Phosphorus from Farmland to Water in Sweden

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ABSTRACT For a long time, research devoted to nitrogen (N) leaching and turnover in agricultural soil has been considerably more comprehensive than that into phosphorus (P) turnover, and losses and management in Sweden. Phosphorus is lost from agricultural land through being mobilized and transported away with running water. There are great variations in the amounts of P lost from agricultural land in different parts of the country as a result of differences in soils, soil hydrology and agricultural production. There are also large regional differences in the form in which the losses occur. Dissolved reactive phosphorus (DRP) can constitute 20-70% of total P in water. Drainage losses can make up between 10-70% or more of P transport. Long-term transport of total P in small agricultural streams in Scandinavia usually varies between 0.1-0.8 kg ha^{-1} yr^{-1}. In southern Sweden, phosphorus concentrations have been declining in recent years at a rate of around 2% per year (1993-2004)(Ulén & Fölster, 2007). To focus prevention efforts against P flow, a conditional d risk index for P has been drawn up in which each individual field is assessed (Djodjic & Bergström, 2005).

INTRODUCTION

From the beginning of the 1950s and up until the middle of the 1970s, large amounts of artificial fertiliser were applied to farmland to increase yields. In addition, the soil received farmyard manure relatively often without any consideration being given to its value as a phosphorus fertiliser. After 1975, the amount of artificial fertiliser used in Sweden decreased rapidly. In recent years the use of manure has also decreased with the decline in livestock farming. Total P fertilisation is now down at the same level as it was a hundred years ago. The P fertilisation in Sweden is generating a surplus of on average 2 kg P ha^{-1}. The value is highest in livestock-intensive areas, whereas in cereal growing areas without livestock there is often a deficit. However, net accumulation is small in relation to Western Europe and at the same level as several countries in Eastern Europe

In Sweden, an agronomic soil analysis is used to determine the concentration of dissolved phosphorus in the soil, based on extraction with acid ammonium lactate (P-AL) according to Egnér et al. (1960). This method is suitable for the relatively acidic Scandinavian soils and generally gives higher values than other extraction methods used in Western Europe and around the Baltic Sea (Neyroud & Lischer, 2003; Csato et al., 2007). This is due to calcium-bound P being dissolved out of soils with high lime content. The mean value of P-AL in Sweden is 106 mg P kg soil^{-1} (Eriksson et al., 1997), which corresponds to the second highest (4) of five classes used to categorise available phosphorus in soil.

MITTIGATION OF P LOSSES

Infiltration of water into frozen soil is mainly governed by the soil structure and the water content of the soil at the time of freezing. Air-filled macropores in frozen soil can also pose a risk of phosphorus losses, since water with its content of dissolved or particle-bound phosphorus can be rapidly transported downwards in the soil. Ulén (1995) demonstrated that considerable leaching losses can occur in such conditions. A marked reduction in leaching losses of P can be achieved by incorporating fertiliser at the time of application (Djodjic et al., 2002).

The prevention of erosion demands systematic and often comprehensive efforts. However, it is important to take action in fields where erosion causes P losses, not just where erosion occurs, since erosion is not necessarily associated with losses of P. In actual fact, large P losses can occur even during periods with low rainfall intensity and small erosion losses. However, knowledge within this area needs to be improved and to encompass not only particle bound P but also P bound to colloidal material (Ulén, 2003, Ulén 2004).

There is often a greater accumulation of particles in a vegetation filter than of P. Several studies (e.g.Ulén 1997) mention that with vegetation filters in cold regions there is a risk of the plant material in the filter freezing. This can lead to increased losses of P since freezing bursts the cell membranes and releases the P in the plant cells, which is then carried away by runoff water. Increased P losses as a result of freezing of plant material has also been demonstrated in Swedish studies (e.g. Ulén & Kalisky, 2005; Torstensson et al., 2006).

A number of studies have shown that P losses are lower in tilled soil compared with undisturbed. However, there are also studies showing that soil tillage does not have this effect. In a Swedish study, this was explained by macropores in the topsoil being recreated by repeated freezing/thawing and the resultant fracturing of soil aggregates (Djodjic et al., 2002). Another explanation may be that soil tillage contributes to percolating water having a longer retention time in the P-rich topsoil layer, which means that leaching increases. However, in the subsoil the structure is relatively unaffected and the downward transport of P through macropores to the drain system can be rapid. One way to decrease leaching of P would be to promote rapid flow in the topsoil through e.g. breaking up the plough pan, while another would be to decrease the flow velocity in the subsoil through e.g. deep ploughing. Some studies have shown that P leaching decreases substantially after ploughing to greater depth in certain conditions, although this has not been tested in Sweden.

The disturbed backfill soil over a tile drain represents a good pathway for generating rapid P transport in the soil similar to the flow through macropores, especially in the first few years after drain installation. Based on the assumption that 2.5% of the soil volume in a newly tile-drained clay soil is made up of backfill (0.5 m wide pipe trench and 20 m drain spacing), it is obvious that the backfilling method has a great impact on e.g. P losses from drained arable soil. A method developed for clayey soils in Finland (the FOSTOP method, Nordkalk Oy Ab) involves incorporating burnt lime (CaO) with the backfill material in drains. The result is a stable and porous backfill that efficiently binds the phosphorus in percolating water. The lime filter drain, as the method is often known, thus acts as a mini chemical treatment plant. The lime requirement has been determined in trials to be 3-8% of soil wet weight. In addition to P removal, the lime filter drain can also lead to improved drainage in impervious clay soils and can thus contribute towards decreasing erosion. The average lifetime for the lime filter drain has been shown to exceed 10 years without any loss in treatment effect. In Sweden, the method has only been tested at one experimental site (Lindström & Ulén, 2003) and the long-term effects have not been monitored.

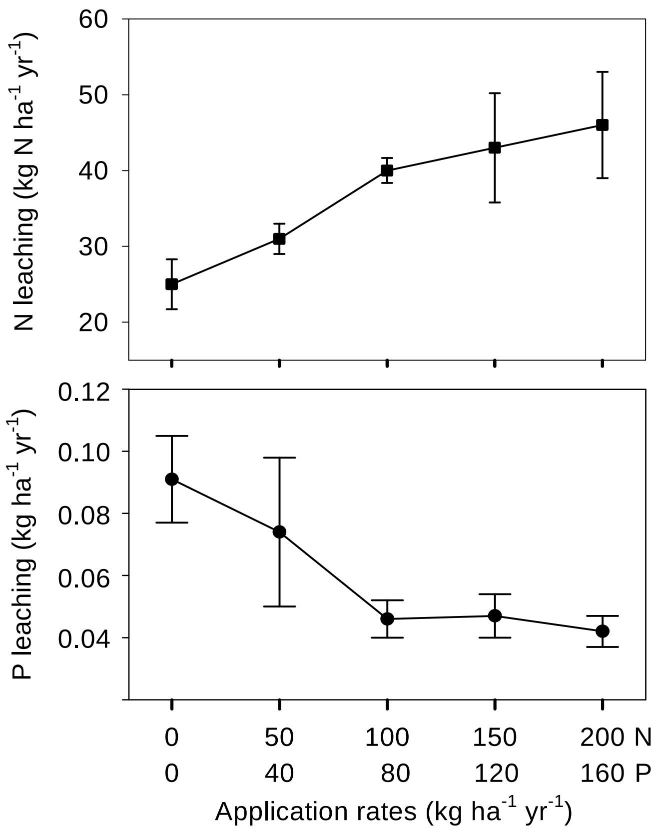

Fig. 1. Leaching of nitrogen and phosphorus with increasing doses of pig slurry on a sandy soil (source: Bergström & Kirchmann, 2006).

An alternative proposed in recent years is to limit drain runoff from tile-drained fields through controlled drainage, i.e. by raising the water level in the field (Wesström, 2002). A condition for this is that the field is relatively flat. However, the resulting reducing conditions that develop in the soil can lead to the release of iron phosphate compounds, which in turn leads to greater losses of DRP.

Another option to reduce the risk of P leaching is to grow crops such as lucerne, which due to their deep root system have the capacity to take up large amounts of phosphorus from the soil without any being added, a process usually referred to as mining. At harvest, the P is then removed from the field. However, the difficulties in establishing a dense lucerne crop can decrease the effect (Ulén & Mattsson, 2003). Perennial ley crops are generally better suited to mining than cereal crops and the practice works best on soils with high phosphorus levels.

Large leaching losses of P are often associated with large phosphorus doses applied with manure and artificial fertiliser. However, this is not necessarily always the case. In a Swedish lysimeter study measuring phosphorus leaching from five soils that had received increasing doses of artificial fertiliser P since the 1950s, it was found that in three of these soils leaching tended to decrease with increasing phosphorus supply (Djodjic et al., 2004). The explanation given was that the ability of these soils to release P s varied and that the way P was transported through the profile was different in different soils. In another study, leaching of N and P was investigated in a sandy soil given increasing doses of manure over two years (Bergström & Kirchmann, 2006). As expected, N leaching increased as a result of higher doses of manure, but leaching of P decreased). A P dose of 320 kg P ha^{-1} during the two-year period gave lower leaching than when no P was supplied. An explanation for this unexpected result could be that application of manure increases the pH in the topsoil, leading to the formation of relatively insoluble calcium phosphates and a decrease in leaching. However, it is impossible to confirm whether two years of manuring were sufficient to alter the binding conditions for phosphorus in the soil in the example cited. Nevertheless, it is obvious that the studies described above indicate that there is no unequivocal relationship between phosphorus application and P leaching.

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