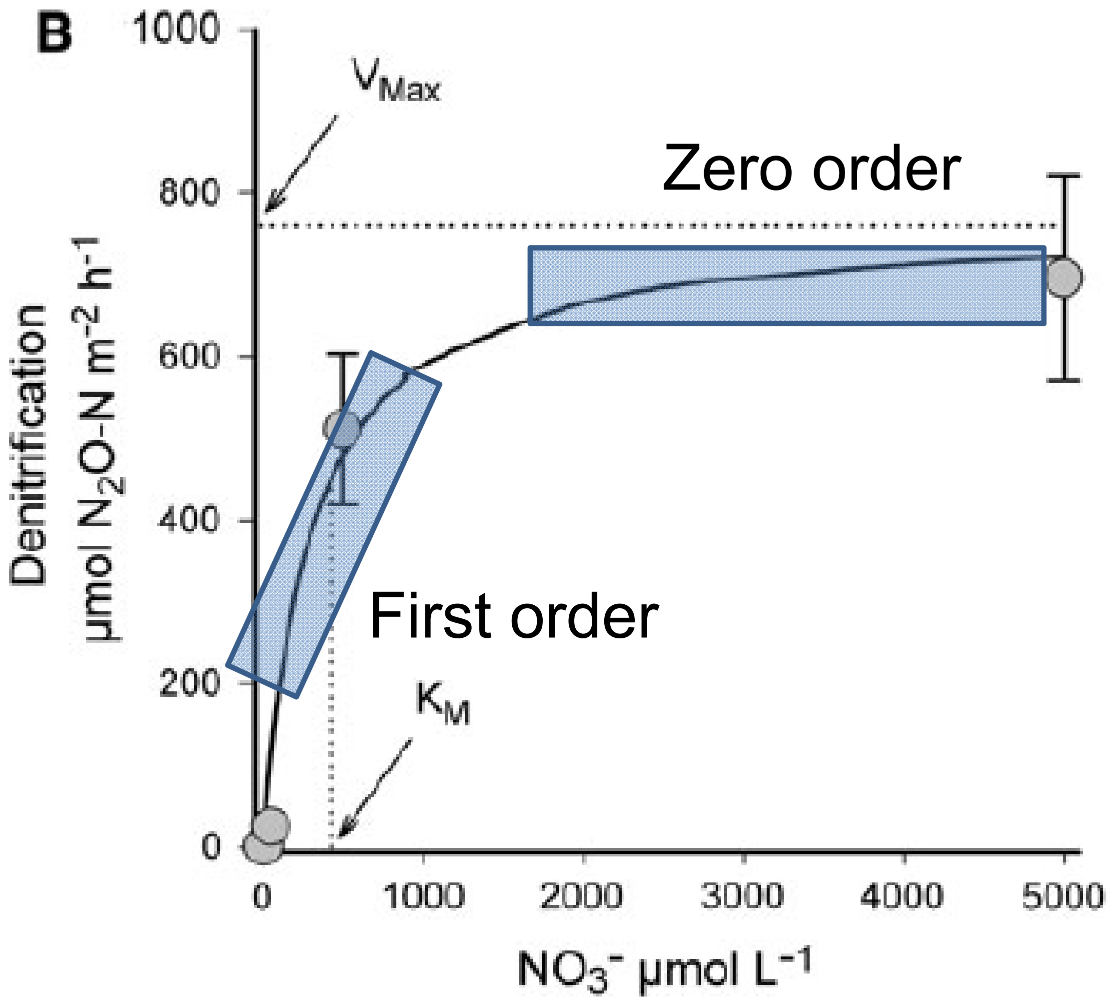


Fig. 3. Relationship of NO_3^- mass removal rate (area-normalized) and effluent temperature. Linear regression line (y=246+54x, r2 = 0.39) does not include sampling events with low stream NO_3^- values (<1mg N L^{-1}).

Elgood et al. 2010 Ecological Engineering *36 (2010) 1575–1580*

Nitrate concentration and nitrate removal



Reported Km vary between 0.2 and 6 mg N/L

Very poorly quantified

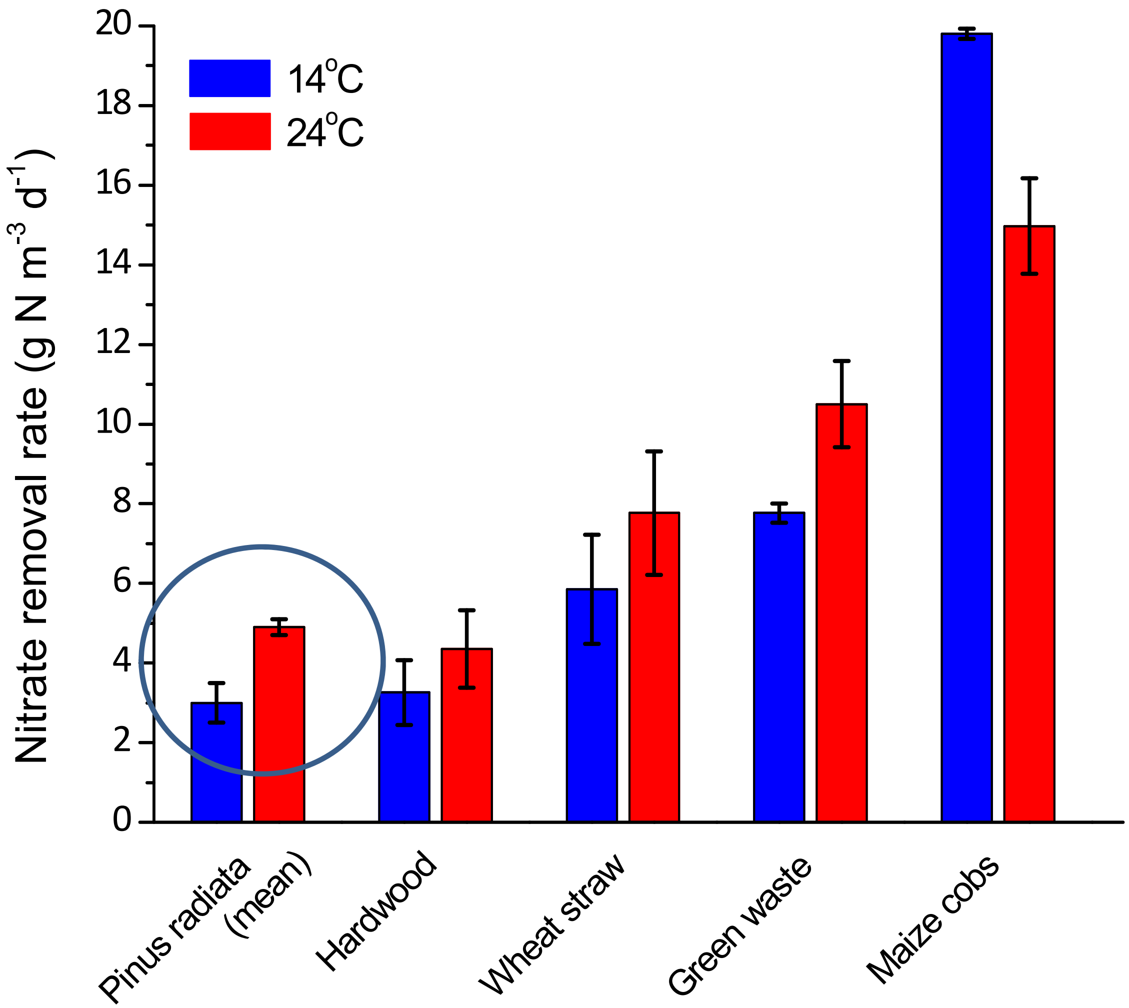
Biogeochemistry (2012) 108:39–54
DOI 10.1007/s10533-011-9571-5

Carbon source

- Sawdust/woodchip – different sizes
- Hardwood vs softwood
- Corn/Maize cobs
- Others – newspaper

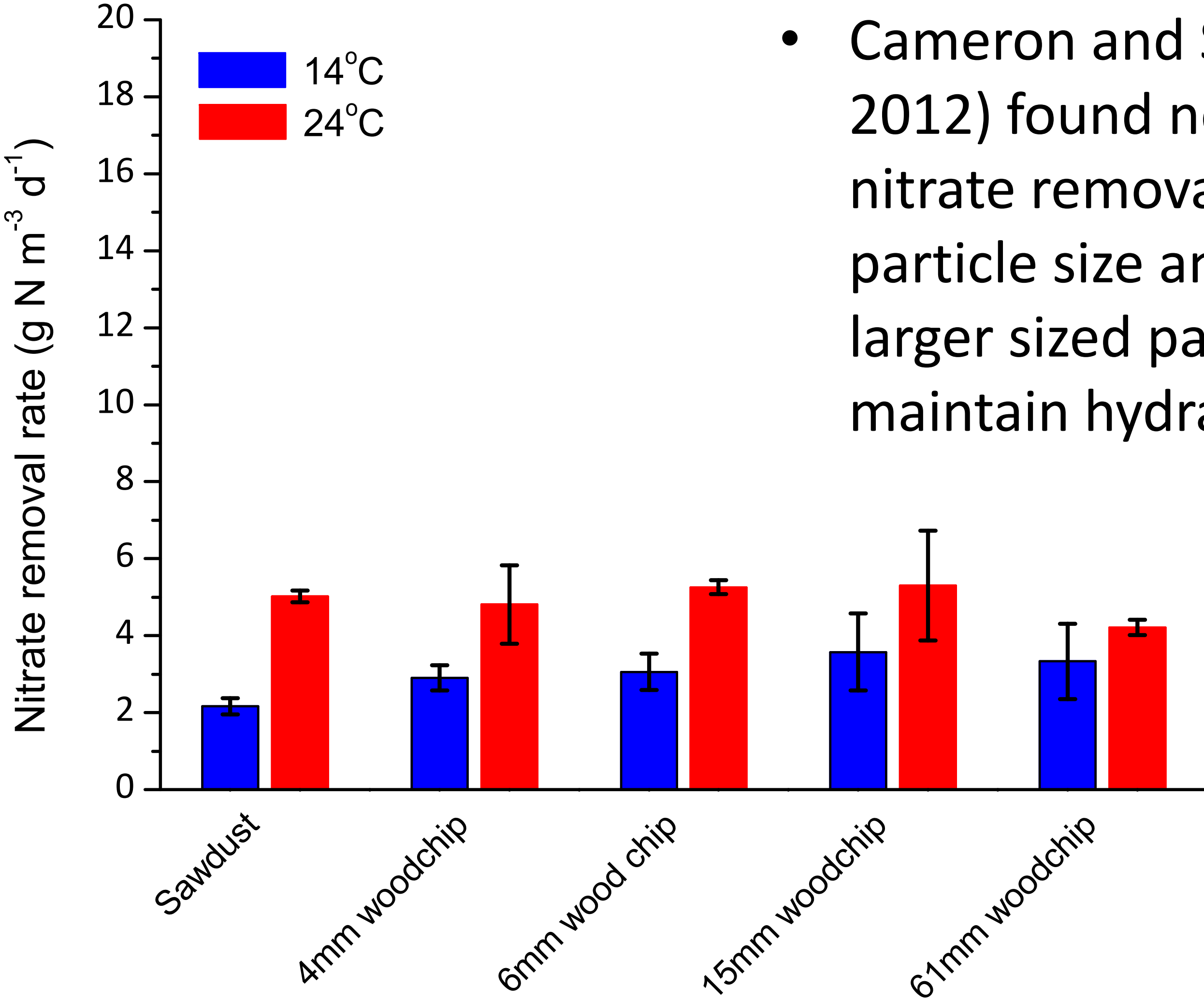
- Many tested in lab based mesocosms ($<1m^3$) and relatively short term

Different carbon compounds



Cameron and Schipper 2010

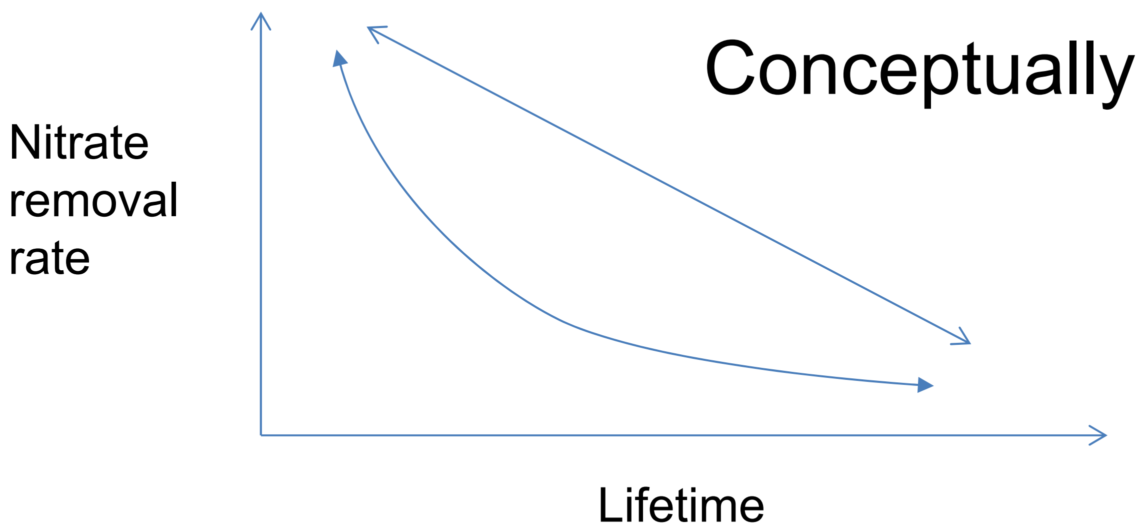
Particle size



- Cameron and Schipper (2010, 2012) found no differences in nitrate removal with increasing particle size and suggested that larger sized particles be used to maintain hydraulic conductivity

Carbon compounds

- What do you have at hand? Cost?
- How much nitrate will it remove?
- How long will it last?



Lifetime - woodchips

- Running in field
  - 15 years, Canada (Robertson et al 2008)
  - 14 years, New Zealand (Long et al 2011)
  - 9 years, Iowa (Moorman et al 2010)
- Estimated by extrapolation
  - Busselton, Western Australia estimated 20 year (Fahrner 2002)
  - Auckland, New Zealand lifetime of 39 years (Warneke et al 2011)
  - Cambridge, NZ half-life of carbon was 11 years (Long et al 2011)

Costs

- Depends on access to wood chips or similar and cost of creating hole, lining and flow structures and assumed life time
  - Jaynes in Schipper et al (2010) estimated cost of nitrate removal of about $2-15 (USD) per kg N
  - Schmidt and Clark (2012) estimated $3.85 (USD) per kg N removed assuming 20 year lifetime
  - There are likely now many more costing available and we probably need to consolidate these

Adverse effects and mitigation

- Greenhouse gases N_2O, CH_4, CO_2
- Dissolved carbon leaving bed
- H_2S – possible health hazard
- Methyl mercury

Conclusions and gaps?

- Rates around 5-7 g N m^{-3} d^{-1} between 10 and 15°C but really depends on temperature?
  - Need to quantify temperature / removal rate relationship
- But there is also a nitrate dependency
  - What is the Km value? ~1 to 4 mg N L^{-1}?
  - Needed for nitrate removal estimate but also to avoid adverse effects N_2O and perhaps methyl mercury
- Wood chips most commonly used, are other carbon compounds worth it for higher rates?
  - Trade-off with longevity
  - Field trials needed

Conclusions and gaps?

- Longevity is decadal when using wood chips
  – Need to determine decline in performance with time
- Costs need to be summarised better
- As always need to have hydraulic connections well worked out