PHOSPHORUS LOSS FROM SOIL TO WATER

END OF PROJECT REPORT

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SUMMARY

The work described under this project covers field work on phosphorus(P) loss from soil to water under field conditions. In addition two International Workshops on P loss to water, held in Ireland in 1995 and 1998, are also covered under this project. The results indicate that P loss to water is a complex process and it is influenced by a number of factors, including hydrology of the soil, rates and timing of P application and soil P levels. Most work on this subject indicates that there is a positive relationship between soil test P levels and P loss to water. There is need for further work to establish the relative contribution of the different variables involved in P loss from soil to water for different soils and farming conditions. This should help provide answers to the most sustainable methods to minimise losses of P to water and ensure that agricultural production is compatible with good water quality.

INTRODUCTION

Phosphorus(P) loss from soil to water is an important issue for agriculture because it is generally the limiting nutrient in natural ecosystems. It was the limiting nutrient for crop and animal production on Irish soils up to the 1950's, at that time the widespread use of chemical fertiliser started to correct the problem. It is also the limiting nutrient in algal and higher plant growth in inland surface waters. Losses from municipal, agricultural and other sources can contribute to eutrophication. Work in Ireland and other countries indicates that agriculture can be a significant contributor to P loss to water. Phosphorus is now considered the major water quality concern in Ireland and it is believed to be responsible for the increase in mildly polluted waters(eutrophication) in recent years, at a time when there is a decrease in severely polluted waters.

The possible impact of restricting P use and of setting upper limits for soil test P levels is a cause for concern for intensive agricultural production and particularly for intensive pig and poultry units. The EPA has set an upper limit of 15 mg P l^{-1} soil for manure spreading from licensed intensive pig units. Pig and poultry producers import large quantities of P in purchased cereal based feed, most of this P is excreted in the animal manure and setting upper soil test P limits will increase the land area and costs involved in spreading manure.

There is only limited information on P loss from soil to water in Ireland. However, a study of riverine inputs indicate that losses of the order of 0.4 kg P ha^{-1} $year^{-1}$ are typical in farming areas. In a 228 ha minicatchment of the Dripsey in Cork, University College Cork found an average water soluble P loss of 1.9 kg P ha^{-1} $year^{-1}$, which was half the total P loss. Work in 1970's and 1980's by staff of the Agricultural Institute (now Teagasc) found losses as high as several kg P ha^{-1} $year^{-1}$ shortly after spreading chemical fertiliser or slurry. There is some debate as to the relative contribution of agriculture to P loss to water relative to municipal and other sources. A study in 1989 by Cork Co. Council, indicated that 36 tonnes soluble P was discharged over the Iniscarra dam on the river Lee, a predominantly rural catchment with a low population density. Only 6 tonnes of this could be attributed to non-agricultural sources. Therefore, in that catchment, it appears that over 80% of P came from natural background and agricultural sources. In catchments with high population densities a higher proportion of P will come from non-agricultural sources. As the EU Urban Waste Water Directive is implemented a lower proportion of P loss to water will come from municipal sources and a higher proportion will come from agricultural sources.

There is also uncertainty regarding the contribution of farmyards to P loss relative to the contribution from fields where manure or fertiliser has been spread or where the soils have high soil test P levels. The information on this is limited. Phosphorus in manure is associated with the solid matter and is, therefore, less mobile than nitrogen (N) or potassium (K), this is also reflected in the greater mobility of N and K under field conditions.

FIELD EXPERIMENTS

The project that is described in this report was started in 1994. The aim was to estimate the loss of P in water from agricultural soils at two sites at Johnstown Castle Research Centre. At the first site, the Warren (A), a minicatchment of 1.4 ha was isolated hydrologically in the 1980's. In the winter of 1994 the overland flow water and the P content of the water was measured. This was a low P site and was used in an attempt to get a baseline of P losses under low fertility conditions. The second site, at the Cowlands (B), was based on a long term P for grazing experiment, that had three treatments of 0, 15 and 30 kg P ha^{-1} yr^{-1} over the past 28 years. At this site water samples were collected by sponge from the soil surface during heavy rain in an attempt to estimate the P levels that would be in equilibrium with overland flow water. This site was selected because it had a range of soil test P levels, with an average of approximately 2, 7, and 17 mg P l^{-1} soil for the three treatments respectively. This report summarises the results of this work which is the first attempt in Ireland to measure P loss from soil to water under practical farming field conditions.

In addition to the field work at Johnstown Castle an International Workshop, on "Phosphorus Loss from Soil to Water" was held at Johnstown Castle in September 1995. A second International Workshop on the same topic was held at Greenmount College, Antrim, Northern Ireland in June 1998. These Workshops brought together many of the international experts in this area of work for the first time and helped with sharing of information and also helped set a sound basis for future work in Ireland. These workshops also helped cooperation of scientists in Northern Ireland and the Republic of Ireland and the Workshop held at Johnstown Castle in 1995 was held in the context of the developing Peace Process. These workshops were organised as part of this project and a briefly summarised here, however, the papers presented are published and should be consulted by anybody with a special interest in this subject.

A. PHOSPHORUS LOSS FROM THE WARREN CATCHMENT

Method

This catchment of 1.4 ha was set up in the 1980's to measure nutrient loss in overland flow(runoff) and drainage water after spreading animal manures. The experimental site was on a heavy clay soil where runoff is high and with low soil P(2mg P l^{-1} soil of Morgan's P). During the study this catchment was used to get information on P loss from a low fertility soil. It received very little fertiliser of animal manure in the past and received no fertiliser of manure in the previous five years and was cut once per year. The site had a uniform slope to one side of the field and the runoff water from the soil surface was collected in a butyl rubber lined channel and then into a tank with a v notch and automatic height recorder by a pen on paper on a rotating cylinder, this information was used to establish a hydrograph of water flow rates. In addition a proportional flow sampler was installed to sample water for analyses. Similarly drainage water flow and composition was also measured.

Results

The results of water flow and P loss to water, during the winter of 1994-95, from this low P catchment were presented as a Short Communication at the International P Workshop held at Johnstown Castle in September 1995 and published by CABI in 1997. A summary of the results for the winter of 1995-96 is presented here.

The monitoring showed that there was a total of 898 mm of rainfall, in the 29-week period between 1st Oct 1995 and 24th April 1996. This was the period during the year when most runoff occurred. More than a third of the total runoff for the period occurred between 30 th. December 1995 and the 29 th. of January 1996.

The total runoff was 299 mm and the evapotranspiration, during this period was 203 mm. The difference of 396 mm, between rainfall and the sum of runoff and evapotranspiration, is assumed to be flow to drains and groundwater. A total of 69 mm was measured in drain flow from the catchment. Based on the above values 33%, 44% and 23% of the rainfall was accounted for as flow to runoff, drains or groundwater and evapotranspiration respectively.

The heaviest rain and runoff of the period occurred in January 1996. The relationship between rain and runoff for that month is summarised in Figure 1.

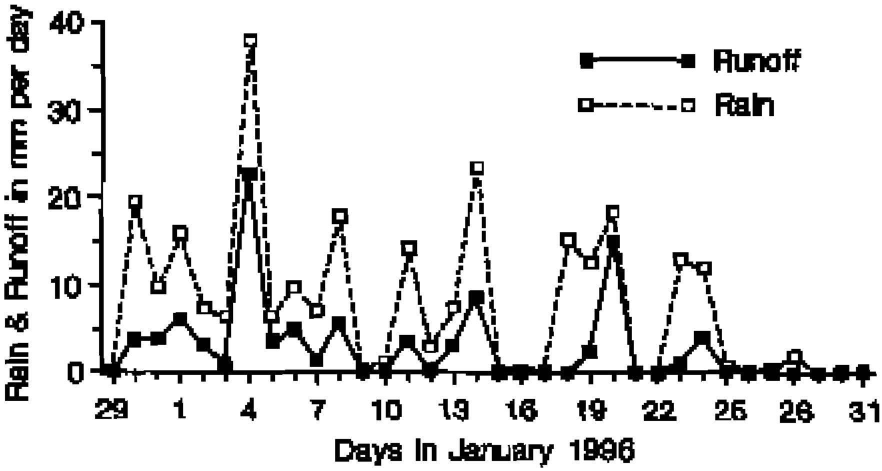

Figure 1. The pattern of rainfall and runoff(overland flow) from the 1.4 ha Warren Catchment for the heaviest rain period in the winter of 1995-96.

Figure 1 shows that in this situation runoff was high during or shortly after heavy rainfall, particularly when runoff occurred after a number of consecutive rainy days. The relationship between rainfall and runoff for January 1996 is summarised in Figure 2.

Figure 2 shows that when rainfall amounts were small, runoff volumes were also low. However, there is a relatively wide variation between rainfall and runoff events. This is dependent on a number of factors, including how dry the soil was before the rainfall occurred and on the quantity of rain that fell in the preceding day or days. Rainfall greater than 10 mm occurred on 11 days and runoff greater than 5 mm occurred on 6 days in the month of January 1996. Between October 1995 and April 1996 there were 15 days with between 5 and 10 mm of runoff and only four days with greater than 10 mm runoff.

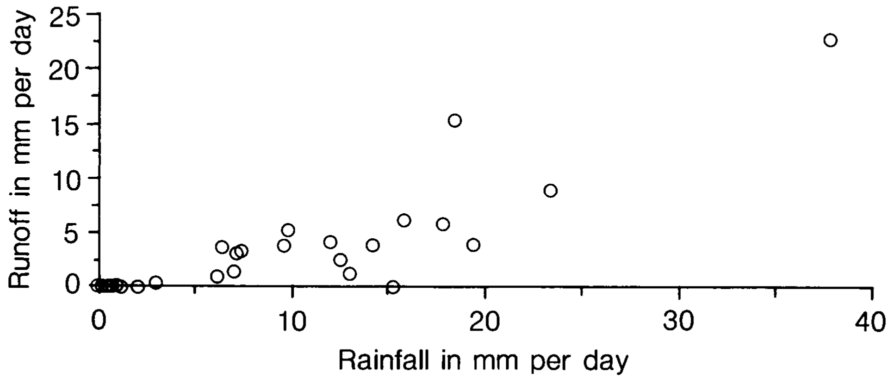

Figure 2. Relationship between daily rainfall and runoff volumes for the Warren Catchment for January 1996.

The molybdenum reactive phosphorus(MRP) in the water was calculated at 0.057 and 0.168 kg P ha^{-1} to the drain or groundwater and to the runoff water respectively, during the period of the study, October 1995 to April 1996. This compares with an estimated input of 0.103 kg P ha^{-1} in the rainwater.

The average MRP in the runoff water, on a weekly sampling basis, varied from 0.005 to 0.39 with an average of 0.098 mg1^{-1} over the 29 week sampling period. The highest P concentrations appeared early in the runoff season(Oct-Nov). There was no significant relationship between the runoff volume and P concentration. It is normal to find a good relationship between flow and P concentration in the runoff from high P soils.

In conclusion this study indicates the relatively low P losses from this low P site. Improvements in the accuracy of water flow recording and water P content were made using digitised flow recorders and samplers, for a follow on study at this site.

B. PHOSPHORUS IN WATER ON SOIL SURFACE IN COWLANDS EXPERIMENT

Method

This work was started in autumn 1994 as a preliminary study to measure P loss in runoff water from soils of different soil P levels, on the long-term P experiment for grazing in the Cowlands at Johnstown Castle.

The Cowlands grazing experiment has had three P treatments of 0, 15 and 30 kg ha^{-1} yr^{-1} over the past 28 years. There is a high and a low stocking rate for each treatment and there are number of plots for each treatment that are grazed by beef cattle during the summer season.

For this study two plots were selected from each of the three treatments for the collection of water samples directly from the soil surface during or immediately after most of the heavy rainfall events that occurred during daylight hours. The water was collected from the soil surface and was considered to be representative of water that would be in equilibrium with runoff water where runoff was likely to occur. Approximately a half litre sample was collected from each of the six plots(0.5 ha each approx.) on each sampling occasion. The water was filtered and analysed for molybdenum reactive P(MRP).

Results

The results of the analyses on 11 sampling occasions between October 1994 and January 1995 are summarised in Figure 3.

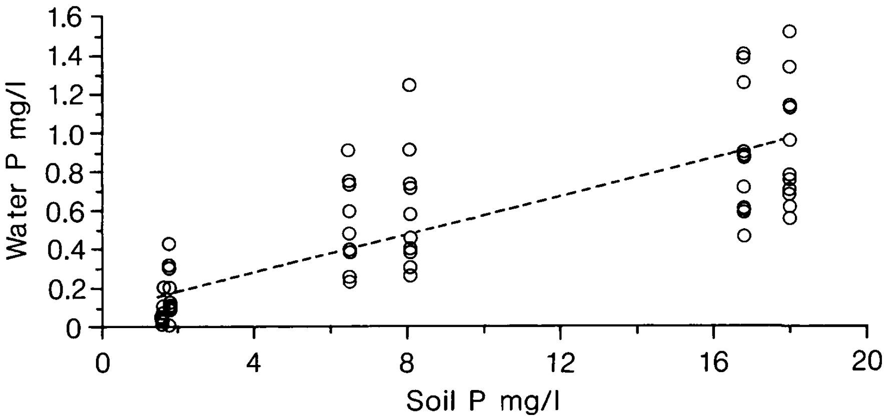

Figure 3. The relationship between the soil test P(Morgans) and the MRP in the water on the soil surface of six plots on the Cowlands experiment, where the water was sampled on 11 occasions during the winter of 1994-95. The equation of the line is y = 0.082 + 0.049 x and R^2 = 0.62 (p=0.95).

Figure 3 shows a wide variation in the P concentration of the water on the soil surface between the different sampling dates. However, there is a significant positive relationship between the soil P levels and the P in the water. The lower soil P levels in Figure 3 are from the zero P treatments, the intermediate levels are from the 15 kg P ha^{-1} treatments and the highest levels are from the 30 kg P ha^{-1} treatments. These results indicate that the soil P loss in runoff water increases as the soil test levels increase. This is in agreement with work in Denmark and the USA that indicates a linear relationship between soil test P and P loss to water.
There was a trend for the P level in the water to decrease with time during the sampling season.

The average P concentration was of the order of 1.0 mg P l^{-1} for the highest P treatment and less 0.2 mg P l^{-1} for the zero P treatment. Overland flow was not measured and was likely to be lower than on the Warren site described above. If it is assumed that there was 200 mm over land flow per year with an average concentration of 1.0 mg P l^{-1} as MRP then the annual estimated annual loss of P, in this form would be of the order of 2 kg P l^{-1}. This is of the same order as the loss from the minicatchment of 228 ha in the Lee-STRIDE study. It is of the order of 10 times higher than the loss for the Warren above. Further the average loss from the zero P treatment can be estimated at less than 0.4 kg MRP ha^{-1} at this site.

In conclusion the results indicate that P loss from soil to water is a complex process influenced by many factors. There is some evidence that the soil test P may have an important influence on the P loss to water and that the relationship appears to be linear. There is need for more work to establish the most important factors influencing P loss to water from agricultural soils and the best approach to minimising these looses.

INTERNATIONAL P WORKSHOPS

As part of this project an international P workshop was organised at Johnstown Castle Research Centre in September 1995. It was attended by 150 scientists from 12 countries. There were 19 invited papers presented. In addition there were 45 posters presentations on all areas of P loss from soil to water. It was the first major international meeting dealing exclusively with this topic. It was sponsored by the Departments of Agriculture in Ireland and the UK as part of the Peace Process, and was attended by ministers from the two countries. The proceedings of this meeting, including the posters, was published by the Centre for Agriculture and Bioscience International(CABI) in 1997. It was edited by H Tunney and O T Carton from Johnstown Castle and P C Brookes and A E Johnston from Rothamsted Experimental Station in England. It has received several good reviews and is considered a valuable reference for people working in this area.

In addition, an OECD sponsored workshop, entitled, "Practical and Innovative Measures for the Control of Agricultural Phosphorus Losses to Water", was organised in Greenmount College, Co. Antrim, Northern Ireland in June 1998. The senior author of this report was involved in organising the Antrim meeting and in editing the proceedings, which are due to be published in the Journal of Environmental Quality in the US in 1999. This brought together experts on this topic from OECD countries. There were 23 invited papers and over 75 poster presentations at the Workshop. These two Workshops have developed contacts and joint projects between experts in different countries. In addition the subsequent publications are a valuable source of information and references for people working and interested in this interesting and sometimes controversial area. Following from the Workshop at Johnstown Castle an EU COST Action on this subject was set up in 1997, with experts from 15 European countries participating.

CONCLUSIONS

The conclusions to be drawn from the results and Workshops described here is that P loss from agriculture to water is a cause for concern in Ireland and many other countries. The limited results available in Ireland indicate that P loss from low fertility and low intensity grassland is low, of the order of 0.2 kg ha^{-1} year^{-1} of water soluble P. However, results indicate that total losses on intensive grassland, from all sources including losses after spreading manure and fertiliser and in losses direct from farmyards may be ten times higher than the above background levels. These results are in broad agreement with results from other countries. Losses of the order of 1 to 2 kg ha^{-1} year^{-1} can be considered very high in terms of water quality. These levels of losses would lead to average P concentrations in water in the region of 0.2 to 0.4 mg P l^{-1} or about 10 times higher than the level considered necessary to prevent eutrophication and maintain good water quality.

The work, however, does not indicate the relative contribution from the different agricultural sources or how the losses can best be minimised. Teagasc has recently revised its P recommendations for grassland and significant reductions in fertiliser recommendations have been made. Work at Johnstown Castle indicates that many farmers are importing and applying excess levels of P to their farms each year in the form of feeds and fertilisers. A good start is to ensure that the Teagasc guidelines for fertilising grassland are followed. This will help ensure that optimum production is achieved and input cost are minimised, while at the same time helping to maintain good environmental quality.