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Agronomic effects of bovine manure: A review of long-term European field experiments

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ABSTRACT

To evaluate the agronomic value of animal manure, we quantified the effects of pedo-climatic, crop and management factors on crop productivity, N use efficiency, and soil organic matter, described with simple indicators that compare manures with mineral fertilizers. We selected 80 European long-term field experiments that used bovine farmyard manure or bovine liquid slurry, alone (FYM and SLU) or combined with mineral fertilizers (FYMm and SLUm), and compared them to mineral fertilizer only reference treatments. We collected 5570 measurements from 107 papers. FYM produced slightly lower crop yields (−9.5%) when used alone and higher (+11.3%) yields when used in combination with N fertilizer (FYMm), compared to those obtained using mineral fertilizers only. Conditions promoting manure-N mineralization (lighter soil texture, warmer temperature, longer growing season, and shallower incorporation depth) significantly increased the effect of FYM/FYMm on crop yield and yield N. The production efficiency of FYM (yield:N applied ratio) was slightly lower than that of mineral fertilizers (-1.6%). The apparent N recoveries of FYM and FYMm were 59.3% and 78.7%, respectively, of mineral fertilizers. Manured soils had significantly higher C (+32.9% on average for FYM and FYMm) and N (+21.5%) concentrations. Compared to mineral fertilizers, yield was reduced by 9.1% with SLU, but not with SLUm. Influencing factors were similar to those of FYM/FYMm. Efficiency indicators indicated SLU (but not SLUm) was less effective than mineral fertilizers. Slurry significantly increased SOC (on average for SLU and SLUm by +17.4%) and soil N (+15.7%) concentrations. In conclusion, compared to mineral N fertilizers, bovine farmyard manure and slurry were slightly less effective on the crop, but determined marked increases to SOC and soil N, and thus, to long-term soil fertility maintenance.

1. Introduction

Animal manures are valuable fertilizers. They supply available nutrients to crops, positively affect soil physical properties, activate soil life by providing easily degradable carbon compounds, and help build soil organic matter (Edmeades, 2003). However, if used incorrectly, manure applications can increase soil GHG emissions and nutrient losses (N, P and others) to water bodies. To evaluate the positive and negative effects of manures (Grizzetti et al., 2011; Moldanová et al., 2011; Velthof et al., 2011), their impacts on crop production, nutrient use efficiency and soil status must be assessed by using adequate indicators.

Since the early 1990s, European legislation has regulated animal production, and indirectly the use of animal manure, with a three-pronged objective: protecting human health, preserving environmental quality, and better equilibrating milk and dairy markets (Oenema, 2004). This legislation requires that management criteria, such as the best rate and timing of manure application, are adapted to specific local

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conditions (soil, climate, crop, manure type, farm organization). Consequently, official ranges of efficiency indicators have been developed in various countries to guide the application of manures and mineral N and P fertilizers. These official values for various European countries are reported by Webb et al. (2013), who list the N fertilizer value of farmyard manure and slurry relative to mineral fertilizers. For bovine farmyard manure, legal N fertilizer value ranges between 10 and 65%, depending on the country. Higher values are used in Italy, the Netherlands, and Denmark, while the UK uses a much lower coefficient. For slurry, N fertilizer values varied within a narrower range (40–70%), with lower values again used in the UK. Values for slurry are always above those of farmyard manure, with the exception of Italy, where the two types of manures are valued the same. Some countries differentiate soil- or season- or crop- or management-specific N fertilizer values. Ideally, official N fertilizer values represent a compendium of scientific knowledge on the crop response to amendments under local conditions.

This scientific knowledge, which can be summarized also using other agronomic performance indicators – such as yield response, nutrient uptake, soil health status, and fertilizer efficiency – is more robust when obtained from long-term field experiments, as the cumulative effects of manure additions only become measurable after several years or decades. Medium- and long-term field experiments (LTEs) are, in fact, widely recognized as essential research infrastructures for environmentally oriented agricultural studies (e.g., Lehtinen et al., 2014; Haddaway et al., 2015; Pikula et al., 2016; Stützel et al., 2016). Their value increases over time (Berti et al., 2016), as global patterns emerge from comprehensive analyses.

The most important animal manures studied in LTEs are bovine farmyard manure (solid; FYM) and bovine slurry (liquid; SLU). Farmyard manure was studied often in LTEs established during the late 19th or early 20th century. Studies using slurries in LTEs are more recent. Manure application rates were typically constant over the years, in terms of fresh mass input, often applied once per rotation cycle to a specific crop, and often without the intention to derive substitution values by direct comparison of manure versus mineral fertilizer. Only recently, LTEs were set up with the purpose of assessing replacement values of amendments at similar N rates. Depending on the study, this equivalency in N rate was either based on total N or only the mineral N fraction in the manure.

Scientific reviews have tried to compile the results of several LTEs to describe the long-term effects of manure. Gutser et al. (2005) summarized various laboratory and field trials in Germany to quantify the short-term and residual effects of manures and other organic fertilizers. The ratio between crop N uptake from manure and from mineral fertilizer ranged from 10 to 20% for farmyard manure, and between 35 and 45% for cattle slurry. Edmeades (2003) collected and analyzed data from 14 LTEs (20–120 years) in Europe, the USA, and Canada to compare the effects of fertilizers and manures (farmyard manure, slurry, and green manure) on crop production and soil properties. Körschens et al. (2013) reported mineral and organic fertilizer effects on crop yield and soil carbon from several LTEs (8–135 years), mainly located in Central and Eastern Europe. However, neither Edmeades (2003) nor Körschens et al. (2013) summarized data from the various experiments, or tried to explain variability across trials, or attempted to derive a N fertilizer replacement value of manure. Wei et al. (2016) analyzed 32 LTEs in China where manures and mineral N were compared; however, these experiments neither allowed comparisons at similar N rates, nor was a comprehensive and statistically sound analysis of measured data reported. Diacono and Montemurro (2010) outlined the effects of various amendments on soil chemical, physical, and biological fertility, using long-term trials (3–60 years) across the world, but they did not explain variability among LTEs. Similarly, a comprehensive and detailed review by Webb et al. (2013) on short- and long-term crop availability of manure-N in Europe did not report a mean N fertilizer value of manures.

Clearly, an European-wide review of the N fertilizer value of manures is missing. To fill this knowledge gap, our aim is to exploit the large data volume generated by European LTEs, with the purpose of assessing the agronomic value of manures.

To assess the N replacement value by its most common and strict definition (e.g. Schröder et al., 2007), a specific experimental setup is required. Such design should either include manure and mineral fertilizer doses at exactly the same total N rate, or several (stepped) mineral fertilizer N rates in parallel to a manure treatment, allowing for interpolation in between observed outcomes (notably, N offtake) from the stepped mineral N response series, in order to calculate the exact replacement value of the manure. Similarly, the assessment of apparent N recovery of manures (irrespective of an aim to determine replacement values), requires the presence of an unfertilized treatment, or better, one where all nutrients applied in the manure are also given in the fertilizer-only treatment, except nitrogen. All of these conditions are rarely found in LTEs. Nevertheless, LTEs do often include manured and mineral fertilizer treatments, and the attractiveness of such experiments lies in the longer time spans over which treatments can be compared.

Naturally then, because LTEs do not meet the above requirements, we have to resort to other indicators than the N replacement value. Moreover, we intend to clarify how these indicators are affected by factors like soil type, crop type, and climate. Besides aiming to explain variation across LTEs, our review differs from those cited above in its attempt to include all available European LTE literature, to examine impacts of amendments on both crop and soil indicators, and to summarize them with a quantitative method.

2. Materials and methods

2.1. Database

We analyzed prominent literature databases (Scopus®, Web of Science®, Google Scholar®) to find long-term experiments (LTEs) with the following characteristics:

- carried out in Europe;
- scientifically sound (included an experimental design and replicates);
- provided measurements that estimated effects on crops and soil in the long-term;
- included at least one treatment in which farmyard manure or slurry (bovine liquid manure) was applied, as well a reference treatment with mineral N fertilizer only.

Besides literature database searches, we collected papers directly from researchers, and included some technical papers, research reports, and PhD theses as well, when details of an LTE were not reported in mainstream scientific papers. The list of LTEs is reported in Table S1, the list of documents consulted is in Table S2, and a map is in Fig. 1. While we aimed to collect data from experiments that lasted a decade or more, we did include a few shorter than 10 years duration, especially in instances of rarely-measured variables (soil microbial biomass) or to expand geographic coverage.

The 80 LTEs considered in this review ensure wide coverage of European climates, soils, and duration (range: three to more than 150 years), with half of the experiments started before 1979. Germany provided the largest number (22) of experiments, Eastern Europe contributed 23 experiments, while Southern Europe was represented by nine LTEs. Light texture soils characterized 53% of the LTEs considered; 38% were of medium texture and only 10% were fine. The eastern European climate was most represented (59% of LTEs), followed by the western (25%), southern (11%), and northern (5%) climates. Section 2.4 and Table 1 report the soil and climate definitions.

Overall, our data set included 5570 measurements. The indicator most available was crop yield, followed in decreasing order by the yield to fertilizer ratio, soil organic carbon content, N offtake in crop yield, N