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Nitrogen leaching from organic agriculture and conventional crop rotations

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Abstract

The Seine basin, characterised by intensive arable crops, has most of its surface and ground-water contaminated by nitrate (Nitrate Directive EU, 1991). The goal of our study is to investigate nitrogen leaching from arable crops in organic (OF) and conventional farming (CF) in the North of France. In 2012-13, a network of ceramic suction cups have been installed in 8 farms taking into account complete rotations. Our first results showed a gradient of sub-roots concentrations : legumes have the lowest subroots concentrations whereas crops fertilised after legumes have the highest. Catch-crops, when efficient, can decrease leaching by a factor 2. Soil and climatic variations have a major impact on the nitrogen leached, due to the amount of infiltrated water (30 to 400 mm). The leaching means are 10 to 36 kgN.ha^{-1}.yr^{-1} for OF and 26 to 41 kgN.ha^{-1}.yr^{-1} for CF in Seine & Marne. In final, OF leads to a decrease of nitric contamination of 20-50% in the different areas.

Introduction

Nitrate (NO_3^-) is the final form of nitrogen produced in the soil in aerobic conditions, following organic matter mineralization and subsequent nitrification or from mineral fertilization (Billen et al, 2013). NO_3^- pollution of groundwater from agriculture is very common (Addiscott et al. 1991) and a huge concern for the European Union (Directive n°91/676/CEE). Long time series in conventional agriculture in the Seine Basin already exist. These scored an average of 25 ± 4 mg N.l^{-1} (standard for drinking water is 11 mg N.l^{-1}) for different types of soil, crops and climatic conditions (Calvet et al., 1990). Such measurements are very scarce for other agricultural systems such as organic farming (Mondelaers et al. 2009). Organic farming (OF) is already recognized as a good alternative for pesticide pollution, but its impact on nitrate contamination is still controversial. Only few articles have dealt with the impacts of organic and conventional agriculture on nitrate leaching in Europe. Most of the studies showed a reduction in nitrate leaching due to organic practice with a global reduction of 40% N leached compared to conventional practices (Hansen et al. 2000, Korsaeth and Eltun 2000). However ample variations were shown and depended of local factors such as rotations, soil characteristics and climate. The objective of this work was to quantify nitrogen concentrations below the root zones for complete organic rotations and to compare them the conventional ones in the immediate surroundings. Such concentrations are essential to document the constraints of the Riverstrahler model of biogeochemical nutrient fluxes developed for drainage networks (the Seine Basin in particular) and to possibly explore agricultural scenarios (Thieu et al. 2011) and their impact at the coastal zone in terms of eutrophication (Garnier et al. 2010).

Material and methods

To overcome the lack of data on nitrate leaching (in concentrations and fluxes), the ABAC project (DIM-Astrea AESN) was designed to equip several farms with porous ceramic cups (Stopes et al. 2002a) although lysimeters are also a well-adapted method, especially used for long perennial experimental plots. Here we used vertical ceramic cups (90 cm) that can be set up quickly without any destruction of the soil horizons of the plots. In each farm, all the terms of the rotation were equipped with 6 ceramic cups (i.e. 230 cups). Sampled water in the sub-root zone can be directly analyzed for nitrate concentrations. In field determination of nitrogen residual in the soil before and after winter period was also determined. In 2012-2013, a total of eight managements systems of arable crops have been equipped on complete rotations (5 in OF and 3 in CF), in three soil types and climatic situations. The three situations are located in the East, North and South of Paris and respectively characterized by clay-silt loam soil with drains, clay-silt loam without drains and sandy-silt loam and efficient rainfall (rainfall – evapotranspiration) of 200, 30 and 400mm. Organic farming systems differed in their nitrogen management, but had similar long crops rotations (average of 8 years) starting with two/three years of alfalfa (generally exported), wheat, cereal, legumes (as faba beans), wheat,

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cereal. Conventional farming was dominated by the rotation wheat-oat-rape seeds or maize in the same region. Exogenous fertilization averages on complete rotations were around 30 kgN.ha^{-1}.yr^{-1} in organic systems, and 150 kgN.ha^{-1}.yr^{-1} in conventional ones. The input after exportation, due to biological nitrogen fixation, was around 100 kgN.ha^{-1}.yr^{-1} in both systems from alfalfa in OF and peas in CF (Anglade et al., in prep).The principle of suction cups is to suck the water sub-root via a set-vacuum 48h prior sampling (Bowman et al. 2002). Samples were taken approximately from every ten to fifteen days throughout the period of drainage. Additionally, soil samples were analyzed at three soil horizons for nitrogen concentrations, granulometry and physico-chemical properties. Nitrogen concentrations (ammonium, nitrite and nitrate) were determined with a colorimetric autoanalyzer (Quaatro, Bran & Luebbe). Climatic data were also gathered for determining water fluxes in three soils layers with rainfall and evapotranspiration.

Results

Regarding organic rotations, the lowest concentrations were found for parcels cultivated with legumes (alfalfa: 2.8 mgN.l^{-1}). The first year after alfalfa was overturned, leaching from mineralization was around 15 mgN.l^{-1} and decrease to 8.5 mgN.l^{-1} in the second year. Crops of the fourth or fifth position in the rotation were generally fertilized with vinasse, poultry droppings or compost which was led to the highest sub-roots concentrations. Legumes with grains (faba beans, lentils, position 4 in the rotation), never fertilized in the organic rotations studied, had a median sub-root concentration of 9.8 mgN.l^{-1}. However, crops after those legumes, sometimes fertilized, had a median sub-root concentrations of 22.7mgN.l^{-1}. At the end of the rotations, cereals with low N input showed a median sub-root concentration of 8.7 mgN.l^{-1}. In total, a median nitrogen concentrations in the sub-root zone of the organic rotations studied was 9.2mgN.l^{-1}. For conventional rotations, crops with intercultures (IC) led to the lowest concentrations (8 mgN.l^{-1}); fertilized crops resulted in a N concentration of 27.7mgN.l^{-1} whereas wheat after legumes, generally fertilized as well, reached 30.2 mgN.l^{-1}. Median sub-root concentrations for such a three years rotation was 30.2 mgN.l^{-1} (Figure 1).

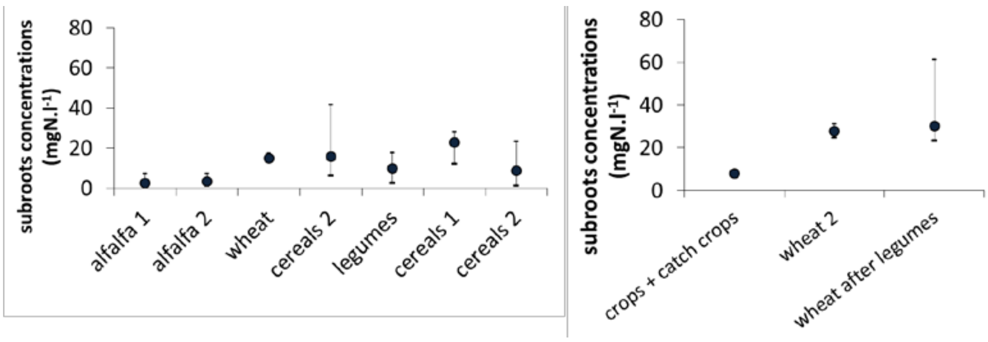

Figure 1: Minimum, maximum and median of nitrate sub-roots concentrations in function of crops in organic (N=39 parcels x 10 samples) and conventional (N=8 parcels x 10 samples).

When converting the concentrations to leaching fluxes (concentrations x runoff water) the final contribution of the farms to nitrate contamination changed. Indeed, the farms in the Yonne with the lowest concentration in fact to a higher leaching (30 kgN.ha^{-1}.an^{-1}) than in the Oise (around 10 kgN.ha-1.an-1). The leaching means were 10 to 36 kgN.ha^{-1}.yr $^{-1}$ for OF and 26 to 41 kgN.ha^{-1}.yr $^{-1}$ in the Seine & Marne. In final, the organic farming systems showed a reduction in nitric contamination from 10-50% in Seine & Marne to 20-50% in Oise, compared to conventional ones. Leaching data are significantly different between regions (Anova, R, 0.0107 *) (Figure 2).

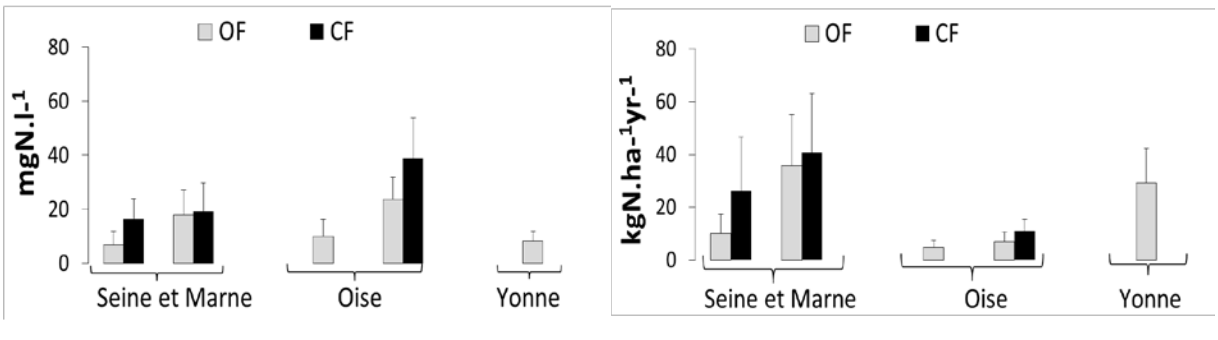

Figure 2: Concentrations and leaching from the different farms in Seine-et-Marne, Oise and Yonne department, for organic farms (OF) and conventional farms (CF).

Discussion

Leaching from agriculture depends on N management, soil water capacity and efficient rainfall. N management is especially important in organic agriculture, where the resort to mineral fertilizer is forbidden. In the North of France and for 50% of organic arable crops, nitrogen fertilization is mainly based on biological nitrogen fixation; however the quantity and quality of N mineralized is still a controversial question. In the farms studied, crops fertilized after legumes are common and appear to have the highest sub-roots concentrations; also, the date of application, the quality and the quantity of fertilizer is very variable in function of the systems so that different degrees of improvements are still possible concerning nitrate leaching. Catch crops can have an important impact on nitrate leaching, however different modality can be experimented, e.g. the incorporation of legumes, the dates of seeding and harvest, their integration into the N balance for the fertilization (Beaudoin et al., 2012). Water retention in soils depends on texture (silt, clay and sand), substratum and depth, so that each parcel may have its own potential of vulnerability for N leaching. A good understanding of the soil and its substratum is needed to limit the risk of leaching within a territory (farm, watershed, catchment areas of groundwater). The network of investigated farms has been extended in 2013-14 to investigate annual variations and a wider panel of N managements (17 farms equipped and a total of 500 ceramic cups).

Suggestions to tackle with the future challenges of organic animal husbandry

Because organic rotations are generally characterized by the introduction of alfalfa and legumes animal husbandry would be complementary. Indeed, when alfalfa, not used as feed, is left on the ground, an excess of nitrogen may contaminate groundwater and rivers. Conversely, promoting animal husbandry within a territory would be beneficial for organic agriculture requiring organic fertilizers . In conclusion, arable crops production associated with animal husbandry would contribute to a more sustainable agriculture.

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