Agriculture, Ecosystems and Environment 192 (2014) 67–79

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Environmental performance of nitrogen fertiliser limits imposed by the EU Nitrates Directive

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ARTICLE INFO

Article history:
Received 7 September 2013
Received in revised form 19 March 2014
Accepted 24 March 2014
Available online 30 April 2014

Keywords:
Balance method
Dose response curve
Flanders
Nitrates Directive
Nitrogen fertilisation rate

ABSTRACT

Despite positive nitrate (NO_3^-) concentration trends in surface waters and, to a lesser extent, ground waters, NO_3^- losses from agricultural soils in Europe must further decrease. A strict limitation of the nitrogen (N) fertiliser application rates is considered to be the best N management strategy to minimise NO_3^- losses to surface and ground water. This limitation, however, has also to be seen in view of plant N uptake characteristics.

Yield and nitrogen dose response curves and residual soil mineral N (RSMN) contents at harvest were tested to scientifically substantiate fertilisation rates and limits. We re-analysed field experiments on cut grassland, silage maize, potatoes, sugar beets and winter wheat with various N fertiliser application rates at various locations in Flanders and northern Wallonia. The aim was to derive yield/crop N uptake and RSMN values at all N levels to derive optimum effective N fertiliser application rates for all of these crops. The relationship between yield/N uptake and effective N fertilisation rates were deduced from these N dose response curves. The RSMN was consistently low for cut grassland, sugar beets and winter wheat. For potatoes and silage maize, the maximum allowed N fertilisation rates resulted in relatively high RSMN. This puts a limit on the allowed N fertilisation rates for these crops.

Minimising the RSMN whilst maintaining crop yields requires a correct understanding and quantification of all parameters of the soil mineral N balance (SMNB). The N dose response curves combined with RSMN values and all other factors of the SMNB during the cropping period allow to calculate the N surpluses. Furthermore, the N dose response curve, the RSMN and N surplus calculated for the cropping period give an indication of the efficiency of the applied effective N and can be used as a basis for a rational N fertilisation advice and maximum allowed N fertilisation rates.

1. Introduction

Despite intense efforts over the past two decades to increase nutrient efficiency and to reduce nutrient losses, eutrophication by nutrients from agricultural sources remains a major environmental concern. To protect ground and surface waters against pollution caused by nitrate (NO_3^-) leaching from agricultural sources, the European Nitrates Directive (91/676/EEC) has imposed a maximum concentration level of 50 mg NO_3^- L^{-1} (Anonymous, 1991b). In most Member States agriculture is responsible for over 50% of the total nitrogen (N) discharge to surface waters (Anonymous, 2010). Flanders (the northern part of Belgium) is an example where increasingly stringent legislation and farmers' efforts have resulted in a downward trend in the NO_3^- concentration in surface water of the rural area as compared with the start of the measurements in 1999 (Fig. 1, left). The average NO_3^-concentrations have decreased from 35 mg NO_3^- L^{-1} (July 1999–June 2000) to 21 mg NO_3^- L^{-1} (July 2012–June 2013). However, 26% of the sampling points still exceeded the limit of the Nitrates Directive at least once between July 2012 and June 2013, especially during winter time. In ground water, average concentrations of 36 mg NO_3^- L^{-1} in autumn 2012 were found in the shallowest ground water about one meter below the water table (Fig. 1, right) (Overloop, 2013).

The evolution depicted here (Fig. 1) is representative for other European regions with intensive agriculture, and demonstrates that despite the positive trends for both surface and to a lesser extent for ground water, compliance with the Nitrates Directive requires a further reduction in N losses from European agricultural soils (Anonymous, 2010). This must be achieved by establishing codes of good agricultural practices (GAP). In nitrate-vulnerable

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http://dx.doi.org/10.1016/j.agee.2014.03.049
0167-8809/

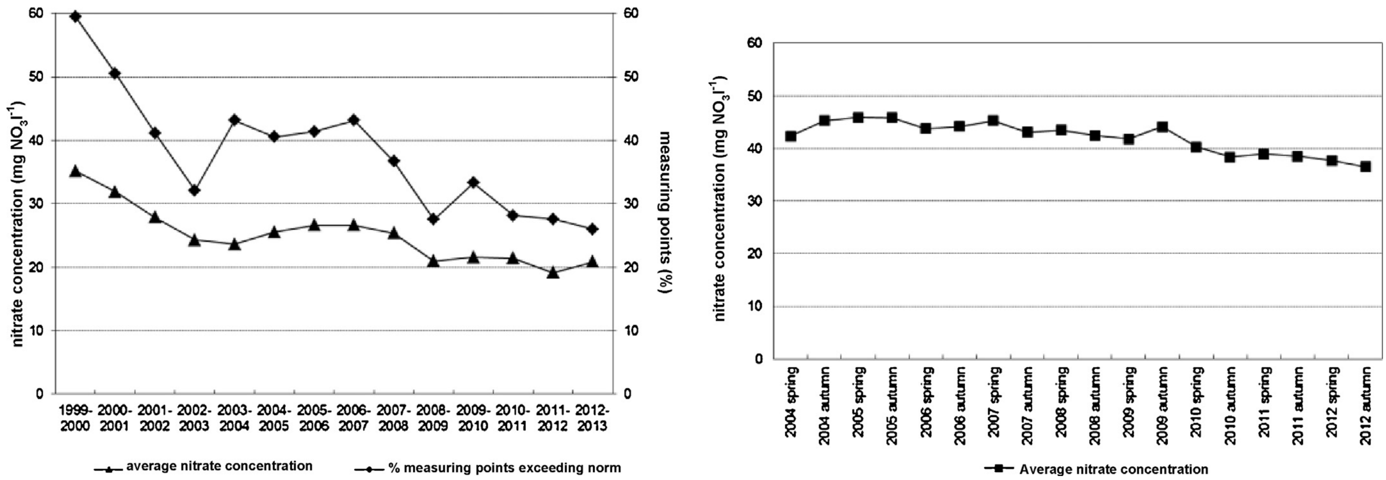

Fig. 1. Average nitrate concentrations (mg NO_3^- L^{-1}) and % of measuring points in surface water that exceeded the limit between 1999 and 2013 (left) and average nitrate concentrations in the shallowest ground water about one meter below the water table between 2004 and 2012 (right) in Flemish agricultural areas (*Source*: Overloop, 2013).

zones, compulsory action programmes should be set up based on measures listed in the GAP, such as maximum allowable fertiliser application rates. Member States may design their GAP and action programme in various ways based on the available scientific and technical data and on environmental specifications, on the condition that the water quality standards are met. One example is the implementation of several successive Manure Action Plans (MAP) in Flanders (Anonymous, 1991a, 2011). An important constituent of the MAP legislation are the permitted N fertiliser rates (or N fertiliser limits), comparable to what can be seen in many other regions including the Netherlands, Denmark, and others (Fraters et al., 2011; van Grinsven et al., 2012).

Strict limitation of the N fertiliser application rates is considered as one of the best N management strategies to minimise N losses. In the range from low to optimum fertilisation rates, most crops show a rather constant residual soil mineral N (RSMN) at harvest. This constant RSMN is considered to be the minimum mineral N buffer necessary to guarantee optimal growth (Hofman et al., 1981). When N fertiliser rates are increased to rates above this optimum, the RSMN increases steeply for most crops, thus increasing the risk of NO_3^- leaching during winter. This is a so-called breakpoint in the relation between the N fertilisation rate and RSMN. Nitrogen fertilisation experiments can help to determine this breakpoint, which is the key to quantifying the environmental effects of N fertiliser advices and restrictions.

The optimum N fertiliser rates can be calculated based on the one hand on the evolution of yields versus RSMN at various N rates and on the other hand on the various N inputs and outputs such as determined by the "soil mineral N balance method", also called the "balance sheet method" (further abbreviated as SMNB method) (Hofman et al., 1981; Neeteson, 1995). The objective of this method is to match available inorganic N with the crop N demand, so as to minimise risks of N losses. In this study, we collected a large set of data from N fertiliser experiments carried out on representative experimental fields in Flanders and Wallonia. We critically re-analysed these data to calculate the effects of different N fertiliser rates and soil N availability on yields/N uptake (for some crops) and RSMN and N surplus values (indirectly linked to N losses). This analysis allowed us to evaluate the effect of current maximum allowed effective N fertiliser application rates on crop yield and potential N losses. The goal is to provide data on the effectiveness of the current maximum allowed effective N fertiliser application rates in Flanders in terms of reducing RSMN and to provide suggestions for further finetuning these fertiliser limits where needed.

2. Materials and methods

2.1. Description of the nitrogen dose response field experiments

Data from field experiments carried out between 1991 and 2011 at different locations in Flanders and northern Wallonia on cut grassland (i.e. temporarily grassland for maximum 5 years), silage maize, potatoes, sugar beets and winter wheat were used (Fig. 2 and Table 1). This region has a temperate marine climate favourable for high crop yields but impacting on the environment via N leaching. In addition to the available crop and soil data of the years involved, information about the preceding crop was collected. As the N fertiliser experiments were carried out on representative experimental fields in Flanders and Wallonia to optimise fertilisation rate towards optimum yield and low mineral N (N_{min}) in autumn, yield was always measured but N concentration of harvested plant parts was not available for all fields.

Due to the high manure application rate in the past, the content of phosphorus (P), potassium (K), and other nutrients of 75% of the soils from the field experiments was in or above the Flemish target zone, while in the remaining fields these nutrient concentrations were in the class just below the target zone (with exception of the K concentration of the grassland field in Geel, where mineral K was added to the different plots based on a fertiliser advice). Furthermore, target zones for nutrients are high in Flanders compared to other European countries using the same extraction method as shown by e.g. Jordan-Meille et al. (2012). Therefore, it is safe to assume that plots receiving manure were responding to the applied N, rather than to other nutrients.

For each crop, we calculated a dose response curve for yield and RSMN and where possible dose response curve for N uptake and N surplus of the growing period with the pooled data of the different experiments. Pooling the data of several experiments provides a possibility to obtain a more general estimate of the fertilisation effect on crop yield/N uptake, RSMN and N surplus of the growing period. A further positive effect of pooling data from different fertilisation experiments is that data from experiments with a limited amount of fertilisation rates can be included in the analysis. Pooling includes searching for the effect of management which conveys essentially the same information as the 'original' un-pooled data, but in a more robust manner, reducing random variability or noise over time and space. The requirements for pooling the data of different experiments are that the experimental designs, objectives and measured data are sufficiently similar and that individual measurements are available. To represent average circumstances and