ANNEX 3: NAP REQUESTED RESEARCH

1. Impact of Spreading in October and February

Two projects have been initiated to analyse an existing database of weather and soil factors that may influence surface runoff and bypass flow to drains which are recognised as being major pathways of nutrient loss. The general aim is determine a predictive capacity to determine the susceptibility of grassland soils to both surface runoff and drain flow as these are major nutrient loss conduits.

Project 0303: Hydrological characterisation of a typical drained grassland soil

Project aim: To characterise the hydrological transport behaviour of a typical drained grassland soil and to determine the relative importance of specific hydrological flow paths and establish relationships between precipitation, soil moisture status and discharge from a typical drained grassland.

The accurate prediction of overland flow requires an understanding of the hydrological processes that control its occurrence over a range of spatial and temporal scales. This study is investigating the factors controlling the initiation of overland flow from a drumlin grassland hillslope and to determine if soil moisture deficit (SMD) could be used as an accurate predictor of the occurrence of overland flow from the site.

Runoff initiation: Fine scale monitoring of soil moisture, rainfall and overland flow was carried out over a four year period from 2003 to 2006 at a drumlin grassland site at the CENIT experimental located at AFBI Hillsborough. Soil moisture has been monitored at four depths, 10, 20, 30 40cm in the soil profile at 30 minute intervals at six locations in plot 6 of the CENIT site. A continuous weather station at the site provides data on rainfall and evaporative losses. Overland flow and subsurface drain-flows were continuously recorded from this plot. Datasets of soil moisture, subsurface flow, overland flow and rainfall have been merged and data analysis carried out. Analysis of the data has focused on identification of threshold values at which overland flow occurs at the site. One peer review publication arising from this analysis has recently been accepted for publication (pending minor changes) in the Journal of Soil Use and Management.

The data was analysed by means of logistic regression to identify the factors controlling the initiation of overland (Table A). In addition, the relationship between the observed volumetric water content (VWC) and predicted SMD was analysed compared with predictions based on two models that have been developed to predict soil moisture. The first is MORECS (Met Office Rainfall and Evaporation Calculation System), which aims to provide a reliable UK-wide assessment of general soil moisture status (Figure A). The second model was developed by Schulte *et al.*, 2005 for Irish soils (Figure B).

Table A: Significant independent variables in the logistic regression models predicting the initiation of overland flow above and below 0.40 m^3 m^{-3} soil moisture content

Soil Moisture (m^3 m^{-3})	Independent Variable	Exp (B)
< 0.40	Av. Intensity (AI) ***	6.2×10^{27}
	SMD**	1.045
	Total Rainfall (T) **	0.178
≥ 0.40	Soil Moisture***	2.5×10^{8}
	Av. Intensity (AI)**	591.1
	Max Intensity***	1.9

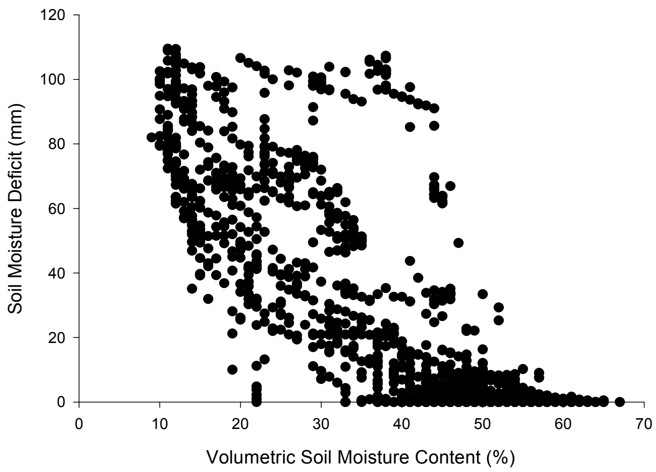

Figure A: **Relation between observed volumetric soil moisture content of a drumlin soil predicted the SMD as calculated using the MORECS equation**

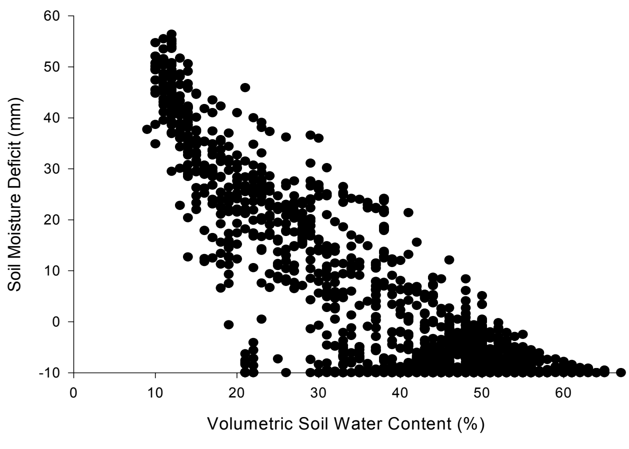

Figure B: **Relation between observed volumetric soil moisture content of a drumlin soil and the predicted SMD** as calculated using the model of

Schulte *et al.* (2005) *Predicting the soil moisture conditions of Irish grasslands. Irish Journal of Agricultural and Food Research* ***44*** *95- 110*

The results from this study have demonstrated that 80% of overland flow events at this site can be classed as saturation excess overland (Figure C). However, small volumes of overland flow also occurred during periods of low volumetric soil moisture content, indicating the occurrence of infiltration excess overland flow.

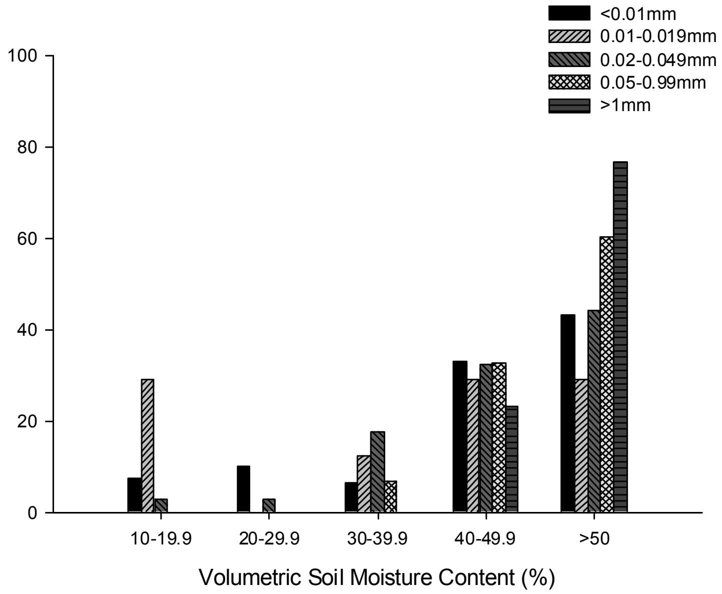

Figure C: **Percentage of overland flow events occurring from a drumlin grassland soil over a range of volumetric soil moisture contents**

The results of the logistic regression analysis indicated that for previously dry condition, when the soil moisture was below field capacity, rainfall intensity was the dominant variable controlling the initiation of overland flow during dry periods (Table A). The results also demonstrate that under current climate conditions the SMD models investigated during this study have limitations as indicators of the risk of overland flow and/or for determining the suitability of soil condition for slurry spreading. The predicted increase in high intensity rainfall events due to climate change will result in overland flow occurring over a wider range of volumetric soil moisture content. These changes would pose challenges for the continued use of SMD as an indicator of the risk of overland flow.

Although the resulting volumes of infiltration excess overland flow are small, these results have important implications for the prediction of overland flow, when considered in the context of the potential impact of climate change on soil hydrology (Figure C). The predicted increase in high intensity rainfall events due to climate change will result in overland flow occurring over a wider range of volumetric soil moisture content.

Hydrophobic soils: A factor which may be influencing surface runoff is the hydrophobicity of soils, which is a recognised phenomenon in organic soils, especially when they become dry. In simple terms, such soils are hard to wet as they repel water and as a consequence infiltration into the soil can be low even if the soil has a significant soil moisture deficit. This in turn may lead to surface runoff. Two MSc projects undertaken in summer 2008 investigated the extent of hydrophobicity in soils in Northern Ireland and at CENIT in particular.

To investigate the extent of soil water repellency (SWR) in Northern Ireland, soil samples from the CENIT site and 20 of the main soil series in Northern Ireland, (accounting for 33% of the total land area) were tested for potential water repellency using the Water Droplet Penetration Test (WDPT). Of the 20 soils sampled, 15 exhibited some degree of water repellency (Table B) with moderately and extremely water repellent soils account for 16% of the total land area of Northern Ireland. The occurrence of infiltration excess overland flow at low rainfall intensities (Figure D) at the CENIT site highlights the potential role that SWR plays in the generation of overland flow in affected soils. These results indicate that a significant area of Northern Ireland is affected by SWR which would have implications for the occurrence of surface runoff in these soils.

Table B: SWR of 20 major soils in Northern Ireland measured using the WDPT

Soil Series	WDPT Class	Persistence rating
Loughall Limestone- brown earth	0	Wetable
Mica-schist till-brown earth	0	
Mica-schist till-SWG1	0	
Shale till-brown earth	0	
Shale till-SWG1	0	
CENIT Site – Shale till-SWG1	1	Slight
Basalt till-brown earth	1	
Red Triassic sandstone till-brown earth	2	
Carboniferous limestone till-brown earth	2	
Granite rock-brown podzolic	2	
Red Triassic sandstone till-SWG1	3	
Basalt till-SWG1	3	
Calp till-SWG3	3	
Basalt till-SWG2	4	Moderate
Carboniferous limestone till-SWG1	4	
Granite till-SWG1	4	
Shale till-SWG2	5	
Calp till-SWG2	6	
Old Red Sandstone till-SWG1	9	Extreme
(Mica-schist till-SWG2) Mica-schist till-SWHG	10	
Old Red Sandstone till-brown earth	10	

The results from the WDPT test indicated that the soils sampled from the CENIT are slightly water repellent (Table B). However, when this soil type (Shale till-SWG1), was sampled at a different location in NI, the results from the WDPT indicated that the soil was not water repellent. These results could indicate that soil water repellency varies temporally and spatially due to land-use factors and distribution of SWR compounds in the soil and so differences in the results for the Shale till-SWG1 at two locations in NI is not unexpected.

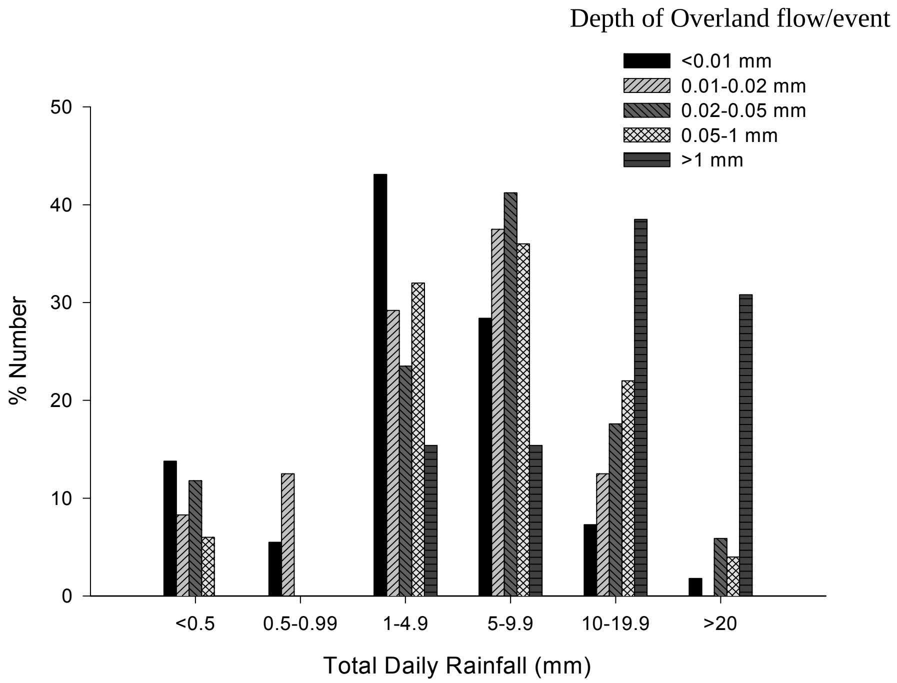

Figure D: Percentage of overland flow events occurring from a drumlin grassland soil over a range of total daily rainfall depths

To further investigate factors controlling the temporal and spatial variations in SWR, the WDPT test was carried out on soil samples from the CENIT site that were rewetted to 10%, 15%, 20%, 25%, 30%, 40% VMC. Following rewetting, each sample was tested for SWR using the WDPT method. Over an eight week period this process was repeated fortnightly on a new batch of soil from the CENIT site so as to investigate temporal variations in the threshold VMC at which SWR occurs. The results highlight the temporal variations in the severity of and VMC at which SWR occurred over the eight week sampling period (Figure E).

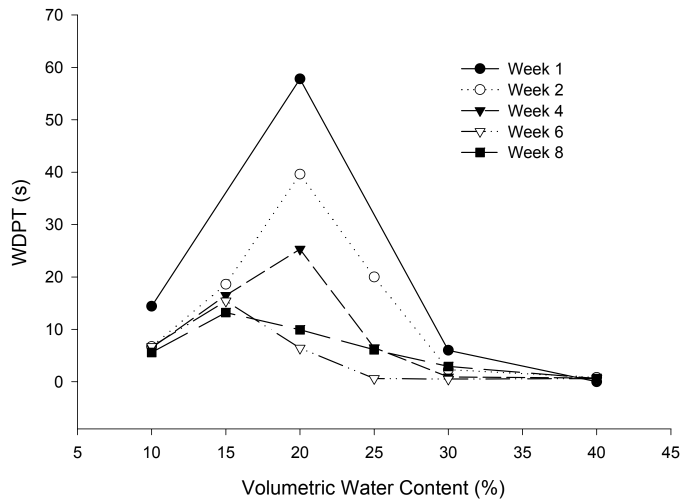

Figure E: Variation in the WDPT over a range of VMCs over an eight week sampling period

The eight week sampling period commenced at the end of an extended dry period with the first soil sample taken (Week 1) when VMC was close to 25%. Following sampling in Week 1, rain occurred frequently over the next eight weeks and the volumetric soil moisture content at the CENIT site increased to > 45%. Over this period the VMC, at which the peak in SWR occurred decreased from 20% to 15% moisture. Figure E also highlights the non-linear relationship between WDPT time and VMC and shows a VMC transitional zone over which SWR occurs to varying degrees. For Weeks 1, 2 and 4 a peak in SWR occurred at 20% VMC with SWR decreasing at VMCs above and below this value. Above VMC of 35% the soil was no longer water repellent. During Week 6 and 8 the peak in SWR decreased to 15% VMC further highlighting the temporal variation in the VMC at which SWR occurs in this soil.

The results obtained have demonstrated that SWR occurs in a significant number of soils in Northern Ireland and the occurrence of infiltration excess overland flow at low rainfall intensities at the CENIT site highlights the potential role that SWR may play in the generation of overland flow in affected soils. However, overland flow events during periods of low soil moisture have to date received little attention due to their limited hydrological significance but, due to the potential impact of climate change on soil hydrology and therefore the vulnerability of soils to phosphorus (P) losses during the summer and autumn, a better understanding of the factors controlling the frequency of overland flow during periods of low VMC is required. More accurate predictions of the frequency of overland flow events during the autumn and summer months has important implications for the effective management of agricultural nutrients and the development of mitigation measures to minimize P export from soils.

<u>Characterisation of organic P in overland flow from grassland plots using ^{31}P nuclear magnetic resonance spectroscopy:</u> The loss of P from agricultural sources has been shown to cause eutrophication in P limited freshwater

ecosystems. Grazing animals are known to change the characteristics of agricultural grasslands as a source of and pathway for P loss to water. The aim of this study was to characterise the organic P (Po) fraction in overland flow from small grazed and non-grazed grassland plots using phosphorus-31 nuclear magnetic resonance (^{31}P NMR) spectroscopy to give a greater understanding of P transfer to water using simulated rainfall.

Concentrations of total unreactive P (TUP), dissolved unreactive P (DUP), and particulate unreactive P (PUP), fractions mostly dominated by Po, as well as total P (TP), dissolved reactive P (DRP), total dissolved P (TDP) and particulate P (PP), were higher in overland flow from the grazed compared to the non-grazed grassland plots. The effect of the grazing animal was most pronounced in the DUP and PUP fractions measured in the overland flow, being over four times higher than from the non-grazed plots. Five distinct classes of P compounds were detected in the ^{31}P NMR spectra, inorganic orthophosphate (δ = 6.83 ppm), orthophosphate monoesters (δ = 4.95 to 5.69 ppm), orthophosphate diesters (δ = 1.89 ppm), phosphonates (occurring at δ = 19.38 ppm), and pyrophosphates (δ = -3.26 ppm). Distinct signals at 5.69, 5.37, 5.10, and 4.95 ppm in the extracts of the overland flow from both sites indicated significant concentrations of *myo*-inositol hexakisphosphate in the orthophosphate monoester region. The signal in the orthophosphate diester region (δ = 1.89 ppm) found only in the grazed plot overland sample could be assigned to the phospholipids, while phosphonates were also only detected in overland flow collected from the grazed plot. These results would indicate that normal grazing management practices may not only affect the concentrations of Po but also the forms of Po, potentially bioavailable, being transferred from grassland systems to water.

<u>Ongoing work:</u> Monitoring of soil moisture, runoff and rainfall will continue at the CENIT site. In June 2009 a short-term research project commenced to investigate the export of sediment and PP from grassland soil. Following on from this work an externally funded PhD project will start in September 2009 investigating the pathways and sources of sediment and PP at catchment scale. The modelling work will be expanded and tested against soil moisture and rainfall probability distributions typical of October and February in Northern Ireland. The model will also be linked to measured losses of P following applications of slurry to grassland soils at AFBI Hillsborough as part of Project 0351 - *Interactions between the phosphorus content of cattle manure and losses of phosphorus in surface runoff following manure applications to grassland.*

<u>Outputs:</u>

Doody, D.G., Higgins, A.J., Foy, R.H., Matthews, D. and Watson, C.J. (2007). Seasonal variations in soil moisture-overland flow relationships from a drumlin grassland soil. Poster Presentation at Agricultural, Water Management and Climate Change Workshop, Bath, March 2007.

Pilatova K., Duffy O., Doody D.G., (2008). Spatial and temporal variation in soil water repellency in Northern Ireland grassland soils. International Conference on Grasslands and Water Framework Directive, 12-14th Nov 2008, Johnstown Castle, Wexford, (Poster Presentation)

Bourke D., Kurz I., Dowding P., O'Reilly C., Tunney H., Doody, D..G., O'Brien J. E., and Jeffrey D. W., (2009) Characterisation of organic phosphorus in overland flow from grassland plots using 31P nuclear magnetic resonance spectroscopy. Soil Use and Management. 25,234 – 242

Doody D.G., Higgins A., Foy R.H., Pilatova K., Duffy O., Watson C.and Matthews D. Overland flow initiation from a drumlin grassland hillslope. Soil Use and Management (Accepted).

Project 0311: The existence and extent of bypass flow conduits in NI soils.

Project aim: To demonstrate the existence of bypass flow conduits in soils in Northern Ireland and to investigate the extent across major soil types in Northern Ireland and possible implications for pollutant transport.

A majority of soils in Northern Ireland have been artificially drained at some time in their history and flows via field drains can account for a large percentage of annual flows. Observations have shown that contamination of drain-flow can occur during and after slurry applications to grassland.

Work on this project overlaps with the work carried out for project 0303 described above but with a focus on drain-flow from the CENIT plots at AFBI Hillsborough. Data analysis of the plot 6 subsurface flows was carried out in conjunction with the analysis carried out for overland flow from the plot.

Flows: The analysis of the subsurface drain flows demonstrated the occurrence of subsurface flows over a range of rainfall intensity and at VWCs below field capacity at (i.e. 40%) (Figure F). The occurrence of subsurface flow at low VWC is potentially due to the rapid movement of rain water through bypass flow channels in the soil.

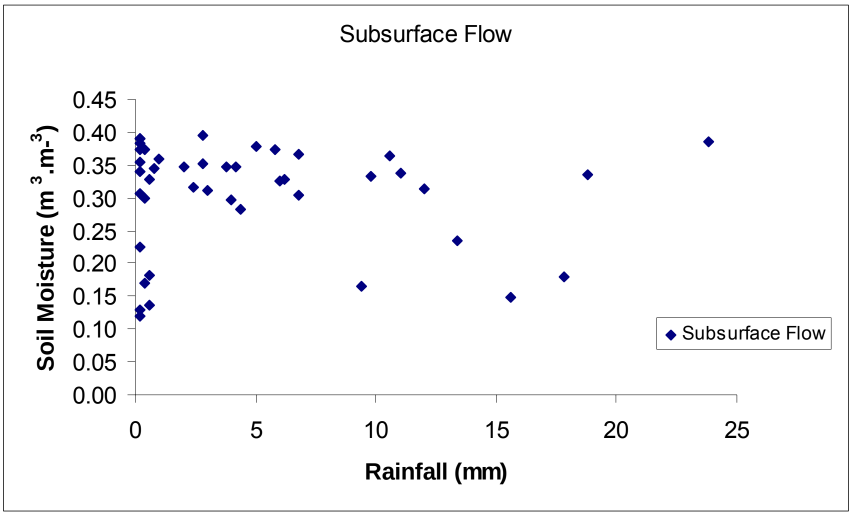

Figure F: The occurrence of subsurface flow under a range of soil moisture and rainfall conditions at the CENIT site

Figure G provides an example of a bypass flow event occurring during a period of low VMC. At the start of the rainfall event soil moisture was below 25% saturation and although only 22 litres of overland flow occurred, 787 litres of subsurface flow was recorded, demonstrating the relative importance of bypass flow pathways during period of low soil moisture.

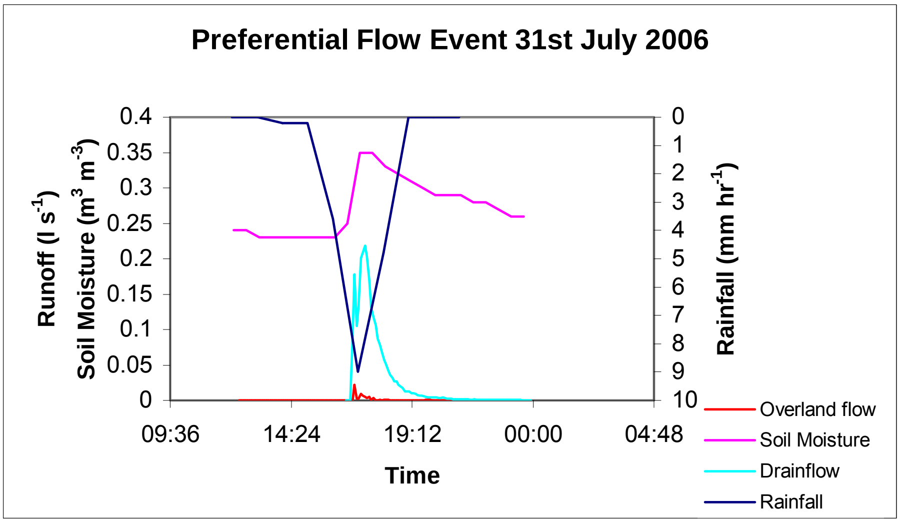

Figure G: The occurrence of a preferential flow event at the CENIT site

Future work: Monitoring of soil moisture, subsurface flow and rainfall will continue at the CENIT site. Following on from the SWR study, a more detailed analysis of the subsurface flow data will be carried out to investigate threshold value of rainfall and soil moisture at which bypass flow occurs.

Effect of time of animal manure application and method of application on potential phosphorus losses in overland flow

During the winter period of 2009/2010 a study will be undertaken by AFBI to examine phosphorus losses in overland flows from slurry applied both during the closed period and after the closed period has ended. In addition, this experiment will examine the effect of two different slurry spreading techniques (trailing shoe vs inverted splash plate) on phosphorus losses. Slurry will be applied on four dates (late November, early January, mid-February and late March). On each application date, dairy cow slurry will be applied to a series plots, and rainfall simulated (20 mm/hour) on a number of occasions after application. Surface run-off will be collected, measured and analysed for phosphorus content, including soluble reactive phosphorus (SRP), total soluble phosphorus, total phosphorus (TP) and particulate phosphorus. The study will be managed to ensure that slurry is not applied on occasions when soil conditions are unsuitable i.e. when the soil is above field capacity, or when the ground is covered in snow, or frozen. In addition, nutrient uptake by herbage (both nitrogen and phosphorus) will be measured in the spring by harvesting herbage which has grown over the winter period

2: Options to Better Manage Dirty Water

Dirty water on farms is generated by runoff from hard standings contaminated by animal faeces, runoff from open silage pits and the cleaning of dairy milking parlours. By definition it has a low nutrient content, typically less than 5% of animal manure slurries so that it has minimal agronomic value as a fertiliser. Currently under the NAP Regulations, dirty water applications to land are not subject to a mandatory closed period and can be applied throughout the year provided ground and weather conditions are suitable. Minimum storage capacities for dirty water have not been defined for farms but adequate storage must be provided for periods when weather and ground conditions prevent land application. . The extension of the current closed period for organic manure applications to cover dirty water would require the provision of tanks with sufficient capacity to store it throughout this period and longer. This is regarded as a costly alternative to land spreading as it offers little return in terms of better utilisation of nutrients.

An alternative to land spreading is to treat dirty water so that it can be safely discharged to water. Although in terms of polluting power it is much less strong than animal slurry, it is never the less potentially highly polluting especially with regards to its organic content. For effluents this polluting capacity is usually expressed as Biochemical Oxygen Demand (BOD). Under the NAP Regulations the maximum BOD of dirty is 2000 mg/l. This is approximately ten times the BOD of untreated sewage and streams and rivers should be kept with a BOD of less than 4 mg/l. Effluents from waste water treatment plants should typically achieve a BOD of less than 20 mg /l. Wetlands which use natural processes have been proposed as offering a low cost treatment option but the scientific literature is contradictory with respect to their ability to retain P.

To test their efficacy under conditions prevailing in Northern Ireland the following project is currently operational.

Project 0655 - Evaluation of a constructed wetland for treatment of farmyard dirty water

Project aim: To determine if constructed wetlands can be managed to efficiently treat dirty water so that the effluent can be safely discharged to surface waters.

A five-pond constructed wetland (CW), was constructed in 2004 at the CAFRE Greenmount campus near Antrim. The CW was planned to treat farmyard dirty water, including dairy washings, from the 170 cows that are milked at the College. The farm yards are managed to minimise yard contamination by livestock by daily cleaning and the volumes of clean water entering the wetland from roofs, yards and roads are also kept to a minimum. The wetland followed a design developed in County Waterford which is distinguished by a long retention time of 100 days. In this regard it differs from much shorter retention times reported for CWs in other countries and potentially offers a way of solving the low P retention observed in ponds with short water retention times. To achieve the long retention time and, because it is shallow (0.6 m), the Greenmount wetland is quite large at 1.2 ha and roughly twice the size of the contributing yard area.

The wetland was planted with emergent aquatic macrophytes in autumn 2004 and the plants were allowed to become established during 2005. The first effluent was diverted to the wetland in November 2005 and since then it has received all the dirty water from the College dairy unit. Because of the long retention time it was not until February 2006 that the dirty water entering Pond 1 had worked its way through the pond system and effluent concentrations in the outflow showed higher concentrations. Therefore the wetland has been in operation for a relatively short time and, as it would be expected that some wetland processes may take some time to reach an equilibrium, the conclusions that can drawn to date as to its long term performance are somewhat tentative. The following paragraphs are extracted from a summary of a report on the wetland performance planned for publication in autumn 2009 by the Global research unit based at AFBI Hillsborough.

Results: From February 2006 the wetland was considered to be fully operational, with treated effluent being discharged from Pond 5. Since then the effluent has been relatively efficient (>90%) in terms of pollution control and nutrient efficiency. Comparing inflow with final effluent, the average reductions in the effluent have been as follows: 96% for TP, 93 % for ammonia nitrogen (NH_4) and BOD by 99%. The largest reductions of BOD and TP occurred in Pond 1, whereas NH_4 levels declined more significantly in Pond 2. Soluble reactive phosphorus and total soluble phosphorus, were significantly reduced during passage through the ponds by 95 and 96% respectively. Other dirty water nutrient contents, total oxidisable nitrogen, nitrite nitrogen were less consistently recorded but reductions were of a similar order.

Across the ponds pH remained constant with an average pH 7.26 ± 0.07 despite large variations (max pH 9.48, min pH 4.29) in the inlet dirty water. The high pH of the inlet probably reflects the impact of cleaning agents used in the dairy while the low pH effluent was due to runoff from an open silage pit. Conductivity was continuously reduced across the ponds, with the inlet average of 760 ± 34 (max 1942) $\mu S\ cm^{-1}$ being reduced to 291 ± 12 $\mu S\ cm^{-1}$ at the outlet. This reduction is consistent with the diluting effect of rainfall, which has a low conductivity of around 50 $\mu S\ cm^{-1}$. However if the rainfall diluting effect on conductivity is indicative of the diluting effect, the reduction in conductivity is much smaller than reductions observed for BOD, ammonium and P. This indicates that the wetlands do operate as treatment systems rather than simply diluting the wastes they receive.

The dirty water entering the wetland is highly contaminated with faecal pathogens. The ability of the wetland to remove these is the subject of a PhD study based in IAFLU (QUB) in partnership with AFBI. In this regard the wetland operates very well and proportionately removes more pathogens than it does other pollutants. Occasionally a pathogen such as *Campylobacter spp.* appeared only in the influent from Pond 5 but was not observed in the intermediate ponds. This indicates local contamination of Pond 5, independent of dirty water from the dairy unit. The *Campylobacter* source may have been was from wild ducks that regularly use the wetland.

A function of its size and high evaporation from the luxuriant plant growth, particularly Phragmites, is that for much of the summer and into autumn, the wetland has no final discharge as evaporation exceeds influent volumes and rainfall inputs to the ponds. For example during the very wet summer of July and August 2009, it was only in the final week of August did any flow leave the wetland. In this regard the wetland can be said to achieve 100% pollution control for approximately six months of the year. A corollary of this is that the wetland is less successful in the winter as a treatment system and in each year to date maximum outflow concentrations have occurred in February. Currently NIEA have adopted an effluent BOD standard for CWs of 40 mg/l and this value has not been exceeded at any time in the final discharge from pond 5 of the wetland system (maximum BOD effluent 28 mg/l). If however the wetland was smaller than currently designed then the 40 mg/l standard would be in danger of being breeched as the maximum concentration measured at the outflow from pond 4 was 130 mg/l.

Conclusion: The wetland system has operated very well to date and the large surface area and long hydraulic retention time seems to have solved the problem of poor P retention reported for other wetland systems. Its has been an excellent pollution control system during the summer and autumn months when there is negligible discharge to the aquatic environment, which is especially beneficial as flows during the summer are low and waters more sensitive to pollution. There are some caveats to these conclusions:

a) it is not known if in future the wetland may become saturated with regard to P retention and leading higher P discharges to the aquatic environment; and

b) the wetland operational efficiency is related to its size and wetlands that are undersized are much more likely to represent an appreciable pollution hazard.

The main problems associated with the wetlands are related to this latter point, as the current wetland specification requires relatively large areas of land and high initial construction costs.

Outputs:

Brettell, J.L, Rowe, M.T., Mulholland, M., Foy, R.H., Grant, I.R. and Forbes, E.G.A. (2008). A micrbiological survey of a constructed wetland system supplied by dairy 'dirty water' effluent. (presentation & abstract). 11th International Conference on Wetland Systems for Water Pollution Control, Indore, India, November 2008.

Forbes E. G. A., Foy R.H., Mulholland M.V. and Woods V.B. (2009) Greenmount Constructed Wetland Bioremediation of farmyard dirty water and dairy parlour washings in the five-pond constructed wetland at the College of Agriculture, Food and Rural Enterprise (CAFRE), Greenmount Campus. A report by the Global Research Unit of the preliminary findings of the performance, efficiency and sustainability of the constructed wetland system. AFBI In press.

3: Minimising Phosphorus Losses

Enrichment by P is the primary cause of eutrophication in freshwaters and it has been shown that P losses from diffuse sources increased steadily between 1975 and 2000, to the extent that agriculture was the largest source of the P observed in surface waters in Northern Ireland. Two AFBI projects are addressing this topic. The first addresses the relationship between P loss rates and soil P status which is fundamental to developing a sustainable P management for agriculture. The second is assessing the benefits of lowering the P content of dairy diets in terms of reduced P losses to water following manure applications to grassland.

Project 0517: The effects of curtailing P fertiliser inputs on the P status of soils and P losses to surface runoff and land drainage water.

Project aim: This project was designed to assess how quickly the Olsen-P status of soils declines when no fertiliser is applied and how loss rates of P are affected.

The project is located at the CENIT site at AFBI Hillsborough and utilises five hydrologically isolated but drained grassland plots. Surface runoff and drain-flow are monitored separately from each plot and P measured in both drainage water surface runoff. (One of these plots provides the flow and runoff data described in Annex 5.1).

These grazed grassland plots were previously subject to a project where soil P was increased by applying variable amounts of P to each plot (0, 10, 20, 40 or 80 kg P/ha/year) over a period of five years (March 2000 - February 2005). The control plot has now received no P fertilisation since 1998. At the end of the project, the plots showed a range of Olsen-P concentrations from 19 to 67 mg/l in the top 75 mm of the soil. The current experiment continues the monitoring of both soils and drainage water after P fertiliser applications have ceased.

Withholding P fertiliser for nine years (March 2000 – February 2009) from a sward initially at the agronomic optimum soil P status (index 2) significantly (p<0.001) lowered Olsen-P but only by 0.35 mg P/l/year (s.e. 0.12). The Seasonal Kendal Test showed that the most significant decline in Olsen-P occurred in February, March and September. There continued to be a significant (p<0.0001) seasonal effect in Olsen-P concentrations in the soil from the zero P plot. Olsen-P concentrations were higher in spring (March-May) than in summer (June-August) and autumn (September-November) months.

The Seasonal Kendal Test on SRP concentrations in drainage water from the zero P plot also showed a significant decline (p=0.003) over the 9 years of the study. Figure H shows the box plots of monthly SRP concentrations from March 2000 to February 2009 on the zero P plot. There was no significant change in soluble organic P or PP fractions over time.

In January and February 2005 the Olsen P status of plots receiving 0, 10, 20, 40 or 80 kg P/ha/yr was 19, 24, 28, 38 and 67 mg P/l, respectively. Subsequently withholding P fertiliser for four years from these plots, resulted in a significant decrease in the Olsen-P status (Figure I). In January/February 2009 Olsen P was 15.4, 17.1, 19.2, 29.2 and 42.9 mg P/l, respectively. Interestingly, there was no seasonal effect in Olsen-P on plots that had previously received fertiliser, in contrast to the zero P plot which did exhibit a seasonality in soil P.

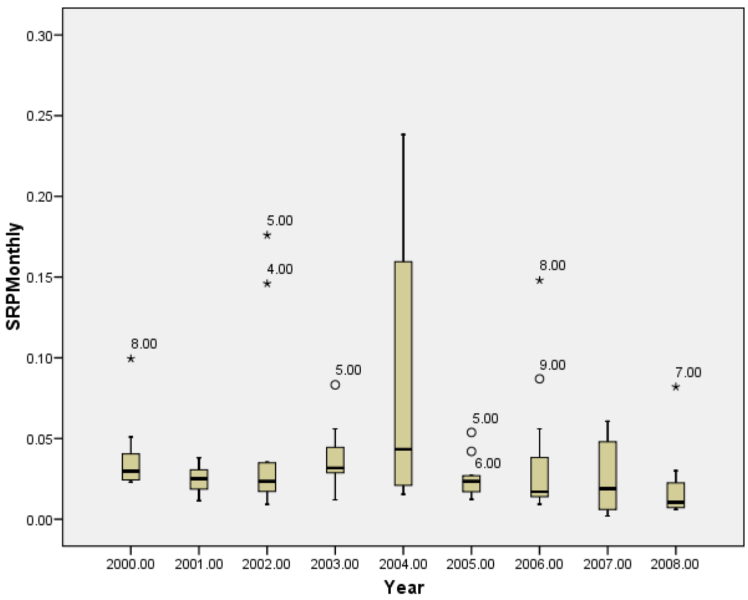

Figure H: Box plot of monthly SRP concentrations (mg P/l) in drainage water from Mar 2000 to Feb 2009 on zero P plot

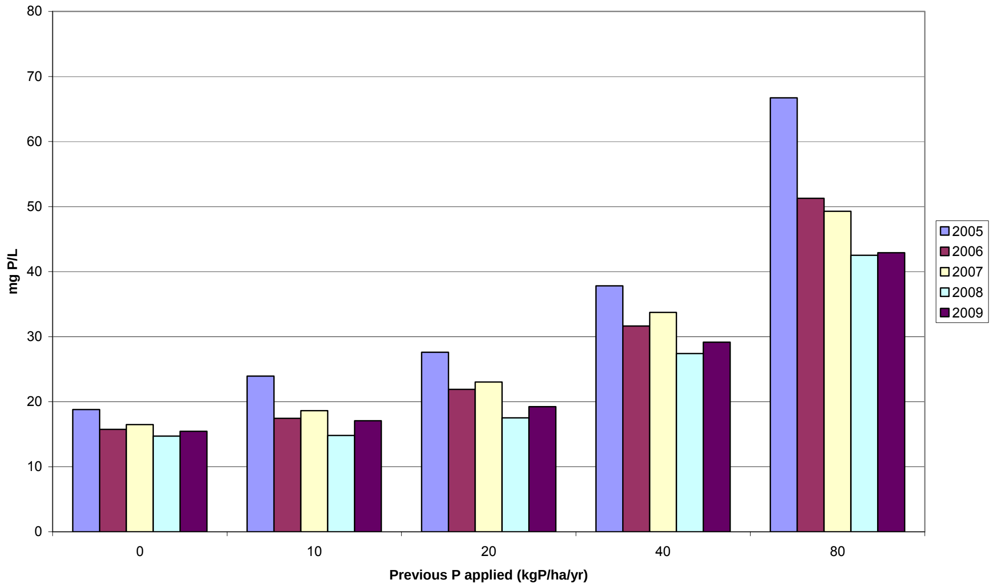

Figure I: Change in Olsen-P status (mg/l) (Jan-Feb sampling) after curtailing P fertiliser applications

Figure J shows the results of weekly soil sampling on the plots receiving 0, 40 and 80 kg P/ha/year. The arrow indicates when a zero P fertiliser policy was introduced (March 2005).

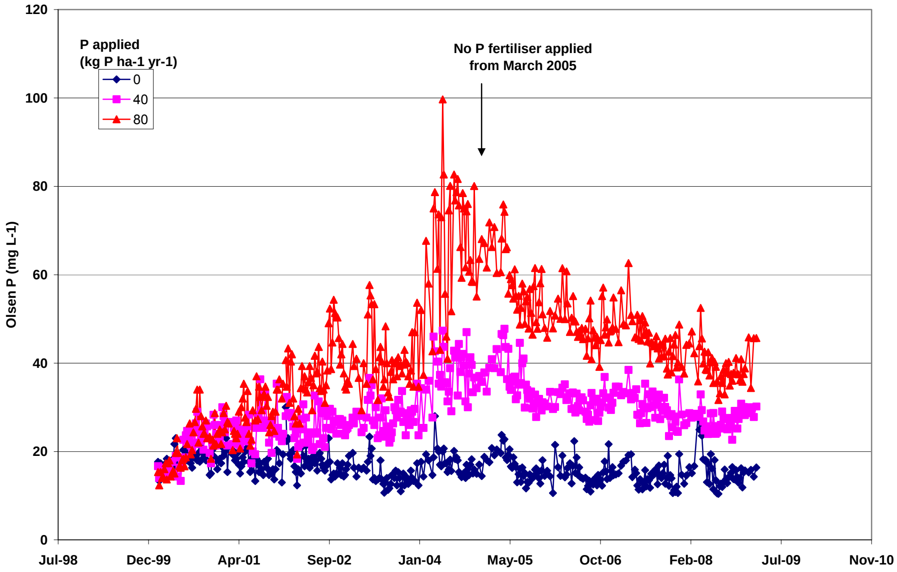

Figure J: Change in weekly Olsen-P (mg/l) status Plots received 0, 40 or 80 kg P/ha/year from March 2000 to February 2005. No P fertiliser was applied from March 2005 onwards.

Figure K shows the rate of decline in Olsen-P since March 2005. The annual rate of decline in Olsen P was -5.6, -2.6, -1.8 and -1.7 mg P/l on plots previously receiving 80, 40, 20 and 10 kg fertiliser P/ha/year (Table C).

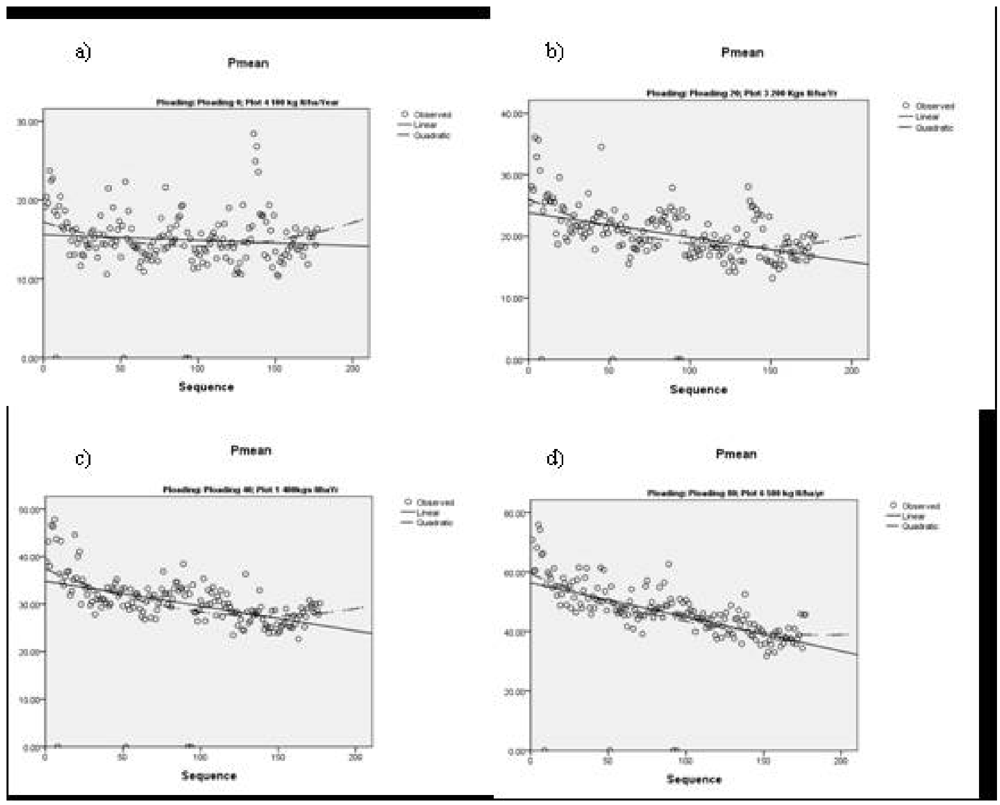

Figure K: Weekly changes in Olsen-P concentrations (mg P/l) from March 2005 when fertiliser P was withheld: a) zero P plot; b) plot

previously receiving 20 kg P/ha/year; c) plot previously receiving 40 kg P/ha/year; and d) plot previously receiving 80 kg P/ha/year

Table C: Annual rate of decline in Olsen-P since March 2005

kg P/ha/yr previously applied	Annual rate of decline in Olsen P (mg P/L/year)	Statistical significance level
10	-1.70	$p<0.001$
20	-1.82	$p<0.001$
40	-2.63	$p<0.001$
80	-5.60	$p<0.001$

The Seasonal Kendal Test showed that with holding P fertiliser resulted in a small decline in P concentrations in drainage water on all plots. However, the decline was only significant for SRP ($p=0.05$) and TSP ($p=0.03$) on Plot 1 that previously had received a fertiliser application rate of 40 kg P/ha/year. Figure L shows the box plots of SRP concentrations in drainage water from 2005/06 to 2008/09 for the plot previously receiving 40 kg P/ha/year.

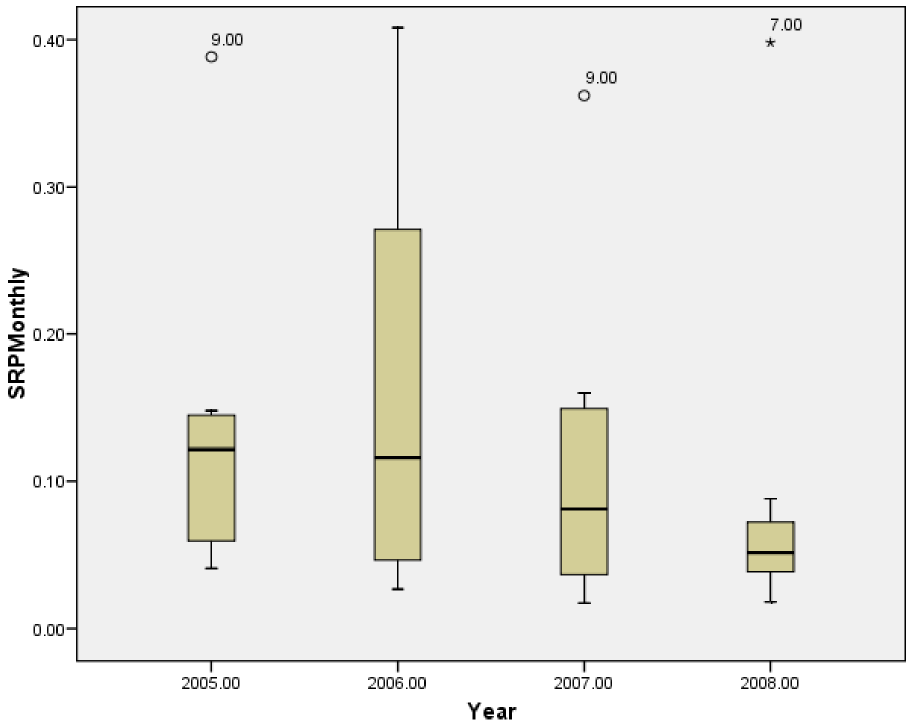

Figure L: Box plot of SRP concentrations (mg P/l) in drainage water from 2005/06 to 2008/09 for plot previously receiving 40 kg P/ha/year

Future work: The site will continue to be managed for a fifth and final year under a zero P fertiliser regime with measurement of soil Olsen-P on a weekly basis and P concentrations in land drainage water and surface runoff and complete data analysis of surface runoff data.

Outputs

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Watson, C.J. and Matthews, D.I. (2008). High losses of P to land drainage water from grassland swards despite a zero P surplus. Poster presentation and proceedings at International Conference on 'Sustainable grassland systems in Europe and the EU Water Framework Directive', Teagasc, Johnstown Castle, Research Centre, Wexford, Ireland, pp 52, November 2008.

Watson, C.J. (2008). Nutrient balances on grazed grassland and long-term effects of slurry on grassland. Oral and poster presentations to Nuffield Scholars during visit to Hillsborough on 6 June 2008 Watson, C.J. and Matthews, D.I. (2008). High losses of P to land drainage water from grassland swards despite a zero P surplus. Poster presentation and proceedings at International Conference on 'Sustainable grassland systems in Europe and the EU Water Framework Directive', Teagasc, Johnstown Castle, Research Centre, Wexford, Ireland, pp 52, November 2008.

Project 0351: Interactions between the phosphorus content of cattle manure and losses of phosphorus in surface runoff following manure applications to grassland.

This project investigated how losses of phosphorus in surface runoff following applications of cattle manure to grass respond to:

a) variations in the phosphorus content and composition of cattle manure; and

b) the timing and seasonality of manure applications.

It was completed in summer 2009 with the graduation of a QUB PhD student who undertook the research based at AFBI Newforge with field investigations at AFBI Hillsborough. While this project has now been completed the relationships between manure application and P in runoff measured over a range of weather and antecedent soil moisture conditions offers data that can be linked to Project 0301 to determine the Impact of spreading manures in October and February (requested research area 1).

Background: The increasing use of feed concentrates in Irish dairy systems results in P surpluses that contribute to increased soil P, but manipulation of the concentrate composition fed to cows can lower the P content of diets without compromising animal performance (see section in “2007 and 2008 Derogation Report for Northern Ireland”). This is both an attractive and cost-effective mitigation strategy for abating P losses to the aquatic environment in Northern Ireland. The project focused on P losses from grassland and evaluated how adjusting the P content of manure impacted on the P composition and concentration in runoff.

Results Lowering the P content in the diet produced proportionately larger reduction in manure P contents, but these reductions were not exclusively in the water soluble P fraction of manures as had been reported in other studies. Manure was applied to small plots at a uniform rate of 50 m3/ha at a dry weight of 6%. Rainfall was applied to the plots at set intervals after the application of manure using a rainfall simulator. Runoff was collected over a 30 minute period.

Following surface applications of manure the greatest impact of varying the P content of slurry was consistently most evident in the first simulated runoff event, two days after slurry application. It was only when manure P was reduced from 1.3 to 0.5 %P that statistically significant reductions in total P concentrations were observed in summer, winter and spring seasonal experiments (Figure M).

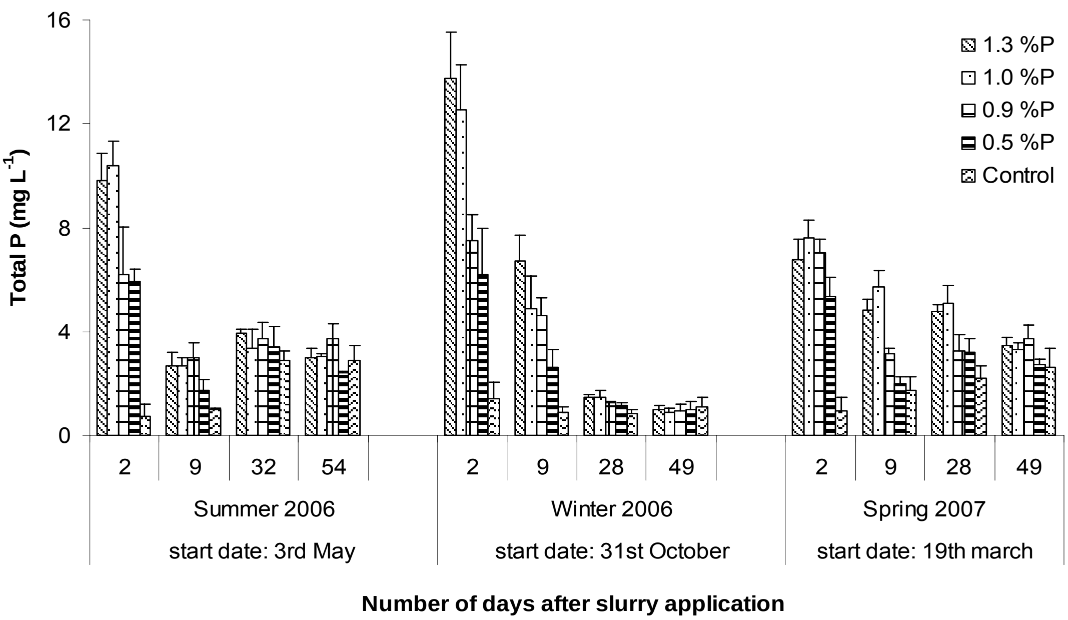

Figure M: **Total P flow-weighted mean concentrations over successive rainfall events in summer, winter and spring following manure applications.** Legend refers to the P contents of the manures.

In the experiments shown in Figure M, each plot received repeated applications of rainfall. Therefore TP concentration for example measured on day 9 was influenced by the rainfall on day 2 which likely washed some of the manure into the soil profile and lowering the risk of P loss in subsequent dates. A subsequent experiment tested the effect on runoff P concentrations of varying the time interval between surface application of manure and rainfall (Figure O). This experiment undertaken in summer 2007 showed that increasing the time interval between manure application and the first simulated rainfall event had more impact on lowering P concentrations in runoff than reducing manure P content.

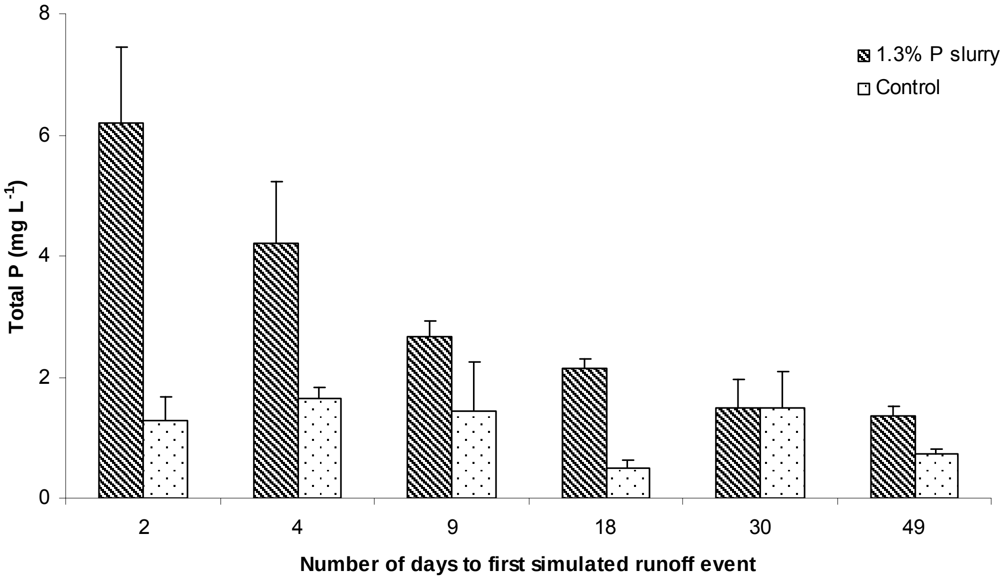

Figure O: Total phosphorus concentrations in runoff for six simulated rain events after slurry was applied

The persistence of manure P signal in runoff after manure had been applied was rather variable but was much longer than the recommended minimum period between manure application and forecasted heavy rain (Figure P). Elevated P concentrations were observed for 28 days in spring but for only nine days in summer and winter. The results of Project 301 described previously have shown that when soils are at field capacity heavy rain is not a prerequisite for the generation of runoff.

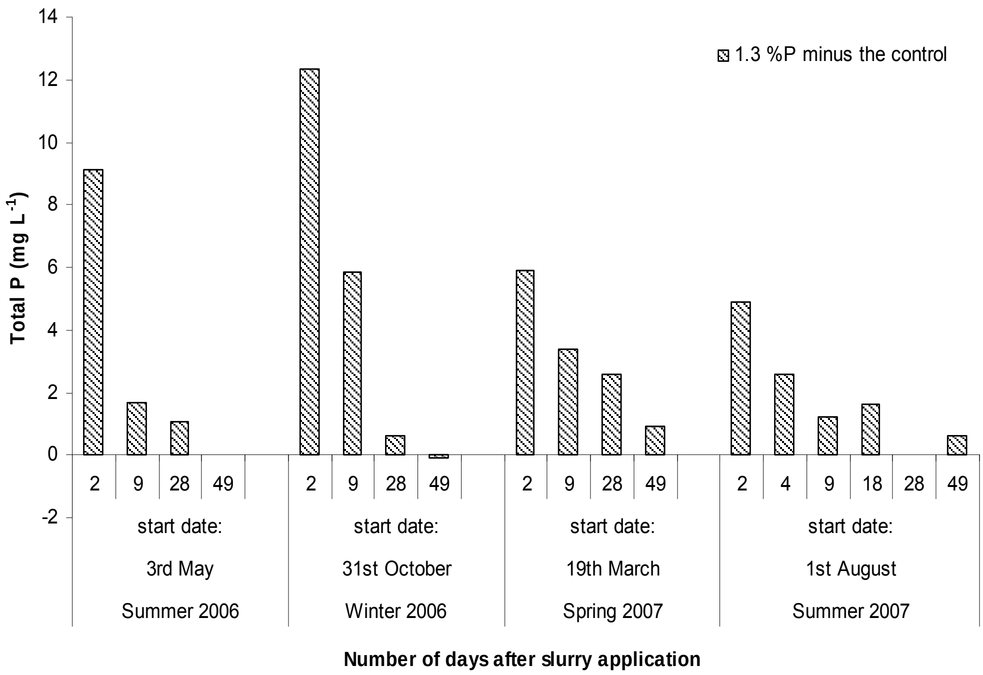

Figure P: TP concentrations in runoff from the manure treatment minus background TP concentrations in the control, in the seasonal experiments and summer 2007

DRP was the largest fraction of P in runoff and thus the driver of TP concentrations in all seasons with PP contributing a slightly greater proportion of TP in winter. Rates of P loss in initial runoff events impacted on the persistence of the P signal in runoff. To investigate if there was a land-use effect on P losses, and if reducing manure P could be a useful mitigation option for reducing the impact of soluble P losses when manures are applied to cultivated soils, manure was applied to maize stubble. Three months post-harvest, P fractionation in runoff differed between manured and un-manured plots. Despite a difference in the runoff generation process, P concentrations in runoff from maize stubble were similar to grassland, suggesting that similar benefits could be achieved by dietary manipulation in both systems (Figure Q)

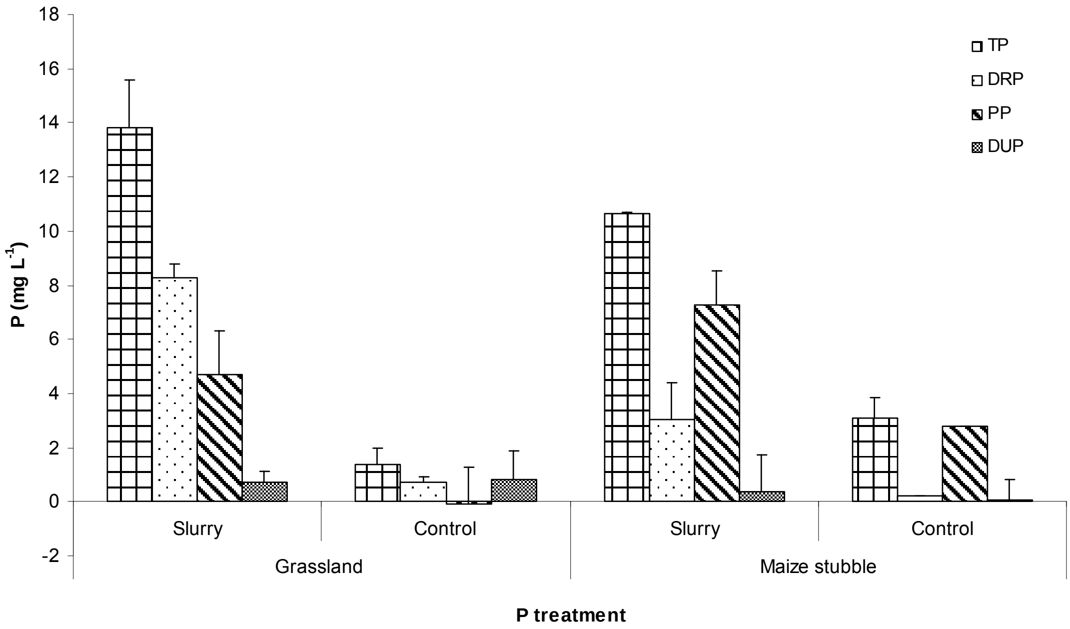

Figure Q: Comparison of P concentrations in runoff two days after slurry application in grassland (October 2006) and maize stubble (November 2007)

<u>Outputs</u>

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O'Rourke, S.M., Foy, R.H., Watson, C.J. and Patterson, M.P. (2006). Phosphorus losses to water following slurry application to grassland. Poster at Slurry Open Day, Hillsborough, 29th June 2006

Tunney, H., Kurz, I., Bourke, D., O'Reilly, C.E., Jeffrey, D.W., Foy, R.H., Kilpatrick, D.J., Haygarth, P.M. and Dowding, P. (2007). The impact of the grazing animal on phosphorus, nitrogen, potassium and suspended solids loss from grazed pastures. Teagasc report to EPA Ireland 42p. ISBN; 1-84095 - http://www.teagasc.ie/research/reports/environment/5022a/eopr-5022a.pdf

4: Improving manure N efficiency and minimising nitrous oxide losses to the atmosphere

Manure N and chemical fertiliser N rates to agricultural land in Northern Ireland are high by Western European standards but, by the same comparison, mean nitrate concentrations observed in rivers are among the lowest. This discrepancy reflects a number of factors. The first is that it simply wetter in Northern Ireland and the higher river flows serve to dilute nitrate that is leached from the soil. A secondary factor is that a relatively high proportion of N applied to the soil as chemical fertiliser and organic manure is lost to the atmosphere. Research has shown how the wet and poorly drained nature of many soils combined with high soil organic matter renders them very prone to the process of denitrification that converts soil nitrate or nitrate applied to the soil to gaseous nitrogen compounds. The dominant end product of denitrification is di-nitrogen gas, which forms around 80% of the earth's atmosphere and poses no environmental problem. However a small, but variable, proportion of nitrate can be denitrified to nitrous oxide, which is a powerful greenhouse gas, with climate warming potential approximately 300 times that of carbon dioxide.

Potentially nitrous oxide emissions can be lowered by a number of means:

1) Use less N fertilisers. This could be achieved on many farms in Northern Ireland by increasing the efficacy by which the N in animal manures are used by crops which in turn will lower the demand for chemical N fertilisers.

2) Where denitrification is likely to occur, define manure and fertilisation strategies that not only minimise denitrification but also lower the proportion of soil and fertiliser nitrate that is lost as nitrous oxide. In other words aim to increase the ratio of di-nitrogen gas to nitrous oxide in the end products of denitrification.

3) Apply products that have been developed that inhibit nitrification of ammonium and may be commercially viable within grassland farming. While a nitrate containing fertiliser, such as calcium ammonium nitrate, the mostly widely used product in Northern Ireland, offers a ready source of nitrate that can be denitrified, switching to a non-nitrate based fertiliser such as urea still leaves the applied N potentially liable to denitrification losses if soil nitrification converts ammonium released from the urea to nitrate.

Research to lower denitrification has advantages beyond lowering the environmental impact of agriculture, as it offers a means of identifying ways to lower input costs to agriculture through increasing availability of applied N for plant growth. The projects described below are designed to address issues associated with denitrification and manure N efficiency.

Project 0615 Measures to improve nitrogen use efficiency in Northern Ireland.

In addition to the measures in the NAP Regulations that increase N efficiency on farms, such as the closed period for manure application and low emission spreading techniques, there are further options that have considerable potential to improve manure N and fertiliser N efficiency. These include:

1) use of inhibitors to slow down the rate of conversion of urea or ammonium-N to nitrate, which is the form of N that is most susceptible to loss either through leaching or denitrification; and

2) minimising the interaction between manure and chemical fertiliser N and hence reducing gaseous N emission (N2O, N2) by denitrification.

The scientific basis for these two options is being investigated in this project. A combination of laboratory and field experiments is being used to investigate processes in soil responsible for global warming gaseous emissions.

Antecedent effects of long-term slurry applications on gross soil N transformations. Repeated long term application of organic manures brings about changes that potentially effect N dynamics in the soil. Enhancement of the mineralisable soil N pool is the most obvious, but repeated applications of manure can also change other soil characteristics that can affect N dynamics. We conducted an aerobic incubation with ^{15}N tracer to determine how soil amendment history affects transformations of recently added N. Gross N transformation rates were determined with a ^{15}N tracing model (Figure R).

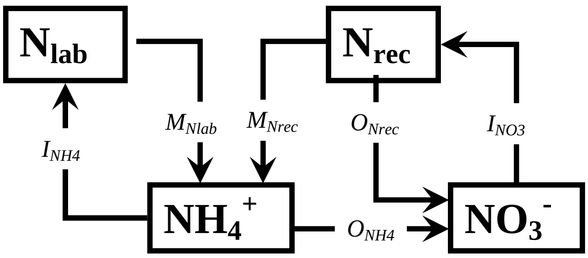

Figure R: Conceptual ^{15}N tracing model to quantify gross N transformation rates (modified Müller *et al*., 2007).

The experiment used a long term experimental site which was set up in 1971 to study the effects of repeated and regular slurry applications to the soil. For the current study five treatments were selected. Three treatments have received high, medium and low levels of cattle slurry each year. Two control treatments receive no cattle manure, but one receives RB209 defined chemical fertiliser rates appropriate for silage production while the other has received no fertiliser since 1971. Grass produced on each plot is harvested and removed.

Manure management history had no effect on the mineralisation or immobilisation of recently added ammonium (Figure S). However amendment history significantly increased heterotrophic nitrification (N_{org} oxidation) and autotrophic nitrification of recently added ammonium (NH_4^+ oxidation), with ammonium oxidation being three times greater than organic N oxidation. Amendment history had no effect on the mineralisation or immobilisation of recently added ammonium. However amendment history significantly increased heterotrophic nitrification of organic N in the soil (N_{org} oxidation) and autotrophic nitrification (NH_4^+ oxidation) of recently added NH_4^+, with NH_4^+ oxidation being three times greater than N_{org} oxidation.

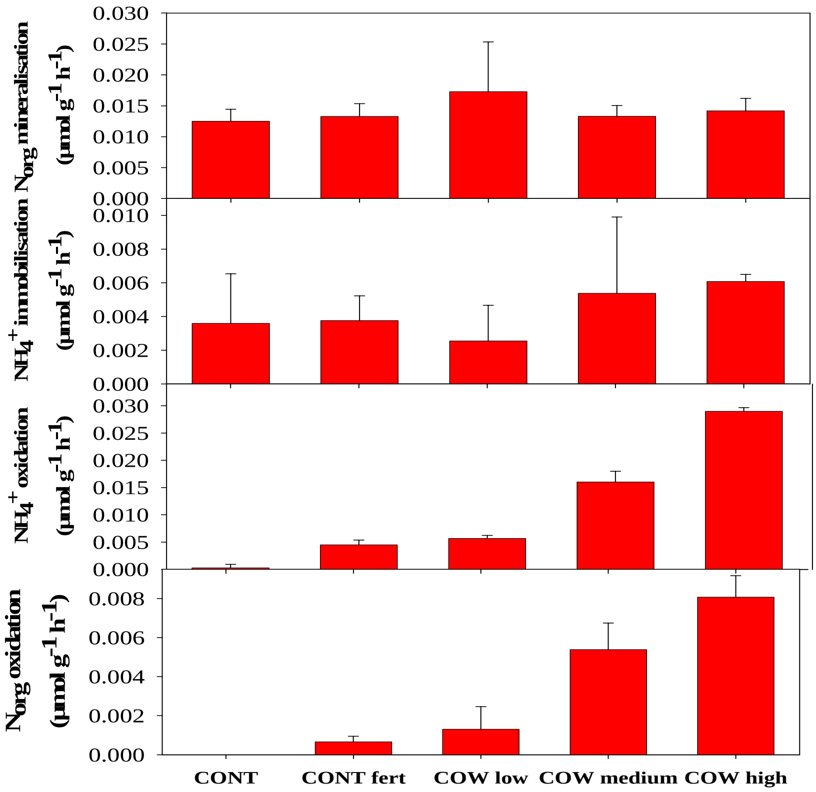

Figure S: Gross N transformation rates between treatments: CONT= no fertiliser; CONT fert = chemical fertiliser, COW low, medium and high receive cattle slurry at rates of 50, 100 and 200 m^3/year respectively

<u>Use of nitrification inhibitors</u> Nitrification inhibitors have been proposed as a means of improving manure N and chemical fertiliser N efficiency. The nitrification inhibitor dicyandiamide (DCD) when applied with an application of urea or urine has been shown to have a large effect on reducing the size of the nitrate pool and hence lowering nitrous oxide emissions. Oxidation of ammonium is a key process in N loss as ammonium is relatively non-mobile but if converted to mobile nitrate and not taken up by herbage can be leached to ground and surface water or denitrified into N-gases. The efficacy of the nitrification inhibitor DCD was tested by conducting aerobic incubations using

^{15}N tracers in combination with selective biomass inhibitors and analyzing the results using the ^{15}N tracer model outlined in Figure R. The selective biomass inhibitors were used as they offer a way of distinguishing between soil processes governed by either bacterial or fungal activity. Until relatively recently it was assumed that soil bacteria were responsible for the nitrification and denitrification processes in surface soils, but recent AFBI research has demonstrated how in grassland soils fungal activity can be more important.

Both total gross N mineralisation and total gross ammonium immobilisation were dominated by fungal activity (Figure T). DCD increased immobilisation and mineralisation in soil when both bacteria and fungi were active (i.e. with no biomass inhibitors). Organic N oxidation (N_{rec} oxidation) was insignificant compared to ammonium oxidation. In this grassland soil ammonium oxidation was dominated by fungi and was completely inhibited by DCD.

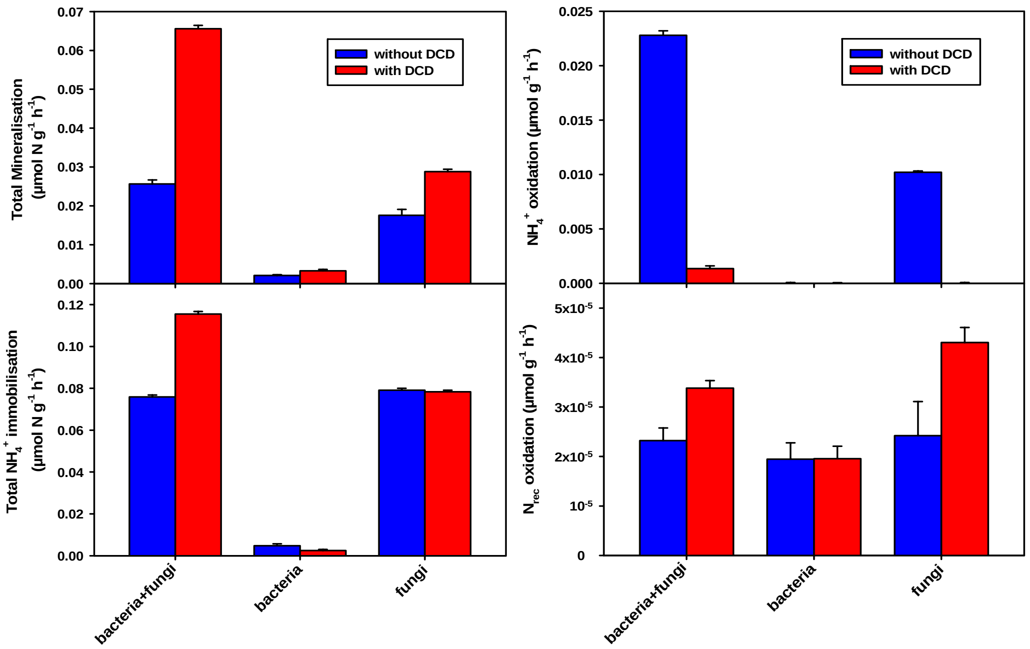

Figure T: Effect of biomass inhibitors and DCD on gross mineralisation and immobilisation of ammonium (NH_4^+) (left hand graphs) **and ammonium oxidation and organic N oxidation** (right hand graphs). The x-axis shows the form of the microbially active biomass in the soil.

The mode of action of nitrification inhibitors is thought to be by the inhibition of the ammonium mono-oxygenase enzyme, which is present in bacteria, but has not been demonstrated in fungi. This study has shown that DCD inhibited both bacterial and fungal ammonium oxidation (i.e. nitrification) and so has considerable potential to reduce N losses, by inhibiting the production of nitrate, even in soils where nitrification is dominated by fungal activity.

Future work: Reviews suggest that interactions between chemical N fertilisers and organic manures results in much higher losses of nitrous oxide compared with chemical fertilisers used alone especially if chemical fertiliser was applied a few days after the application of cattle slurry. Previous AFBI research has shown that emissions of nitrous oxide increased when slurry and inorganic fertiliser were applied together or within two days of each other, compared to when slurry and inorganic fertiliser were applied more than two days apart. Apart from delaying the application of nitrate containing fertilisers until 3-4 days after cattle slurry application, another strategy proposed for lowering the interaction between labile carbon in slurry and nitrate in the soil would be to remove the readily degradable or labile organic substrates from the slurry by anaerobic digestion, as it is these organic substrates that provide an energy source to drive the soil microbial processes.

In a previous laboratory experiment that compared denitrification rates from anaerobically digested slurry with rates from undigested slurry, losses of N because of denitrification were lowered by 49%. In addition, the method of spreading cattle slurry could also affect nitrous oxide emissions as when cattle slurry is band spread, the contact area between inorganic fertiliser and slurry will be less, compared to slurry applications by the traditional splash plate method. To test the generality of these results in field situations a series of field experiments commenced in May 2009 at AFBI-Hillsborough to determine if anaerobic digestion of cattle slurry and method of cattle slurry application are effective strategies to lower the contribution of agriculture to greenhouse gases.

<u>Outputs :</u>

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