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Achieving legislation requirements with different nitrogen fertilization strategies: Results from a long term experiment

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ABSTRACT

The Nitrates Directive (91/676/EEC, Anonymous, 1991) was developed in Europe to limit environmental threats from intensive livestock farming and N fertilizer applications to crops. It imposed several rules on farmers and public bodies, one of which was nutrient fertilization plan adoption. Here we use results from the Tetto Frati (Northern Italy) Long-Term Experiment to verify the terms and coefficients in the official Italian guidelines and evaluate the limitations imposed to organic fertilization amounts. For this purpose, we mined long-term experimental data of crop yield, N uptake, N use efficiency, and soil organic matter content from miscellanea cropping systems fertilized with farmyard manure (FYM) and bovine slurry (SLU), typical of a dairy farm in Northern Italy. N fertilization efficiency indicators (Removal to Fertilizer ratio, Apparent Recovery and Nitrogen Fertilizer Replacement Value) indicated that in the long run, FYM behaved similarly to urea, and better than SLU. Even N supply rates as high as 250 kg N ha^{-1} were justified by high rates of crop removal. In fact, among the terms of the mass-balance equation, SOM mineralization was found to be most relevant, followed by meadow rotation residual effects. We conclude that a revised Nitrates Directives application scheme could be more relaxed in its application limit of manure-N, but should be more ambitious in setting efficiency coefficients for manure fertilization.

1. Introduction

During the Eighties many researchers showed that nitrogen (N) amounts applied in Western European agriculture were excessive and risked producing pollution. Furthermore, excesses were unevenly distributed across the continent and linked primarily to areas of intensive livestock farming (Velthof et al., 2014). By all accounts, measures to protect human health, living resources, and aquatic ecosystems were needed. Today, despite reduction in chemical fertilizer usage, the European Union (EU-28) still exhibits excess N supply (the sum of organic and mineral fertilizers, natural deposition, and N-fixation) compared with removal by crop yields (Leip et al., 2011).

Imbalance in the input vs output N budget can produce various types of N losses to the environment (Sutton et al., 2011). While initial scientific attention focused mainly on the problem of nitrate leaching, soon other threats linked to excess manure use or imbalance gained attention (Solomon et al., 2007; Galloway et al., 2008), such as ammonia volatilization and N oxide emissions, as well as the inherently-associated massive phosphorous load that can over-enrich the soil to menace fresh and marine waters with eutrophication produced from sediment runoff (Schoumans et al., 2015).

The Nitrates Directive (91/676/EEC, Anonymous, 1991) was approved in Europe 24 years ago to address the excessive distribution and/or discharge of livestock effluents onto agricultural land and the excessive use of mineral fertilizers in several parts of Europe. Northern Italy soon emerged as a high-risk area because of its numerous intensive livestock farms. The Nitrates Directive defined a few but clear monitoring actions and limitations to the application of N: (i) member States must extensively monitor fresh waters to identify areas where nitrate content exceeds a threshold of 50 mg NO_3^- l^{-1}; (ii) member States must designate Nitrate Vulnerable Zones (NVZs), where actual or potential nitrate pollution of agricultural origin is problematic; (iii) farms lying in NVZs must implement Action Programs to adopt sustainable management practices. A core part of the Action Program established constraints for land-application of all nitrogen-containing fertilizers, and in particular, set specific limits for livestock manure application.

A key component of Action Programs is balancing N inputs and outputs. The definition of “balance” rested on a rather simple principle that the difference between expected nitrogen crop requirements and the nitrogen supply from the soil, air, and fertilization approximate one another. However, predicting the equation

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components (e.g., crop removal, initial N availability when crop growth starts, soil N net mineralization, efficiency of N from livestock manure and chemical fertilizers) is not trivial (Webb et al., 2013; Schröder, 2008).

The Tetto Frati Long Term Experiment (LTE) has been underway about as long as the Nitrates Directive has been in effect in Europe. It was initially created in 1992 to mimic a set of intensive forage systems for a typical Northern Italy dairy farm, where maize is the main fodder crop, and liquid and solid manures are fertilizer resources (Grignani et al., 2007). It was used for several purposes, all of which were connected to the study of N efficiency and the fertilization impacts of highly manured cropping systems (Zavattaro et al., 2012). Studied treatments are semi-static in the sense that zero, low, and high input levels have been applied continuously, with exact N low and high input amounts having been adjusted just twice to produce data relevant to scientific and technical questions on application of the Nitrates Directive in Italy. Prior to 2006, the LTE was used to investigate a frequently applied fertilization strategy that combined manure and chemical fertilizer as inputs. The low and high input levels were determined by fixed amounts of slurry and farmyard manure while actual nitrogen input changed according to manure and slurry characteristics, and all organic treatments were top-dressed with a fixed amount of 100 kg urea-N ha^{-1}. During 2007–2011, LTE research centered on the two maximum levels of manure-N inputs mandated within and external to Italian NVZs (170 and 340 kg N ha^{-1}). Top-dressed urea was excluded from manured treatments to test the simple effects of manures and mineral fertilizers. The third phase of LTE research began in 2012 and is still ongoing; it is devoted to verification of the application effects of the 250 kg manure-N ha^{-1} Derogation scheme in Italy (low level is 170 and high level is 250 kg N ha^{-1}).

Results from the first period have been presented in previous papers. Here we utilize Tetto Frati LTE data from 2007 forward to answer two questions.

- Are the coefficients used to estimate the terms of the N balance equation consistent with long-term experimental data?
- Are the limitations imposed by the Nitrates Directive sufficient and/or necessary to guarantee an N-balanced cropping system?

In particular, we wanted to evaluate the N use efficiency of animal manure-N (farmyard manure and bovine slurry) compared to mineral N fertilizers such as urea, and to demonstrate that the application of 250 kg ha^{-1} of manure-N to high demanding crops under adequate environmental conditions increases the value of manure-N and minimizes the need of purchasing additional N fertilizers.

2. Materials and methods

2.1. LTE description

The long-term experiment of Tetto Frati (44°53′N; 7°41′E; 232 m a.s.l.) of the University of Turin, Italy was started in 1992, but the first year of data has been excluded to mitigate the effect of past fertilizations. The climate is temperate sub-continental, the average annual rainfall is 760 mm, and the mean annual temperature is 12 °C. The soil, Typic Udifluvent, is deep and calcareous with loam texture in the first horizon and silty texture in deeper horizons (Grignani et al., 2007).

The experiment, designed as a randomized block with three replicates, compares four cropping systems at five nitrogen application levels, plus a rotational maize-lucerne system at a single fertilization level. Cropping systems are: entirely-harvested maize for silage (Ms); maize for grain with residue incorporation (Mg); silage maize + Italian ryegrass double cropping with almost continuous soil cover (Mr); 4-years or 6-years rotation of entirely-harvested maize and long-growing grass ley (Ml); 4-years or 6-years rotation of maize for silage and lucerne, Mu. The five N application levels are arranged in nine distinct fertilization treatments: 0 N control, four doses of mineral N as urea (U100 to U400), two doses of bovine slurry (SLU), two doses of farmyard manure (FYM). The Mu system was fertilized as SLULow in the maize phase, while lucerne received no N fertilizer. Further details on fertilization treatments are reported in Table 1. The target amount of N supplied was based on total N contents of FYM and SLU. Manure was always distributed in spring and incorporated quickly into the soil, a few days before maize sowing. Urea was chosen as the reference mineral fertilizer because it is the most commonly used N fertilizer in maize in Italy, due to its low cost. It was partly distributed few days before maize sowing and partly top-dressed and incorporated through ridging. Phosphorous (P) and potassium (K) were supplied through mineral fertilizers at levels above plant needs to exclude any possibility of nitrogen interaction. Nine different commercial maize hybrids of the 500 or 600 FAO were used throughout the 23 years period. Further details on the crop management are reported in Grignani et al. (2007), Bertora et al. (2009), and Zavattaro et al. (2012).

Fertilization amounts were modified from experimental start to conform to a semi-static management, in which the number of levels remained constant. Table 1 reports all fertilization data for completeness, but in this paper we discuss results from the 2007 to 2014 period only, with the following qualifications:

- Crop yield, N uptake, and N use efficiency indicators were reported separately for 2007–2011 (five years) and 2012–2014 (three years) according to the two fertilization levels (U300 and U400 were averaged to allow a direct comparison with the 340 kg ha^{-1} dose of manured treatments);
- Incorporated crop residue and rotational ley effects were derived by averaging data over the entire 2007–2014 period;

Maize was sown in Ml and Mu systems in 2011 and 2012, while grass or lucerne leys lasted from 2008 to 2010 and from 2013 to 2014. Leys growth failed in 2007, therefore no crop data are reported in that year.

Table 2 reports the general characteristics of the organic fertilizers used in the two periods analyzed.

2.2. Sampling and chemical analyses

Values of crop dry matter yield and N content were determined annually at harvest. N analyses were performed on samples pooled from the three replicates, using an elemental analyzer (Flash EA 1112, Thermoquest). In this work, Mg yield was from grain only. Mr was based on the sum of two crops (Italian ryegrass and late-sown maize), whereas Ml came from the average of the two crops.

Organic fertilizers were sampled and analyzed before each distribution to determine several measures: dry matter (oven dried at 105 °C), organic carbon, C (NA2100 protein Carlo Erba elemental analyzer), total N (Kjeldahl method after acid mineralization of organic N), ammonium N (Kjeldahl method), phosphorous (P) and potassium (K) contents (nitric or perchloric acid microwave solubilization followed by ICP spectroscopy).

Soil organic C and total N content were determined in all plots at a depth of 0–30 cm (total C and N contents: NA2100 protein Carlo Erba elemental analyzer, mineral C content: Dietrich-Fruhling calcimeter). Sampling was made in the early spring of years 2007, 2010, 2012, and 2015.