**Project number:** 5814
**Funding source:** DAFM
**Date:** November, 2013
**Project dates:** Dec 2007 - Jun 2012

# Agri-engineering solutions for remediation of nutrients in water

RUNOFF COLLECTION DRAIN

DRAINAGE COLLECTION

## Key external stakeholders:

Farmers, Department of Agriculture, Food & Marine, Environmental Protection Agency, County Councils, food industry

## Practical implications for stakeholders:

Land drainage is an important component of grassland agriculture and is vital to increase or maintain productivity. Matching global trends, Irish drainage systems will continue to be modernised and maintained on existing lands. From a production perspective it is a good idea to drain suitable lands in Ireland and land drainage will help achievement of goals set out in Food Harvest 2020. There are cases where nutrients and gases will be lost but the research is now in place to mitigate such losses before they have a deleterious effect on the environment. Soil type, water table depth or field size are important controls on nutrient losses to water and air from Irish grasslands. With this in mind, artificial drainage "tailored" to local conditions (e.g. drain designed to intercept permeable layers) is likely to better reduce nutrient losses than standard designs. Denitrifying bioreactors placed as "end of pipe technologies" are efficient at reducing leaching of Nitrate ($NO_3$) by enhancing its microbial reduction to benign Di-Nitrogen gas.

- **Farmers:** On-farm drainage works need to be tailored to site specific conditions.
- **Policy makers:** Metrics and frameworks are needed to quantify both environmental and productivity costs and benefits in drained grasslands. The design of novel green technologies to achieve environmental sustainability is a unique opportunity for the Irish Agri-tech sector.
- **Scientific:** Achieving environmental sustainability in drained grassland requires a holistic understanding of the linkages between hydrologic, soil chemical and physical processes controlling the fate of nutrients in drained systems.

## Main results:

- In drained grassland, a decrease in plot size and water table depth increases nutrient losses per unit area in overland flow and decreases P bioavailability; ammonium and $NO_3^-$ are higher in overland and subsurface drainage flow, respectively; Nitrous Oxide emissions increase downslope.
- Denitrifying bioreactors placed at the end of drainage outlets are efficient at remediating Nitrate using a variety of organic carbon media. Pollution swapping increases with increasing water transit times and carbon media surface area.

## Opportunity/Benefit:

- Environmental sustainability can be achieved with site-specific drainage and remediation solutions.

## Collaborating Institutions:

NUI (National University of Ireland), Galway
University of Sheffield, UK



Contact Dr. Owen Fenton Email: owen.fenton@teagasc.ie.

**Teagasc project team:** Dr. Owen Fenton
Dr. Tristan Ibrahim

**External collaborators:** Dr. Mark Healy (NUIG)
Reader Steve Thornton (University of Sheffield)

## 1. Project background:

Food Harvest 2020 has set ambitious goals for Irish agriculture by targeting an increase in productivity while maintaining the protection and enhancement of the natural environment. This dual approach is summarised in the concept of "sustainable intensification". One of the greatest challenges facing the farming sector is the need to increase land drainage, to expand farming to the wettest months, improve yields in existing fields and develop farming on marginal lands. Because drainage has the potential to reduce the nutrient attenuation capacity of the soil and increase greenhouse gas emissions through an increase in fertiliser applications and a modification of the soil saturation and permeability, research needs to focus on 1) identifying the most environmentally sustainable drainage designs and 2) developing novel technologies to remediate "unavoidable" nutrient losses from drainage systems. As a starting point, this project aimed at testing the environmental sustainability of uniformly drained grasslands and the performance of an existing remediation technology (i.e. Denitrifying bioreactor) which could alleviate nutrient losses from such drained lands.

## 2. Questions addressed by the project:

- What are the physical controls on nutrient losses to water and to the atmosphere in uniformly drained grasslands?
- Are Denitrifying bioreactors a viable solution to increase the environmental sustainability of drained grassland?

## 3. The experimental studies:

- At the Teagasc Environment Research Centre (Co. Wexford), four drained grassland plots (0.4 and 0.8 ha, uniform 1 m deep piped drains arranged in a herring bone network) with similar soil types over glaciated tills, minimal fertiliser inputs and no grazing, were monitored for more than a year. Water generated by the plots as overland flow and subsurface drain flow was collected at the bottom of the slopes, where flow was continuously monitored and water sampled to quantify nutrient losses in these two pathways. In addition, GHG emissions to the atmosphere were regularly monitored using static chambers.
- A laboratory column study was setup with four different carbon media (Lodgepole needles (LPN), Lodgepole woodchip (LPW), Cardboard and Barley Straw (BBS)) mixed with soil and loaded with a solution containing 19.5 to 32.5 mg $L^{-1}$ of $NO_3$-N at a hydraulic loading rate of 3 cm $d^{-1}$ for several hundreds of days. Hydrochemistry and dissolved gas concentrations were sampled at the inlet and outlet, and at ports along the columns.
- A semi-controlled field experiment was set up at the Teagasc Environment Research Centre. A 9 x 3 x 1.5 m tank divided into 7 interconnected cells was filled with sand and woodchip. Nitrate spiked water (up to 36 mg $L^{-1}$ $NO_3$-N) was circulated at a flow rate of circa 0.2 $m^3$ $d^{-1}$, and hydrochemistry and GHG emissions monitored along flow paths using a network of multi-level samplers and static chambers. Also, a microbial and molecular characterisation of pore-water, sand and woodchip was undertaken.

## 4. Main results:

In such a uniformly drained system, one would expect water and nutrient losses to be very similar across plots. Instead, results showed that the inherent differences in the physical characteristics of the plots had a predominant impact on such losses. Smaller plots with shallower water table could generate more than twice more nutrient losses in overland flow per unit surface area than larger plots with a deeper water table. This occurs as there are lesser opportunities for water to infiltrate into the soil where the slope is shorter or the depth of the water table limits the storage capacity of the soil. In contrast, GHG emissions were very similar across plots, and only increased within each plot towards the bottom of the slope, as a result of the decrease in water table depth. This is important as vegetated riparian buffers are implemented in these areas to intercept sediment and phosphorus losses in overland flow. Also, the water table depth influenced the make-up of the nutrient pool in water, with less bioavailable forms of phosphorus being more abundant in areas of shallow water table, and Ammonium and Nitrate being more abundant in overland and subsurface drainage



Contact Dr. Owen Fenton Email: owen.fenton@teagasc.ie.

flow, respectively.
Our preliminary experiments using laboratory Denitrifying bioreactors showed that several carbon media (e.g. woodchip) were able to remove >99% of Nitrate in slow moving water. Such good performances were counterbalanced by "pollution swapping", i.e. the production of other contaminants inside the bioreactor, either in water (e.g. Ammonium and Phosphorus) or as GHG. Results from the semi-controlled field experiment showed that dividing the bioreactor in several cells was efficient to manipulate water transit times and regulate flow path length in order to achieve full Denitrification with limited pollution swapping. Nevertheless, even in the area of full Denitrification, pollution swapping was observed as $N_2O$ emissions originating from shallow flow paths, as well as Ammonium and Phosphorus produced in deeper flow paths with longer transit times. Hence, this design should be complemented by additional remediation sequences, such as a biochar cap to reduce Nitrous Oxide emissions in the area of Denitrification, or a zeolite cell allowing for Ammonium or Phosphorus sequestration. Such multi-remediation technologies are the way forward, as they can minimise pollution swapping while remediating mixed contaminant sources (e.g. Ammonium and Phosphorus in addition to Nitrate). Also, they offer the potential for enhancing nutrient efficiency in farms, by nutrient stripping and recycling (e.g. nutrient saturated zeolite can be spread back into the land as a fertiliser). Internationally, the woodchip bioreactor and the additional reactive media sequences are separated on the landscape but it is our research goal to merge them into a single remediation technology termed a "permeable reactive interceptor" targeting artificial drainage and spring outlets.

## 5. Opportunity/Benefit:

Drainage installation will continue but with associated environmental sustainability.

## 6. Dissemination:

The results of the project have been presented at national and international conferences. There are three scientific papers published and a number of other papers in preparation. The outputs from the project have been sent to relevant national policy makers.

### Main publications:

Fenton, O., Healy, M.G., Brennan, F., Jahangir, M.M.R., Lanigan, J., Richards, K., Thornton, S., Ibrahim, T.R. (2014). Permeable reactive interceptors – blocking diffuse nutrient and greenhouse gases losses in key areas of the farming landscape. *Journal of Agricultural Science*, in press

Healy M.G., Ibrahim T.G., Lanigan, G., Serrenho, A. and Fenton, O. (2012). Nitrate removal rate, efficiency and pollution swapping potential of different organic carbon media in laboratory Denitrification bioreactors. *Ecological Engineering,* 40, 198-209.10.1016/j.ecoleng.2011.12.010

Ibrahim, T.G., Healy, M.G., Richards, K.G., Fealy, R.M. and Fenton, O. (2013). Spatial and temporal variations of nutrient loads in overland flow and subsurface drainage from a marginal land site in South East Ireland. *Biology and Environment,* 113B (2), 1-18. 10.3318/BIOE.2013.01

### Popular publications:

Ibrahim, T.G., Fenton, O. (2013). Drain, drain, sustain. *TResearch* (Winter)

## 7. Compiled by: Dr. Tristan Ibrahim



Contact Dr. Owen Fenton Email: owen.fenton@teagasc.ie.