

Environmental RTDI Programme 2000–2006

Eutrophication from Agricultural Sources: The Impact of the Grazing Animal on Phosphorous Loss from Grazed Pasture

(2000-LS-2.1.2-M2)

Synthesis Report

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Prepared for the Environmental Protection Agency

by

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WATER QUALITY

The Water Quality Section of the Environmental RTDI programme addresses the need for research in Ireland to inform policy-makers and other stakeholders on a range of questions in this area. The reports in this series are intended as contributions to the necessary debate on water quality and the environment.

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Preface: Overview of LS-2 Projects: Eutrophication from Agricultural Sources

The main objectives of the LS-2.1.2: *Grazed Pastures* project were to provide an assessment of grazing on phosphorous (P) losses under Irish conditions. The project was carried out in three parts:

- (a) Field-plot study: the impact of the grazing animal on phosphorus, nitrogen, potassium and suspended solids loss from grazed pasture.
- (b) Small-plot study: the impact of the grazing animal on nutrient losses to water.
- (c) Phosphorus dynamics in a grazed grassland ecosystem.

This project was one of six that formed the LS-2.1 project: *Pathways to Nutrient Loss with Emphasis on Phosphorus Losses*. This aimed at measuring the absolute and relative losses of phosphorus from soil, grazed pastures, slurry and fertiliser spreading and farmyards. The LS-2.1 project is part of the large-scale research project LS-2 – *Eutrophication from Agricultural Sources* (Figure 1).

The objective of this large-scale integrated research project, commissioned in 2000, was to supply scientific data that could underpin appropriate actions or measures that might be used in the implementation of national policy for reducing nutrient losses to waters from agricultural sources. The research, including desk, laboratory, field-plot, farm and catchment studies, was conducted by teams in Teagasc; the National University of Ireland at Dublin, Cork and Galway; Trinity College Dublin; the University of Limerick and the University of Ulster at Coleraine.

The LS-2.2 project – *Models and Risk Assessment Schemes for Predicting Phosphorus Loss to Water* – aimed at developing three modelling approaches that explored the sources of phosphorus and the hydrology that transports it from land to water. The LS-2.3 project – *Effects of Agricultural Practices on Nitrate Leaching* – aimed at measuring nitrate leaching from an intensively managed dairy farm on a soil type typical of a nitrate vulnerable zone (NVZ).

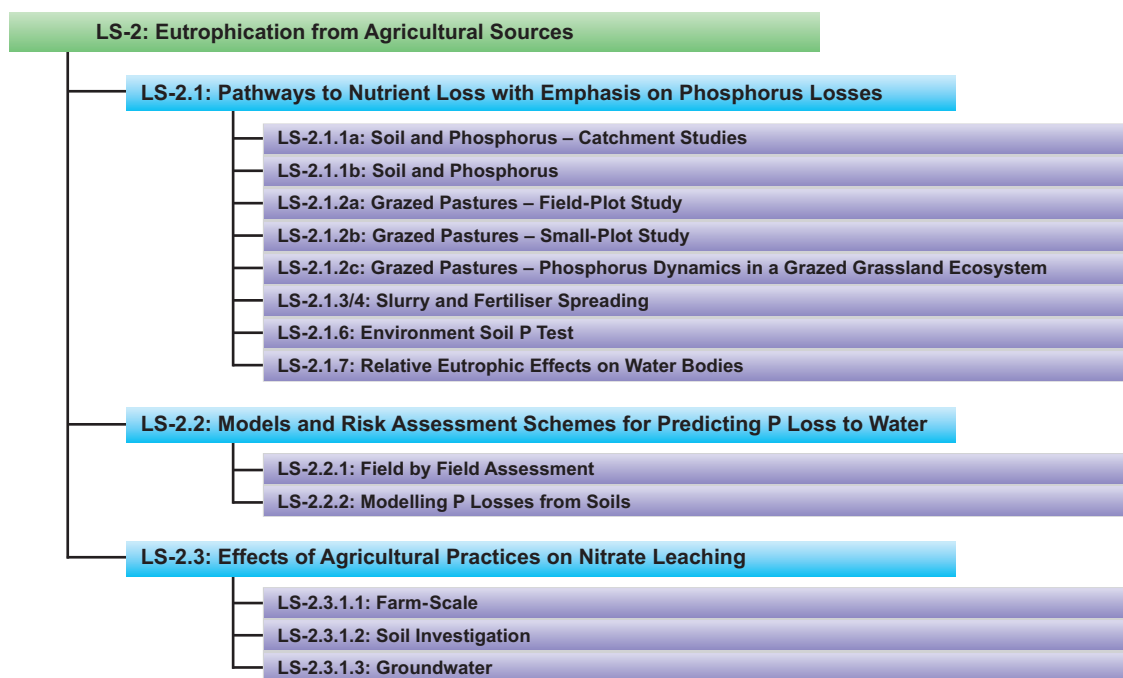


Figure 1: Overview of LS-2 projects

Integrated synthesis reports and individual reports from each subproject are available for download on the EPA website: www.epa.ie/downloads/pubs/research/water/.

Executive Summary

Over 90% of the 4.2 million ha of farmland in Ireland is under grass. Most of this is grazed and approximately 25% of this area is cut at least once per year. Little information is available on the impact of the grazing animal on phosphorus (P) loss from grassland soils to water. The main objectives of this project were to:

- Review existing information on P loss from grazed grassland.
- Measure the P and nitrogen (N) loss from grazed and cut grassland on a number of soils.
- Identify the most important factors influencing P loss.
- Investigate physical, chemical and biological processes that affect P fluxes.
- Propose remedial measures to reduce P loss from grassland.

The project was carried out in three parts:

- (a) Field-plot study – *The Impact of the Grazing Animal on Phosphorus, Nitrogen, Potassium and Suspended Solids Loss from Grazed Pasture*. The nutrient concentrations and nutrient loads from grazed and cut field plots (0.24 to 1.54 ha each) were studied in this experiment which started from September 2000 and finished into March 2004, at Teagasc, Johnstown Castle, Co. Wexford.
- (b) Small-plot study – *The Impact of the Grazing Animal on Nutrient Losses to Water*. The small-plot (1.5 m x 15 m each) studies assessed the impact of the grazing animal on nutrient losses to water. These were carried out at four sites over two years (spring 2002 to spring 2004). Two of the study sites were located at Teagasc, Johnstown Castle, Co. Wexford and two at Teagasc, Grange, Co. Meath.

- (c) Phosphorus Dynamics in a Grazed Grassland Ecosystem – This study investigated the pools and fluxes of P in grazed grassland (mainly in 1.5 m² field plots and laboratory studies, from August 2002 to July 2004).

This report is a synthesis of the main conclusions and recommendations from these three studies. The final reports from the three individual subprojects are available from the Environmental Protection Agency (EPA) and are published on the EPA website (www.epa.ie) at:

- Tunney, H. (in press). *Eutrophication from Agricultural Sources – Field Plot Study – The Impact of the Grazing Animal on Phosphorus, Nitrogen, Potassium and Suspended Solids Loss from Grazed Pasture*, EPA, Ireland.
- Kurz, I. and O'Reilly, C. (2006). *Eutrophication from Agricultural Sources – Small Plot Study – The Impact of the Grazing Animal on Nutrient Losses to Water*, ERTDI Report Series No. 41, EPA, Ireland.
- Bourke, D., Jeffrey, D., Dowding, P., Tunney, H. and Kurz, I. (in preparation). *Eutrophication from Agricultural Sources – Phosphorus Dynamics in a Grazed Grassland Ecosystem*, EPA, Ireland.

The principal conclusion from this study is that the grazing animal can have a significant influence on total P concentrations in overland flow but not on soluble P concentrations. This impact is minor when compared to the other factors (i.e. effect of soil P level) that determine P loss from grassland under standard management conditions. The wide variation in P concentrations between the six field plots was related predominantly to factors (i.e. accumulated surplus applied P reflected in soil test P) other than the presence or absence of grazing animals.

In the small-plot (22.5 m²) study (b), the presence of cattle led to physical changes in the topsoil. These changes favoured the occurrence of overland flow and altered the natural drainage characteristics of the soil. They persisted over the winter period when the animals were housed. Recovery of the soil did occur when cattle were excluded from areas over the growing season. The P forms in rainfall-simulated overland flow revealed that inorganic orthophosphate was the principal form of P found, but that the concentrations of organic P forms measured were higher in the flow from grazed than from cut plots. The effect of cattle on the quality of rainfall-simulated overland flow from small plots (0.5 m²) could not be detected before the start of the grazing season (March 2004), but was measurable in a number of water-quality parameters after the first grazing cycle (b).

There was a wash-out effect on P, N and K concentrations in overland flow from the field plots during autumn when overland flow recommenced after an extended summer dry period (a). The concentrations decreased and stabilised over the following one to two months. Concentrations of P in overland flow were significantly higher in field plots with the highest Morgan's soil test P (STP) and visa versa. Suspended solids (SS) concentrations in overland flow averaged 45 mg/l for all six field plots and were not significantly different between grazed and non-grazed plots. There were significant correlations between the concentrations of the three P fractions (dissolved reactive P, total dissolved P and total P) that were measured in overland flow from the field plots.

The N concentrations in overland flow were high on a number of occasions on both grazed and cut plots and these were sometimes associated with heavy rainfall after fertiliser N application (a).

Grazing animals and associated dung deposition were shown to increase the rate of P recycling in grazed compared to cut grassland (c). Dung-pat decomposition was affected by the seasonality and amount of rainfall over each of the 90-day decomposition periods studied. Soil test P concentrations in soil under dung-pats were shown to increase three- to four-fold over the decomposition period. The soil microbial biomass plays an important role in P cycling in Irish grassland soils and an annual turnover of 50 kg P per ha per year was calculated (c).

It is recommended that soil test P is maintained at the minimum for optimum grassland production (soil Index 2/3, i.e. 3.1 to 8 mg available [Morgan's] P per litre soil). To minimise nutrient losses from pasture areas to water, the use of site-specific nutrient management planning is recommended as a tool for addressing the complex interactions between agricultural management practices, nutrients in soil, soil biology and nutrient release from grassland to water.

The current study dealt with normal good grazing management. The out-wintering of animals and the use of sacrifice paddocks for winter feeding are potential sources of high nutrient and sediment loss to water and also merit study.

1 Introduction

1.1 Project Summary

In Ireland, data from the Environmental Protection Agency (EPA, 2004) estimates that half of phosphorus (P) losses to water is from agricultural sources. National and European Union (EU) policy and legislation (SI No. 258, 1998; SI No. 378, 2006) aim at reducing phosphorus (P) loss in order to protect water from eutrophication. In common with many developed countries, the eutrophication of Irish surface waters stems from a number of factors – including elevated losses of P from agricultural land. Agriculture in Ireland is relatively unusual in that grassland accounts for over 90% of the agricultural landscape, with grazing by cattle predominating. Approximately 25% is cut at least once per year for silage or hay, and conserved for winter forage (Drennan et al., 2005).

To date, attempts to explain the increase in P losses from Irish agriculture have been linked to higher levels of soil P. However, this is only one change that has occurred in Irish agriculture: increases in chemical fertilisers and grass production have facilitated a doubling of stocking rates. From this, at least two possible mechanisms for increased P losses can be postulated:

- 1 Losses associated with land spreading of P in manures collected during the winter housing, especially as there has been a switch from solid farmyard manures to slurry.
- 2 Losses associated with the increased numbers of grazing livestock maintained on farms.

1.2 Objectives

The main aim of this study was to provide information on the impact of the presence or absence of grazing animals on P loss to water from grassland.

Results of an earlier EPA study (Tunney et al., 2000) found that P loss from grassland can be higher than the maximum consistent with good water quality. There is relatively little information on the impact of the grazing animal on diffuse P losses from grassland soils under normal farming practices in Ireland.

In 2000, the EPA published a call for tender for an ERTDI-funded study on the impact of the grazing animal on nutrient loss to water (LS-2.1.2 Grazed Pastures). Teagasc undertook this study with the help of scientists from Trinity College Dublin, the Agri-Food and Biosciences Institute Northern Ireland (AFBINI), and the Institute of Grassland and Environmental Research (IGER, Devon, England).

The main objectives of this project were to provide an assessment of grazing on P losses under Irish conditions as follows:

- 1 Review existing available information on P loss from grazed grassland, including a simple model of P pools and fluxes.
- 2 Measure the P and also nitrogen (N) loss from grazed and cut grassland on a number of soils.
- 3 Attempt to identify the most important factors influencing P loss from soil to water under grazed grassland conditions.

- 4 Investigate the interactions between physical, chemical and biological processes that affect P fluxes and loss to water.
- 5 Recommend possible remedial actions necessary to reduce P loss to water from grazed grassland, based on the results obtained and other available information.

The project was carried out in three parts. Part A studied field-scale plots of the order of 1 ha each. Part B studied

small plots (1.5 m × 15 m [22.5 m²] each) for impact of grazing on soil physical properties and 0.5 m² for the rainfall-simulated overland flow study. This allowed more replication and statistical significance testing of results than was possible with the larger field-scale plots. Part C complemented the other two parts by studying the pools and fluxes of P in the soil. Figure 2 shows a map of the experimental sites used in the three projects.

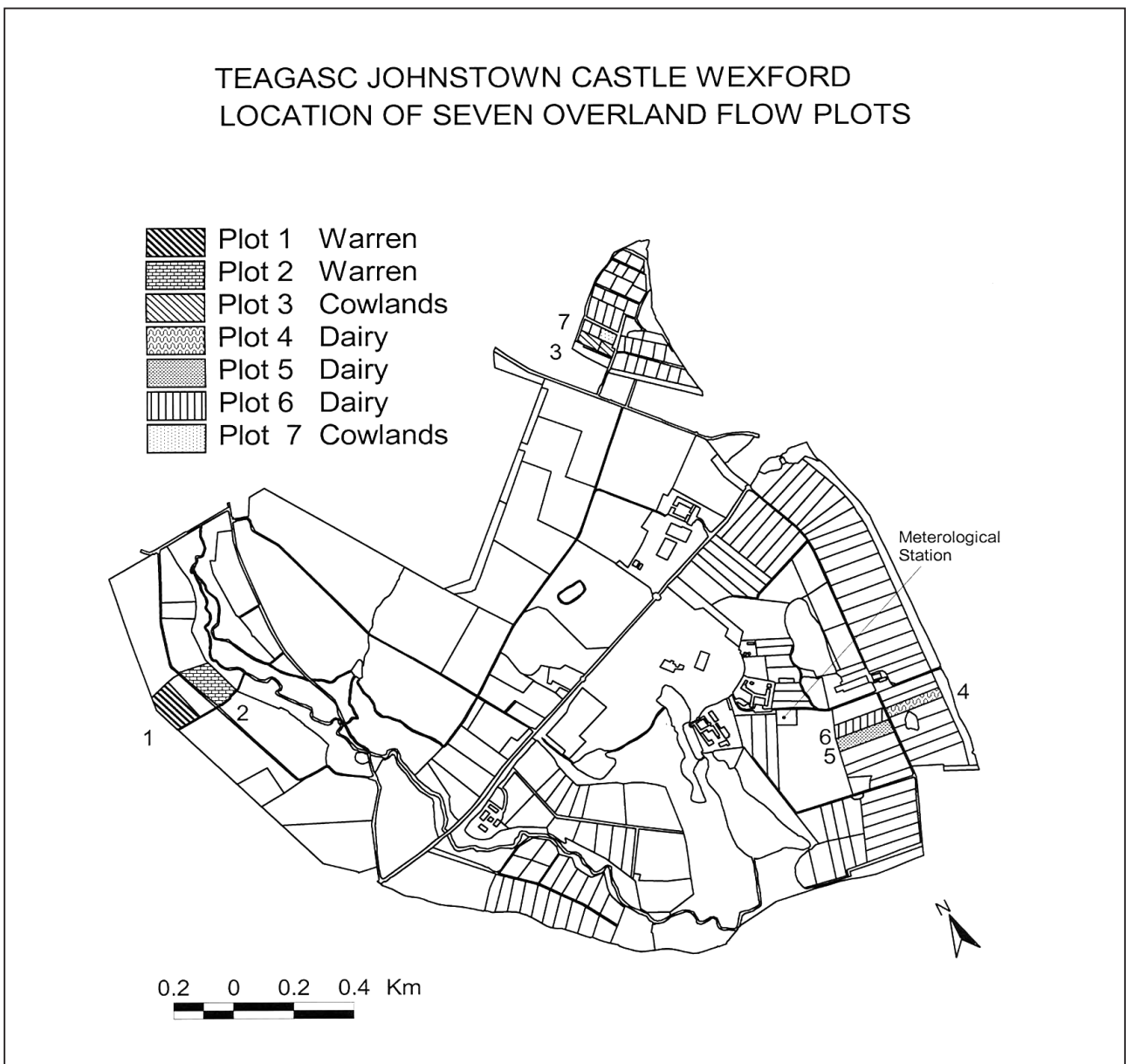


Figure 2: Location of experimental plots and meteorological station at Teagasc, Johnstown Castle, Co. Wexford

1.3 (A) Field-Plot Study – The Impact of the Grazing Animal on Phosphorus, Nitrogen, Potassium and Suspended Solids Loss from Grazed Pasture

Nutrient concentrations and loads from six grazed and cut-field plots (0.24 to 1.54 ha each) were studied in this experiment which started in September 2000 and finished in March 2004, at Teagasc, Johnstown Castle, Co. Wexford. The main results cover the three years 2001, 2002 and 2003. Flow proportional overland flow samples were collected and analysed for P and N fractions; in addition, some samples were analysed for potassium (K), and suspended solids (SS). The results provide information on seasonal difference in nutrient concentrations and loads in the overland flows from the different plots.

1.4 (B) Small-Plot Study: The Impact of the Grazing Animal on Nutrient Losses to Water

The small-plot studies were carried out at four sites over two years (spring 2002 to spring 2004). Two sites (Dairy Farm and Cowlands) were located at Teagasc, Johnstown Castle, Co. Wexford and also at the Teagasc farm, Grange, Co. Meath. Within each field site, 10 small plots (1.5 m x 15 m each) were selected randomly. The experimental plots were assigned to one of two treatments:

- 1 Cattle had unrestricted access to the plot.
- 2 Cattle could graze the plot but they could neither walk on the plot area nor deposit excrements on it.

Soil physical measurements to assess the impact of cattle on soil hydrology were taken at the four study sites. Rainfall simulation (20 to 25 mm/hr) were employed to produce overland flow on subplots (0.5 m² in 1.5 m x 15 m plots) assigned to the grazed and non-grazed treatments on one field plot at the Dairy Farm at Johnstown Castle from late March to early May 2004. The P, N, K, and SS concentrations were measured in overland flow samples to estimate the effect of cattle trampling and excretion on overland flow quality.

1.5 (C) Phosphorus Dynamics in a Grazed Grassland Ecosystem

This study investigated the pools and fluxes of P in grazed grassland. The experiments began in August 2002 and ended in July 2004, and were mainly field (1.5 m² plots) and laboratory based. The experiments provided information on P in soils, dung and overland flow from grazed grassland. The seasonal dynamics of soil P and related soil properties were examined. Dung-pat decomposition and associated changes in P within the dung-pat and soil below it were also examined over the 90-day decomposition periods. In addition, P was characterised in dung from 6 sites receiving different P fertiliser treatments. Phosphorus was also characterised in the rainfall-simulated overland flow samples collected from grazed and non-grazed plots in Study B.

This report gives a synthesis of the main findings, conclusions and recommendations arising from these studies.

2 Main Findings and Conclusions

2.1 Main Conclusion

The principal conclusion from Study A is that while the grazing animal can influence P concentrations in overland flow, this impact is smaller and less consistent than the effect of soil P level on the P concentration in overland flow. The wide variation in P concentrations in overland flow between fields was related predominantly to factors other than the presence – or absence – of grazing animals. It is concluded that accumulated surplus-applied P, reflected in soil test P (STP), is a more important factor than grazing in influencing the P concentration in overland flow.

2.2 Impact of Grazing

The effect of cattle on the quality of rainfall-simulated overland flow from the 0.5 m² small plots (Study B) could not be detected before the start of the grazing season, but was measurable in a number of water-quality parameters after the first grazing cycle. The presence of grazing animals did not influence the dissolve reactive P (DRP) significantly but led to an increase in the concentrations of dissolved and particulate organic and condensed P fractions, K and particulate N in overland flow. The grazing animal had a short-lived effect on the quality of rainfall-simulated overland flow in the small plots.

For some overland flow events, there were significantly higher total P (TP) concentrations (up to double for TP, but not for dissolved P) in the overland flow from grazed compared to cut field plots (Study A).

In the field plots (Study A) the mean annual and monthly DRP concentrations in overland flow were significantly higher on Plots 3 (grazed) and 7 (cut) (STP 17.9 and 16.7 mg/l, respectively) than on Plots 1 and 2 (both grazed in 2002 and cut in 2003) (STP 3.5 and 4.8 mg/l, respectively), in both 2002 and 2003 and in all months where there were

overland flow samples. This is one of the most significant results of this study. Other differences between P concentrations in water flow from the plots were lower in magnitude and less consistent.

A comparison of P forms in rainfall-simulated overland flow (Study C), using ³¹P nuclear magnetic resonance (NMR) spectroscopy, revealed that inorganic orthophosphate was the principal form of P found in rainfall-simulated overland flow samples from grazed and non-grazed small plots collected on 6 May 2004. However, the main differences between the treatments were found in organic P forms. A higher percentage and a more diverse range of orthophosphate monoesters were found in flows from grazed plots compared to non-grazed plots.

Orthophosphate diesters were only found in flows from grazed plots. Approximately 20% of grazed plots had dung cover after the first grazing in 2004 and before the rainfall-simulation study. The higher percentages of orthophosphate diesters (and pyrophosphate, i.e. condensed inorganic P) in grazed plot flows suggest that there was more microbial activity associated with the samples from these subplots, as such P forms are associated with microbial activity.

2.3 Seasonal Effects

In the field plots (Study A), a wash-out effect on P, N and K concentrations was observed in overland flow when it recommenced in the autumn (normally September/October but November/December in 2003) after an extended period of no flow during the summer. The concentrations decreased and stabilised over the following 1 to 2 months. The highest concentrations and loads were associated with high overland flows in autumn and early winter. This is similar to the results found in the three-catchments study (LS-2.1.1a: *Soil and Phosphorus – Catchment Studies*).

2.4 Dung-Pats

The grazing animal and associated dung deposition (Study C) play an important role in increasing the rate at which P is recycled in grassland. Dung-pat decomposition was affected by the seasonality (the study was carried out over 90 days only; the dung was applied in October 2002 and in March, August and September 2003) and the amount of rainfall over the 90-day decomposition period. There was a significant positive relationship between dry-matter content and changes in dung-pat total P over the 90-day decomposition period. The principal mechanism of P entry into the soil from the dung-pat was through physical incorporation, relying on soil fauna and physical degradation of the dung-pat. Leaching of nutrients such as K from dung-pats was important during periods of high rainfall.

Dung-pats affected soil inorganic P and STP significantly. The STP concentrations in soil under dung-pats were shown to increase three- to four-fold over the 90-day decomposition periods. Uneven redistribution of nutrients within grazed grassland, because of livestock standing at drinking troughs, ring feeders and shelter areas and the associated increased soil compaction and run-off potential, may create areas of greater risk of P loss to water.

2.5 Soil Physical Effects of Grazing

In Study B, the presence of cattle led to physical changes in the topsoil. These changes altered the natural drainage characteristics of soil that would be expected to favour the occurrence of overland flow. They had persisted over the winter period when the animals were housed. Recovery of the soil did, however, occur when cattle were excluded from areas over the growing season. As these observations were made with rainfall simulation at small-plot scale, further investigations are needed to determine if the effect occurs at the field scale.

2.6 Additional Conclusions

In the field-plot study (Study A), the concentrations of P fractions in overland flow were positively correlated with STP. SS concentrations in flow proportional overland flow samples from the field plots (measured from November 2003 to March 2004) averaged 45 mg per litre for all plots, and only a small number of samples were over 100 mg/l. Most of these high concentrations were associated with a storm event in spring 2004. Ironically, the highest were on two plots that were not grazed from October 2002 up to the end of the experiment (March 2004).

There were highly significant correlations between the three P fractions measured (dissolved reactive P [DRP], total dissolved P [TDP] and total P [TP]) in run-off from the field plots. On average, DRP made up more than 80% of TDP and over 70% of TP concentrations. There was a significant correlation between total dissolved N (TDN) and total N (TN) concentrations, with TDN making up over 70% of TN, on average. There was also a significant correlation between TP and TN concentrations, and the latter were about five times higher than the former. The N concentrations in overland flow were high on a number of occasions; some of these were associated with heavy rainfall after fertiliser N application and others with the recommencement of overland flow in the autumn.

Significant seasonal variation in soil P fractions (and the other soil properties), particularly STP (ranging 5 to 10.5 mg P l⁻¹), was observed in grassland soil (Study C). Soil temperature, moisture and biological demand (plant, animal and microorganisms) appear to be the key factors responsible for this variation. The soil microbial biomass plays an important role in P cycling in Irish grassland soils. An annual turnover through the microbial biomass of 50 kg P ha⁻¹ yr⁻¹ was calculated.

3 Recommendations

3.1 Action Recommendations

Farm according to good farming practice with minimum STP for optimum grassland production (Index 2, 3.1 to 5.0 mg P and Index 3, 5.1 to 8 mg/l soil. Index 3 for grassland was reduced from 10 to 8 mg P per litre soil by SI No. 378 of 2006). This is in line with recommendations of a previous EPA study (Tunney et al., 2000) on P desorption. It is also in line with results of the current study on the three catchments (LS-2.1.1a). In addition to the increased risk of direct P loss from high STP soils, such soils also contribute to high P in herbage; in turn, this gives rise to high P in the dung and thus to an increased risk of P loss to water.

The complex interactions between agricultural management practices, nutrients in soil, soil biology and nutrient release to water are best addressed by nutrient management planning. Taking into account crop demand, soil nutrient levels and soil hydrological factors, a site-specific nutrient management plan specifies the nutrient needs of a planned crop in a particular field. The plan also describes how these nutrient needs are to be satisfied in order to minimise the risk of nutrient losses to the environment. General agricultural management advice, such as the start and end of the grazing season on the different parts of a farm, are also contained in the nutrient management plan.

Thus, careful balancing of nutrient demand-and-supply and taking account of agricultural and environmental concerns in the timing of agricultural management practices and identifying exclusion zones allows site-specific nutrient management planning to enhance the efficiency of nutrient use in agriculture. It also enables the minimisation of the risk of nutrient loss to water that can lead to eutrophication of adjacent waters. Further study is necessary before it is possible to make definitive recommendations on stock management at a national scale that could reduce P loss to water. However, good grazing management practices and preventing animals grazing when soils are very wet (particularly on high STP soils) should contribute to reducing P loss to water.

Compaction and decrease in macroporosity of the topsoil, which were induced by the presence of grazing animals (Study B), may be remedied by rotating pasture and silage areas on farms. Such fields would need to be cut under dry conditions in order to reduce the soil damage caused by heavy machinery. The possibility of this approach for reducing P loss to water should be researched further at field scale, and should take account of the potential impact on such loss and its practical and economic implications before a national recommendation is made.

3.2 Research Recommendations

As grazing animals were shown to have a substantial effect on particulate N and P levels in overland flow from the small-plot study (Study B), the potential of filter strips (ideally of natural riparian plant communities) to remove nutrients from overland flow before it enters a surface water body merits further investigation.

Research to establish if practices such as ploughing down the P-enriched layer on high STP soils or other approaches (e.g. liming) can be used in the medium term to reduce the P loss in overland flow water from P enriched soils is necessary.

The current study dealt with normal good grazing management. The out-wintering of animals and the use of sacrifice paddocks for winter feeding are potential sources of high nutrient and sediment loss to water and merit study.

Occasional high N levels, including high ammonium and nitrate concentrations, were found in overland flow from the field plots. It is suggested that some of these were related to overland flow commencing soon after fertiliser spreading. This should be studied further.

There were indications at small-plot scale that P concentration in overland flow increased after fertiliser N application in spring. This merits further study.

References

- Drennan, M.J, Carson, A.F. and Crosse, S. (2005). *Overview of Animal Production from Pastures in Ireland*. Proceedings of a satellite workshop of the 20th International Grassland Congress July. Cork, Ireland. (ed.) J.J. Murphy. Wageningen Academic Publishers, The Netherlands, pp. 19–35.
- Environmental Protection Agency (2004) *Ireland's Environment*, EPA, Wexford, pp. 214 and 316.
- SI No. 258 (1998) Department of the Environment and Local Government. Local Government (Water Pollution) Act, 1977 (Water Quality Standards for Phosphorus) Regulations. Government Publications Office, Dublin.
- SI No. 378 (2006) European Communities (Good Agricultural Practice for Protection of Waters) Regulation 2006. Government Publications Office, Dublin.
- Tunney, H., Coulter, B.S., Daly, K., Kurz, I., Coxon, C., Jeffrey, D., Mills, P., Kiely, G. and Morgan, G. (2000). *Quantification of Phosphorus Loss from Soil to Water – Final Report and Literature Review*. Environmental Research, R&D Report Series No. 6. EPA, Wexford.