Identification of key factors for reducing N and P leaching from organic crop rotations

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Abstract

Leaching of nitrogen (N) and phosphorus (P) for different 6-year organic crop rotations was examined in separately tile-drained field plots on two different sites in southwest Sweden. On each site, two different farming systems, one with dairy cows and one without stock, were evaluated to identify parts of the crop rotations with the greatest risks of N and P leaching and to examine the scope for improvement. Although organic farming methods themselves already led to a reduction in nutrient leaching, critical periods in the crop rotation could nevertheless be identified for the two soil types. While P leaching is of major importance on clay soils, sandy soils are strongly susceptible to N leaching. From the present study it could be concluded, that key factors for reducing N and P leaching from clay soils are late ploughing, avoidance of early incorporation of clover-grass leys in order to sow a winter cereal, the use of undersown crops and an even distribution of nutrients within the crop rotation. For the sandy soil, where measures like undersown crops and spring tillage were already integrated in the studied crop rotation, potato cultivation and application of farmyard manure were identified as the main sources of N losses to the drainage water.

Introduction

The Baltic Sea is exposed to high nutrient loads, leading to severe outbreaks of algal bloom. Nitrogen (N) and especially phosphorus (P) are the sources of this eutrophication and agricultural activities are substantially responsible for a large share of these nutrients to the sea. In Sweden, 47% of the total N and 40% of the total P load to the Baltic Sea are estimated to come from agricultural land. Leaching is the main source for these nutrient losses as in Sweden surface runoff is not a significant factor. Organic agriculture, with its reductions in animal density and use of fertilizers, offers a form of agricultural land use which may make it possible to reach the intended reductions of non-point pollution from agricultural land as defined in international agreements such as the Water Framework Directive and the Baltic Sea Action Plan. However, some components of organic crop rotations are subject to considerable nutrient leaching. For example, clover-grass leys (CG), which are a central component of organic crop rotations in order to supply the system with N, need to be incorporated into the soil and this incorporation has often been reported to cause a high release of mineral N in the soil (e.g. Lindén & Wallgren 1993). Preliminary observations indicate that the incorporation of CG might also be a critical stage for P leaching (Ulén *et al.* 2005). On the other hand, N leaching during the growth of CG has been shown to be low and the same seems to be true for P losses (Ulén *et al.* 2005). Therefore, whole crop rotations instead of just single components need to be considered when studying nutrient losses from organically managed farmland to the water. Currently, Sweden is

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one of the EU-27 countries with the highest percentage of organic farming (12.5% of the total arable land), a share which is still increasing. This shows the importance of taking this farming method into account when trying to identify key factors for reducing nutrient leaching from agricultural land. It was therefore the aim of the present study to monitor N and P losses from organic crop rotations with and without livestock and to figure out, which parts of the crop rotation are most exposed to leaching risks and have to be improved. The study uses observed data for the amounts of N and P in drainage water from different organic crop rotations at two sites with different soil types in southwest Sweden.

Materials and methods

The two sites used for the present study represent two common soil types used for agricultural production in Sweden: (1) a clay soil and (2) a sandy loam (Figure 1). On both sites, independently tile-drained plots with a surface area of 0.16ha (40x40m) and drainage pipes at an average depth of 1m were used to collect drainage water for analyses for tot-N and tot-P. Crop biomass was sampled, dried at 50°C and analyzed for N and P content.

(1) Lanna, 58°21'N, 13°08'E;
Ø annual temperature 6.1°C,
Ø annual precipitation 558mm;
Uderic Haploboroll; **clay**/silt/sand/gravel
47/46/6/1 (0-30cm), 56/41/3/0 (30-60cm)

(2) Mellby, 56°29'N, 13°0'E;
Ø annual temperature 7.2°C,
Ø annual precipitation 803mm;
Fluventic Haplumbrept; clay/silt/**sand**/gravel
9/14/**77**/0 (0-30cm), 2/7/91/0 (30-60cm)

Figure 1: Map of south Sweden with the sites and soils used in the study

The 6-year crop rotations, representing organic crop production with livestock (+L) and without livestock (-L) are described below. Vegetation covers during the winter are given in brackets. The abbreviation BF stands for bare fallow.

(1) clay: +L: **1**=winter wheat (BF), **2**=broad bean (BF), **3**=spring barley (BF), **4**=oat (insown CG), **5**=CG (CG), **6**=CG (freshly sown winter wheat)

-L: **1**=winter wheat (BF), **2**=broad bean (BF), **3**=oat (insown CG), **4**=CG (BF), **5**=spring wheat (insown CG), **6**=CG (freshly sown winter wheat)

(2) sand: +L: **1**=oat (insown ryegrass), **2**=oat-mixture (insown ryegrass), **3**=potato (freshly sown rye), **4**=spring barley (insown CG), **5**=CG (CG), **6**=CG (freshly sown oil seed rape)

-L: **1**=oat (insown CG), **2**=CG (CG), **3**=potato (freshly sown rye), **4**=rye (insown CG), **5**=CG (CG), **6**=spring wheat (insown CG)

Although crop rotations were designed including as many catch crops as possible growing during the winter, bare fallow after autumn ploughing appeared 3x in the crop rotations on the clay soil. This was because spring ploughing is not practical on this site. There was no autumn ploughing on the sandy soil, with one exception in +L, where CG was incorporated in late summer before the sowing of oil seed rape.

In order to take the effect of year into account, the same components of the crop rotation were grown in different years. This means that each of the 6-year crop rotations circulated on six field plots with two replicates, so that three of the crops in the rotations were present every year. CG was cut 2-4 times in each crop rotation. However, while biomass was left on the field in –L, it was removed for forage production in +L and returned as slurry (return of nutrients: clay 295/42 and sand 426/70 kg N/P ha^{-1} over the 6-year crop rotation).

Results

The sandy soil showed higher leaching of N to the drainage system than the clay soil, while for P leaching the opposite was the case (Figure 2). Mean annual N leaching loads were 6.8 and 9.1 kg ha^{-1} (clay) and 32.1 and 23.7 kg ha^{-1} (sand) for +L and –L, respectively. For P leaching the values were 0.39 and 0.55 kg ha^{-1} (clay) and 0.20 and 0.15 kg ha^{-1} (sand). For both N and P, the +L crop rotation showed significantly lower leaching compared to the –L crop rotation. On sandy soil the opposite was the case for N and no significant difference between the farming systems was found for P.

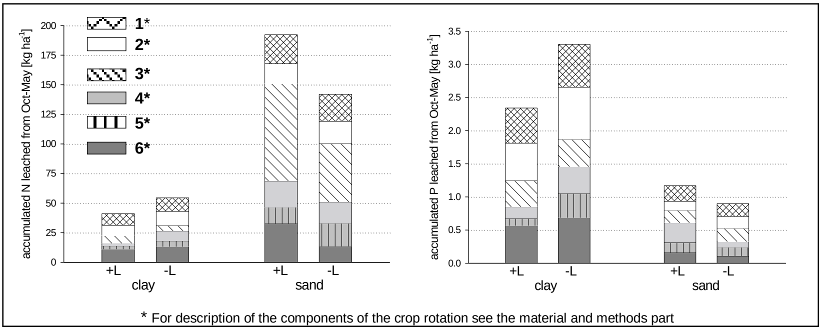

Figure 2: Amounts of N and P leached (October till May) from the different 6-year crop rotations (+L, -L) on clay soil and sandy loam

On the clay soil, the drainage periods during the growth of freshly sown winter wheat (**6**), BF after winter wheat (**1**) and BF after broad bean (**2**) were most exposed to N and P leaching (Figure 2). On the sandy soil, the drainage periods with freshly sown rye after potatoes (**3**) and freshly sown oil seed rape after incorporation of CG (+L: **6**) showed the highest N leaching, while for P leaching no difference between the components of the crop rotation was determined. N losses through leaching after potatoes corresponded to 164% (+L) and 82% (-L) of the harvested amount of N.

Discussion and conclusions

In a national survey for 2005 the estimated yearly nutrient losses from agricultural land in the studied areas were on average 25.0 and 46.6 kg N/ha and 0.56 and 0.65 kg P/ha for the clay soil site and the sandy soil site, respectively (SwEPA 2005). The lower leaching losses from the present study indicate that organic farming methods may lead to below average nutrient leaching. However, the results also show that some components in the crop rotation are more susceptible to nutrient leaching than others. Two conclusions are that there is room for improvement with respect to crop rotations and that different soils require different measures.

On clay soils, choosing a late date for ploughing/incorporation of CG seems to be an important measure to reduce N and P leaching, which in turn means that winter cereals are not suitable after CG incorporation. Lower nutrient losses in the +L crop rotation compared to the –L crop rotation indicate that effective measures to reduce nutrient losses include (i) allowing for only one CG incorporation through the use of biennial CG and (ii) distributing nutrients more evenly within the crop rotation by removing CG biomass and returning the nutrients in the form of manure. Stinner *et al.* (2008) reported that the positive effect of (ii) could also be reached when harvested CG material was digested in a biogas digester and digestion effluents were used as a fertiliser within the crop rotation. This could therefore be a possibility for stockless organic farms on clay soils to increase N use efficiency and reduce N losses. Phosphorus losses were highest after broad beans. This may be due to the tap root system of the beans leading to an increase in the occurrence of macropores. Undersown CG could be a possible countermeasure for reducing these losses, as the present study shows that on clay soils, CG is not only a useful catch crop for N but also for P.

On sandy soils, phosphorus leaching is less severe and as a result measures can target the reduction of nitrogen leaching. One key factor is the reduction of the residual soil N content and this is why undersown crops, catch crops and spring tillage were included in the studied crop rotations. However, the drainage periods after potatoes showed very high N losses even though rye was sown 3-4 weeks after the potato harvest. Reents & Möller (1999) found that sowing a winter cereal immediately after potato harvest can be more effective in reducing residual soil N than sowing it a few weeks later. Haas (2002) suggested undersown crops in potatoes as a useful measure to reduce residual soil N. However, as potato will always be a critical crop in terms of nitrogen leaching on sandy soils, other measures suitable for organic farming methods, for example the use of N efficient potato varieties (Shreshta *et al.* 2010), should also be taken into account. From the +L crop rotation can be seen, that incorporation of CG in early autumn in order to establish a new crop should be avoided. Higher N leaching from the +L crop rotation additionally highlight the importance of N management and cautious farmyard manure application on sandy soil.

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