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# Organic and mineral fertilization management improvements to a double-annual cropping system under humid Mediterranean conditions

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ABSTRACT

The efficient use by crops of nitrogen from manures is an agronomic and environmental issue, mainly in double-annual forage cropping systems linked to livestock production. A six-year trial was conducted for a biennial rotation of four forage crops: oat-sorghum (first year) and ryegrass-maize (second year) in a humid Mediterranean area. Ten fertilization treatments were introduced: a control (without N); two minerals equivalent to 250 kg N $ha^{-1}$ $year^{-1}$ applied at sowing or as sidedressing; dairy cattle manure at a rate of 170, 250 and 500 kg N $ha^{-1}$ $year^{-1}$ and four treatments where the two lowest manure rates were supplemented with 80 or 160 kg mineral N $ha^{-1}$ $year^{-1}$. They were distributed according to a randomized block design with three blocks. The highest N mineral soil content was found in the summer of the third rotation, in plots where no manure was applied. The yearly incorporation of manure reduced, in successive cropping seasons, the amount of additional mineral N needed as sidedressing to achieve the highest yields. Besides, in the last two years, there was no need for mineral N application for the manure rate of 250 kg N $ha^{-1}$ $year^{-1}$. This amount always covered the oat-sorghum N uptake. In the ryegrass-maize sequence uptakes were as high as 336 kg N $ha^{-1}$ $year^{-1}$. In the medium term, the intermediate manure rate (250 kg N $ha^{-1}$ $year^{-1}$) optimizes nutrient recycling within the farming system, and it should be considered in the analysis of thresholds for N of organic origin to be applied to systems with high N demand.



## 1. Introduction

Double-annual forage crop production where crops are grown in sequence is a very intensive agricultural management system. It is usually associated with dynamic livestock farming where animals are fed with forages and their feces, usually mixed with straw, are applied to crops as fertilizers. Thus, nutrients are recycled as much as possible within the system. This practice also has economic advantages since it reduces the application of mineral fertilizers.

Despite these advantages, crop intensification requires a better understanding of fertilization management of such animal waste, in order to maintain high productivity while reducing environmental impacts. This is a complex issue, as organic materials show different constraints: high variability in nutrient content depending on many management factors (Klausner et al., 1994; Yagüe et al., 2012), residual effects in the years following application due to organic components (Ketterings et al., 2013; Sieling et al., 2014), as well as some difficulties when applied at different crop development stages as sidedressing, or due to inability to incorporate manure (Thilakarathna et al., 2015). Nutrient use efficiencies from manures are lower, mainly the nitrogen efficiency, when compared with those obtained under mineral fertilization (Schröder, 2005).

Improvements to organic fertilization require several years of experimentation. Results must not be influenced by initial soil fertility (Guillaumes et al., 2006), and the residual effects of fertilization undertaken in previous years should be included, meaning

*Abbreviations:* CM, cattle manure; DM, dry matter; MN, mineral nitrogen fertilizer; OM, organic matter.

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a stable situation (equilibrium) at the end of the field experiment (Schröder, 2005).

When a double-annual cropping system is established, there is an almost permanent N extraction by the plants that restricts N leaching loss. Under humid temperate conditions, it is possible to take advantage of the manure's residual N effect if soil is covered in autumn (Sørensen, 2004). These climate characteristics also mean an important increment in soil mineral N content as temperatures rise, and this N can be leached if a summer crop is not established. Zavattaro et al. (2012) found that the double-annual cropping system of ryegrass followed by maize increased the efficiency of organic fertilizers and reduced N leaching when compared with a maize monoculture system. Crop rotations compared with a monoculture allow better N use efficiency (Kurtz et al., 1984) and yield increments, as described for maize by Borrelli et al. (2014). In addition, double-cropping results in more efficient use of land, labor and equipment resources than monocropping (Crabtree et al., 1990). Production of two crops per year draws attention to the importance of the use of residual soil nutrients from the preceding crop, which includes organic matter mineralization from the manures or slurries applied to it (Yagüe and Quílez, 2013).

The implementation of Directive 91/676/CEE (European Union, 1991) on water quality protection across Europe designates part of the Garrotxa region (NE of Spain) as a nitrate vulnerable zone (Generalitat de Catalunya, 2009a), and N fertilization practices are regulated. One of the agronomic measures establishes the amount of 170 kg N $ha^{-1}$ $year^{-1}$ as the maximum to be applied from organic fertilizers. This limit seems quite reasonable if only one crop is cultivated annually, but when two crops a year are introduced in a fodder rotation, there is a considerable increase in N demand, and this limit may prevent appropriate nutrient supply. Indeed, the European Union (EU) has allowed derogations of the Directive concerning this specific aspect (Van der Straeten et al., 2012), and in some regions or countries it allows the application of higher N amounts of organic origin, up to a maximum of 250 kg N $ha^{-1}$ $year^{-1}$ (European Union 2005, 2006, 2007a,b, 2008, 2011). The demand from an EU member state must be reasonable in the sense that the objectives of the Directive are still met. Situations for derogation include crop rotations with long growing seasons, crops with high N uptake, or soils with high denitrification capacity.

In the Garrotxa region, there is high and diversified stockbreeder activity, bovine and porcine stock being the most abundant. This stock equals 75% of the livestock census (Perramon et al., 2011). Therefore, organic materials (manure and slurry) are readily available and constitute an agronomic opportunity, mainly in double-annual forage cropping systems which are directly related to the stockbreeder. Some information about N management in similar intensive agricultural systems (double-annual cropping) is available. Nevertheless, some of the existing studies were set up in different environments, such as the one of Chataway et al. (2011) for oat-sorghum in a semiarid region of Australia, or they include different varieties with different crop cycles, such as sorghum in Goff et al. (2010), or the crops have different management requirements, as described in Tomasoni et al. (2011) for ryegrass and silage maize.

Our hypothesis is that, in nitrate vulnerable zones associated with high animal density, if a double-annual forage cropping system is established, it ought to be possible to surpass the threshold of the amount of N (from an organic origin) to be applied, while maintaining high productivity, minimizing the environmental impact to underground waters, and maximizing the nutrient recycling from animal manures within the agricultural system. The aim of this study is to evaluate different fertilization strategies with manures, mineral fertilizers or a combination of both, in a medium term (six years) double-annual forage cropping system. The evaluation is undertaken in terms of crop yields and their N uptake, as well as the evolution of the mineral N soil content.

## 2. Materials and methods

The experiment was conducted over six years (from October 2007 to September 2013) on the same agricultural area in La Garrotxa Volcanic Zone Natural Park (Catalonia, NE Spain; 42° 08′ 32″ N, 2° 30′ 10″ E, altitude 534 masl).

### 2.1. Soil and climate description

The climate is humid Mediterranean; average annual rainfall is about 1000 mm (Fig. 1) without significant dry periods in summer. Weather data were collected from a meteorological station four kilometers away from the experimental field. Crops are usually grown under rainfed conditions, and only in long periods of dry weather can irrigation be used to maintain yields. In this experiment, plots were not irrigated.

For the period 2000–14, the annual average temperature was 12.4 °C, with a maximum daily average of 21.0 °C in July, and a minimum daily average of 4.1 °C in December (Fig. 1). Average annual precipitation was 914.3 mm, with a maximum of 1431 mm in 2011 and a minimum of 606 mm in 2012. Although the precipitation distribution is quite regular over the year, most rain falls in spring and autumn (Fig. 1).

The soil is a well-drained sandy loam, a Fluventic Eutrudept (Soil Survey Staff, 2014), without superficial stoniness. At the start of the experiment, organic matter (OM) content and available phosphorus were medium and available potassium low (Table 1).

### 2.2. Crop management

During the first year, oat (*Avena sativa* L.)–sorghum (*Sorghum bicolor* L.) was the crop sequence, and in the second year, ryegrass (*Lolium multiflorum* L.)–maize (*Zea mays* L.). This biennial rotation was common in the area. Winter crops are maintained in the field from October to May. Summer crops are maintained from May to October.

Plants from winter and summer crops are cut and used as fodder (ensilage) for bovines (meat production). The experiment was maintained over three full rotations (six years).

Oat varieties were Prevision, the first two cropping seasons, and Blond (a local variety) the third. Sorghum varieties were Digestive (1st and 3rd cropping seasons) and Sweet (local sorghum) the second. The ryegrass variety was Trinova and maize varieties were: PR34P88, PR34B39 and P1114 (all of them belong to a 500 FAO cycle). We used certified seeds. Sowing was done mechanically. Oat seeds were treated with an authorized fungicide. Maize seeds were treated with an authorized fungicide and insecticide while sorghum and ryegrass seeds were not treated with any pesticide. Seed densities at sowing were: 180–190 kg $ha^{-1}$ for oats, 40–45 kg $ha^{-1}$ for sorghum, 35–40 kg $ha^{-1}$ for ryegrass, and 67,000 seeds $ha^{-1}$ for maize (distance between rows is 0.75 m and between plants 0.2 m). During the different crop cycles plant health controls were set up but it was not necessary to apply any pesticide. Crops were harvested at the development stage, where the equilibrium yield vs forage quality was considered to be the best: oat at milky grain stage, sorghum when 50% of inflorescences were visible, ryegrass at maximum biomass before coming into ears and maize at the doughy grain stage. The experiment was conducted with a similar management system to that used in commercial practice.