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ScienceDirect
Europ. J. Agronomy 27 (2007) 102–114
European Journal of Agronomy
www.elsevier.com/locate/eja

Permissible manure and fertilizer use in dairy farming systems on sandy soils in The Netherlands to comply with the Nitrates Directive target

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Received 26 June 2006; received in revised form 20 February 2007; accepted 20 February 2007

Abstract

Properly managed manures have a high fertilizer equivalency and are thus a valuable source of nutrients in forage production systems. An efficient utilization of these nutrients, however, is limited by the crop's demand for nitrogen (N) and phosphorus (P). Moreover, environmental goals implied by the EU Nitrates Directive impose constraints on the use of manure and mineral fertilizer. Through calculations based on experimental data from various sources, the present study explores the limits on the use of cattle slurry and mineral fertilizer in grass and silage maize production on sandy soils in the Netherlands. The study concludes that cut grasslands can utilize cattle slurry up to average rates of 330–340 kg N/ha (120 kg P_2O_5) per year without exceeding a target value of 11.3 mg nitrate-N/l in the upper groundwater or accumulating P in the soil, provided that (i) appropriate amounts of mineral fertilizer N are supplemented, and (ii) growing conditions are good and the grassland is well-managed. When grassland is commonly used for both cutting and grazing, slurry rates have to be reduced by 60 kg N/ha per year (20 kg P_2O_5) to achieve these targets. Similarly, not more than 170 kg slurry-N/ha (60 kg P_2O_5) per year should be applied to silage maize. When grown on dry soils susceptible to leaching, slurry rates on maize land need a further reduction to 155 kg N/ha per year (=55 kg P_2O_5). When grass and maize are grown in rotation, cattle slurry and fertilizer applications to maize should be reduced even more drastically, whereas application rates to grassland can be extended to compensate for the temporal investment in the new sod. Consequently, from the point of view of N leaching and P accumulation, manure rates should be determined by (i) the harvest regime of the grass, (ii) the proportions of grass and maize in the farm area and the way they are positioned in a rotation, and (iii) the susceptibility to leaching (i.e. the hydrological situation). The study also indicates that reductions of 50–60 kg and 25–30 kg slurry-N/ha per year are required in grassland and maize, respectively, if growing conditions or cropping management are suboptimal.

Keywords: Dairy farming; Leaching; Management; Manure; Modelling; Nitrates Directive; Nitrogen; Phosphorus; Sandy soils

1. Introduction

Sustainable crop production requires nitrogen (N) and phosphorus (P) inputs to compensate for the N and P removed from the system by exported produce and losses (Carton and Jarvis, 2001). Losses of N and P are positively related to input levels and negatively related to their use efficiency, i.e. output–input ratios. Agricultural losses should be minimized as they largely determine the quality of water bodies (Tunney et al., 1997; Rabalais, 2002). In view of the negative relationship between animal density and water quality on a European scale, the European Union (EU) Nitrates Directive (Anonymous, 1991) has set 170 kg manure-N/ha per year as a precautionary application threshold for regions that are vulnerable to N leaching. Manure application rates however, are at most indicative of environmental quality and not necessarily effective as environmental effects are determined by all inputs and outputs together instead of the manure input only. Farming in general and livestock production in particular, is undeniably associated with the risk of exceeding the EU target of 11.3 mg nitrate-N/l water, especially because manures are inherently difficult to manage (Schröder, 2005). Manure management on grassland and maize deserves special

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doi:10.1016/j.eja.2007.02.008

scrutiny in the Netherlands; these two crops occupy almost 80% of the agricultural area in regions with sandy soils, the soil type most sensitive to N leaching (http://statline.cbs.nl). Due to the favourable climate in The Netherlands and the presence of ample irrigation equipment on farms growing grass and maize (Schröder et al., 2005a), forage yields and thus N outputs belong to the highest in Europe (Peeters and Kopec, 1996). Moreover, similar differences between inputs and outputs, i.e. N surpluses, may result in completely different N losses to water bodies due to differences in climate, hydrology, management and land use (Schröder et al., 2004). P also poses a threat to water quality, whenever input rates exceed removal via crops, as accumulated P may eventually leach as well.

The aim of this paper is (i) to estimate which soil N surplus can be permitted on sandy soils without exceeding the target of 11.3 mg nitrate-N/l groundwater, (ii) to explore via modelling which rate combinations of fertilizer N and cattle manure N applied to grassland and maize achieve this nitrate target without depleting or accumulating soil-P pools, and (iii) to check to what extent these rates support the specifications of the EU Nitrates Directive.

2. Materials and methods

2.1. General

Water quality under and on agricultural land is determined, among other factors, by the discrepancy between N and P inputs and outputs to and from that land (i.e. the surplus per unit area) and the loss pathways of this surplus. In order to relate (allowable) inputs to (required) water quality and vice versa, it is crucial to assess and define inputs and outputs and the fate of their difference in any model.

2.2. Input

In our model we define N input as the sum of manure-N (so, minus the gaseous N losses from housing and storage), mineral fertilizer N, soil mineral N at the onset of the growing season (SMN_{spring}), deposition of atmospheric N, biologically fixed N and N mineralized from soil organic matter. Sources of this mineralization are crop residues (including roots, stubbles, harvest losses and winter cover crops), and manure applied in previous years. Of these inputs manure-N, mineral fertilizer N and atmospheric N are the external inputs, the others represent internal fluxes (Fig. 1).

We assume a SMN_{spring} input of 30 kg N/ha (Schröder et al., 1998) and an annual atmospheric deposition of 31 kg N/ha (Anonymous, 2004). We estimate that on an annual basis 75 kg N/ha is mineralized from grass roots and stubbles (Velthof and Oenema, 2001), 25 kg N/ha from maize roots and stubbles (Schröder, 1991) and 40 kg N/ha from winter cover crops grown after maize (Schröder et al., 1996). These contributions to mineralization can only be sustained through similar annual inputs into the soil organic N pool. Likewise, the N mineralization from manure inputs in previous years is also accounted for. Our calculations are restricted to cattle slurry which is by far the dominant manure type on farms growing grass and maize in the Netherlands (Menzi, 2002). The long term residual N mineralization from cattle slurry (i.e. beyond the first 12 months after

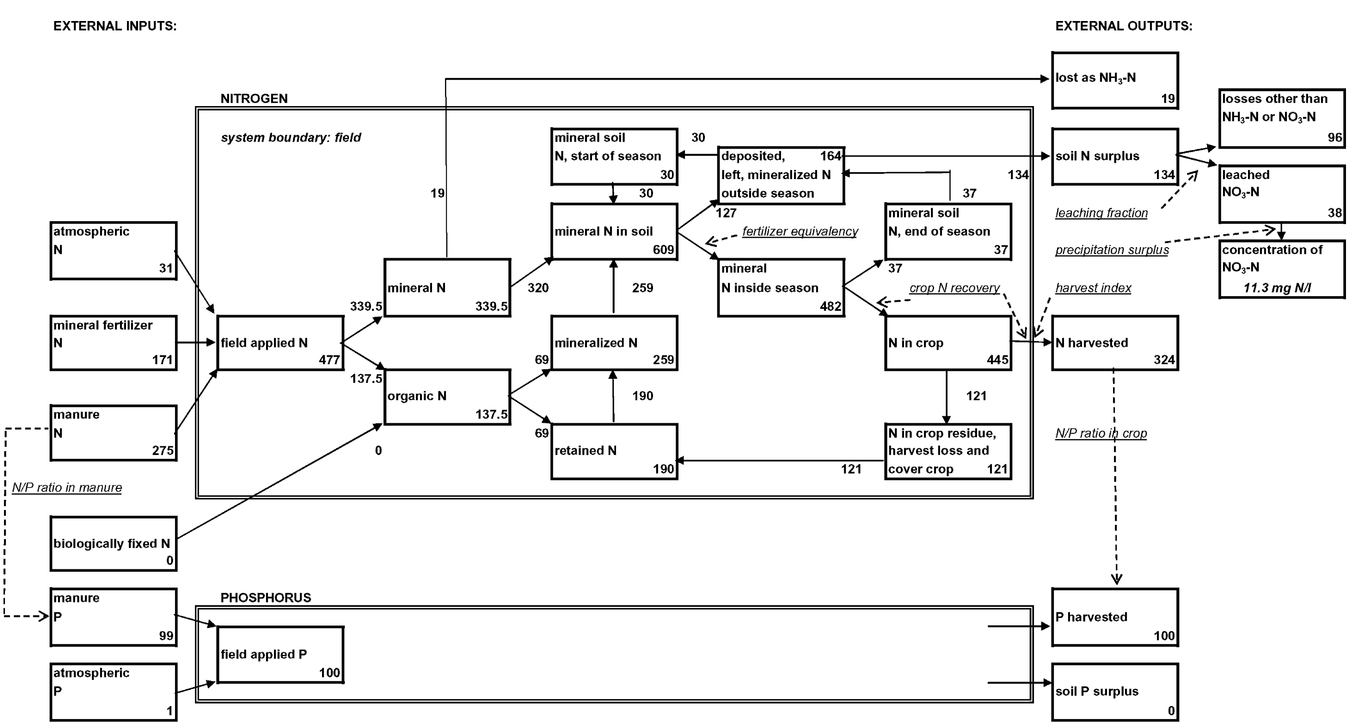

Fig. 1. Flow diagram of external N inputs and outputs and internal N fluxes in the present model, including a numerical example referring to grassland under good growing conditions and management with a mixed use of cutting and grazing, grown on a sandy soil with a mean highest groundwater table between 0.40 and 0.80 m below the soil surface.