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Effect of nitrogen fertilization on nitrate leaching in relation to grain yield response on loamy sand in Sweden

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ABSTRACT

High rates of nitrogen (N) fertilizer may increase N leaching with drainage, especially when there is no further crop response. It is often discussed whether leaching is affected only at levels that no longer give an economic return, or whether reducing fertilization below the economic optimum could reduce leaching further. To study nitrate leaching with different fertilizer N rates (0–135 kg N ha^{-1}) and grain yield responses, field experiments in spring oats were conducted in 2007, 2008 and 2009 on loamy sand in south-west Sweden. Nitrate leaching was determined from nitrate concentrations in soil water sampled with ceramic suction cups and measured discharge at a nearby measuring station. The results showed that nitrate leaching per kg grain produced had its minimum around the economic optimum, here defined as the fertilization level where each extra kg of fertilizer N resulted in a 10 kg increase in grain yield (85% DM). There were no statistically significant differences in leaching between treatments fertilized below this level. However, N leaching was significantly elevated in some of the treatments with higher fertilization rates and the increase in nitrate leaching from increased N fertilization could be described with an exponential function. According to this function, the increase was <0.04 kg kg^{-1} fertilizer N at and below the economic optimum. Above this fertilization level, the nitrate leaching response gradually increased as the yield response ceased and the increase amounted to 0.1 and 0.5 kg kg^{-1} when the economic optimum was exceeded by 35 and 100 kg N ha^{-1}, respectively. The economic optimum fertilization level depends on the price relationship between grain and fertilizer, which in Sweden can vary between 5:1 and 15:1. In other words, precision fertilization that provides no more or no less than a 10 kg increase in grain yield per kg extra N fertilizer can be optimal for both crop profitability and the environment. To predict this level already at fertilization is a great challenge, and it could be argued that rates should be kept down further to ensure that they are not exceeded due to overestimation of the optimum rate. However, the development of precision agriculture with new tools for prediction may reduce this risk.

1. Introduction

In Sweden, as in many other countries, farmers are encouraged by the authorities to fertilize no more than the economic optimum, in order to minimize nitrogen (N) leaching and subsequent pressure on the environment. This involves choosing the right source, right place, right timing and right application method, and can be referred to as best management practice (Goulding, 2000; Roy et al., 2006). The optimum N fertilization rates vary between sites and years, due to differences in yield potential and soil nitrogen supply. To meet the requirement on each farm or field, general recommendations for each crop and area should be adjusted depending on previous crop, sowing date, soil type and soil and plant N analyses. However, optimum N fertilization rate may vary considerably even within individual fields (Delin et al., 2005) and site-specific fertilization with respect to variations within fields could therefore reduce N leaching further (Basso et al., 2011). For this there are tools such as the Yara N-sensor (Reusch, 1997), which has been used on a limited number of farms in Sweden and other countries during the past 15 years. This type of equipment may lead to reduced average fertilizer rates, since farmers may otherwise tend to adjust their fertilization to the best yielding parts of the field. However, the main effect is likely to be that the N is better distributed within fields and that the average rate is similar. The effect on leaching would then depend on the difference in leaching between fertilization above and below the optimum. According to some empirical models on N leaching response to N fertilization rate (Simmelsgaard and Djurhuus, 1998), the effect on leaching is similar above and below the economic optimum. If such a model is used for calculating the benefit of site-specific fertilization compared with uniform fertilization the decreased leaching in areas where fertilization is reduced would be cancelled out by increased

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leaching where fertilization is increased. However, if leaching is much less affected below the optimum, as reported by Lord and Mitchell (1998), site-specific fertilization within individual fields has the potential to reduce leaching regardless of whether the average fertilization rate is reduced or not.

The extent to which N leaching is affected above and below the economic optimum varies in literature. Bergström and Brink (1986) studied leaching at different N fertilization levels in a 10-year study on a clay soil in Sweden and found a gradual increase at levels above 100 kg N ha^{-1}. In their study fertilization levels were the same in each plot between years, regardless of crop and expected fertilization demand. The gradual increase may therefore have been a consequence of accumulated effects from several years where one plot may have been fertilized above the optimum one year and below it the next. However, Simmelsgaard and Djurhuus (1998) compiled data from several different experiments and described the dependence of leaching on fertilization by an exponential function rising considerably already at small fertilization rates, meaning that the relationship was close to linear around the economic optimum, increasing by 0.25–0.35 kg N ha^{-1} per kg N applied at differences of up to 20 kg N above or below the recommended rate (i.e. as practised by farmers in Denmark around 1980). Lord and Mitchell (1998) present British results on N leaching at different N inputs in relation to the economic optimum calculated for a known yield response to fertilization. In contrast to the studies cited above, they found that leaching was only affected very slightly (<0.05 kg kg^{-1} N applied) at rates below the economic optimum, but on average by 0.52 kg kg^{-1} above economic optimum rates. Engström et al. (2010) studied nitrate N leaching at different N fertilization levels in oilseed rape and also found a steeper response in terms of leaching above the optimum (0.5 kg kg^{-1} applied) than below (0–0.2 kg kg^{-1}), with less effect of fertilization on N leaching when the winter was cold. The effect of fertilization on leaching is described in a number of models for simulating N dynamics, in Sweden mainly the SoilN and SoilNDB models (Johnsson, 1990; Eckersten and Jansson, 1991; Larsson et al., 2002) or in the advisory model STANK in MIND (Aronsson and Torstensson, 2004). The way in which leaching is affected by fertilization differs between models. In some models leaching is significantly increased already at low fertilization rates (Eckersten and Jansson, 1991; Simmelsgaard and Djurhuus, 1998), while in others leaching only begins to be affected by fertilization first at or slightly below economic optimum fertilization (Brentrup et al., 2004; Larsson et al., 2002; Aronsson and Torstensson, 2004; Beaudoin et al., 2005).

The objective of the present investigation was to study the effect of N fertilization on nitrate N leaching depending on grain yield response, i.e. above and below the economic optimum, in a cereal crop grown on loamy sand under Swedish weather conditions. The hypothesis was that N leaching response is dependent on crop N removal from the field with harvest, and that N leaching is significantly affected by N fertilization rate only at fertilization levels with a weak grain yield response, i.e. above a certain level that could coincide with the economic optimum, depending on the price ratio between grain and fertilizer N.

2. Materials and methods

2.1. Experimental setup

Nitrate N leaching in response to different fertilizer N doses was investigated on an Inceptisol (USDA Soil Taxonomy) in south-west Sweden ($58^{\circ}22$ N, $13^{\circ}29$ E) with loamy sand soil (14% clay, 22% silt and 64% sand) with pH (H_2O) 6.4 and 2.8% soil organic matter (1.6% C and 0.14% N) in the 0–30 cm layer. Cation exchange capacity (CEC) was 130 mmol$_c$ kg^{-1} dry soil and base saturation 78%. The subsoil had a larger fraction of coarse sand in the 30–60 cm layer (12% clay, 17% silt and 71% sand) and the 60–90 cm layer (13% clay, 20% silt and 67% sand). Bi-annual field trials were conducted with spring oats (*Avena sativa* L.) as the first crop in three consecutive years (2007, 2008 and 2009). Each trial had the first year seven N fertilization treatments (Table 1) distributed randomly within each of four blocks. The following crop was winter wheat (*Triticum aestivum* L.) (2008 and 2010) or spring barley (*Hordeum vulgare* L.) (2009), which received the same rate throughout the experiments, according to local recommendations for each crop (160 and 90 kg N ha^{-1} for winter wheat and spring barley, respectively). Nitrogen was applied as granulated ammonium nitrate on the soil surface at the time of sowing of spring cereals, except in 2008, when fertilization was delayed until after crop emergence. In the subsequent winter wheat N was applied in spring, at stem elongation (GS 30–32; Zadoks et al., 1974). Phosphorus and potassium were applied at uniform rates according to current recommendations for the crop and area. Grain yield was measured plot-wise by combine harvester and reported at 85% dry matter. Grain samples were analysed for N content with Near-Infrared Transmittance detector (NIT, Infratech 1240) and used for calculating N removal with the harvested grain (N offtake).

Table 1
Nitrogen fertilization levels used in oats in the trials.

	Percentage of expected economic optimum fertilization level	Actual fertilization rate, kg N ha^{-1}
A	0%	0
B	50%	45
C	75%	70
D	100%	90
E	125%	110
F	150%	135
G	100% (adjusted after crop emergence)	60 + (30, 0 and 40 in 2007, 2008 and 2009, respectively)

2.2. Weather

The growing season in 2007 was favourable, with adequate amounts of precipitation and normal temperature for the area, and was followed by a mild winter (Fig. 1). The spring of 2008 was very dry, followed by heavy precipitation in August and then a rather mild winter. In 2009, the spring was also dry, but the growing season was followed by a cold winter.

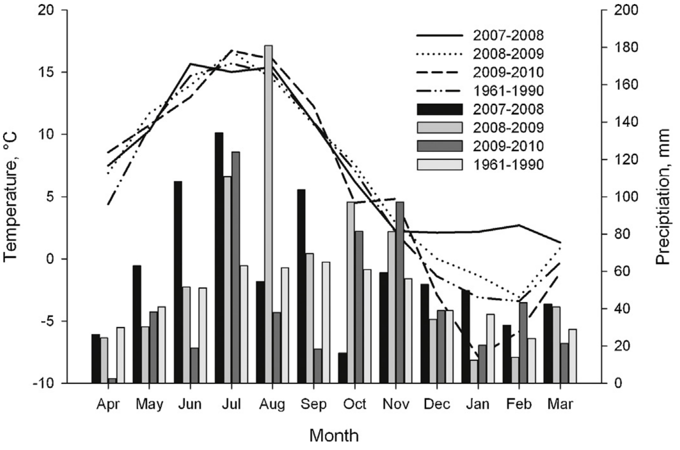

Fig. 1. Weather data for the three years and long-term averages for the period 1961–1990.