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Residual effects of pig slurry and mineral nitrogen fertilizer on irrigated wheat

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ABSTRACT

The residual effects of pig slurry beyond the year of application have yet to be clearly quantified to determine if it is possible to reduce N fertilizer rates for the subsequent crops. The objective of this study was to assess the residual effects of pig slurry (PSRE) and mineral N fertilizer (MRE) applied to maize (*Zea mays* L.) with respect to the subsequent wheat (*Triticum aestivum* L.). A wheat crop was established in the Ebro valley (Northeast Spain) following a 6-year maize monoculture (2002–2007). The maize crops had been annually fertilized with a combination of three pig slurry rates (0, 30, and 50 $m^3\ ha^{-1}$) and three mineral N rates (0, 100, and 200 kg N ha^{-1}) commonly applied by farmers in the region. The soil mineral N levels before wheat sowing ranged from 94 to 609 kg N ha^{-1} and increased as pig slurry and mineral N applications to maize increased. The PSRE were high and ranged from 2287 to 3796 kg ha^{-1} for wheat grain yield and from 36 to 84 kg N ha^{-1} for grain-N uptake. Results suggested that the PSRE would mainly originate from the carry-over of unused mineral N. Mineralization of the organic N applied with pig slurry, at rates based on European Union Nitrates Directive, contributed with further residual N effects and would allow farmers to reduce N fertilization of wheat about 30 kg N ha^{-1}. A reduction in the typical N rates applied to maize along with additional N fertilization of wheat is necessary to maximize crop profitability and reduce the risk of water pollution with nitrates.

1. Introduction

In the irrigated areas of the Ebro valley (Northeast Spain), a typical crop rotation includes several years of maize (*Zea mays* L.) followed by wheat (*Triticum aestivum* L.). The maize sequence can last from two to several consecutive years. A survey conducted in the region reported that farmers typically fertilize maize with more than 350 kg N ha^{-1} per year in order to minimize the risk of yield losses (Sisquella et al., 2004). The most common N sources applied to maize are pig slurry, mineral fertilizer, and a combination of the two types of fertilizer; this last option is favoured by about 50% of farmers (Sisquella et al., 2004). Part of the N applied with pig slurry is immediately available to crops, but another part is immobilized in the soil, in organic forms, and can be released over a period of many years (Sørensen and Amato, 2002; Schröder, 2005; Gutser et al., 2005). As a result, the crops that follow maize in rotation can take advantage of the residual effects of pig slurry (PSRE) beyond its year of application. These PSRE may originate from the carry-over of unused mineral N applied with the slurry and from the carry-over of mineralizable organic N applied with the slurry, because organic N do not fully mineralizes within 1 year of application (Schröder et al., 2005). Moreover, the PSRE can accumulate if it is repeatedly applied to the same field (Schröder et al., 2005).

While the response of crops to pig slurry and mineral N fertilization has been widely studied, further research is needed to better estimate the residual effects of organic fertilizers (Gutser et al., 2005). Most of the studies that have previously addressed this issue were conducted under Northern Europe conditions. For example, Sørensen and Amato (2002) and Sørensen (2004) studied the residual effect of dairy cattle slurry and pig slurry on barley and ryegrass on sandy soils in Denmark, with irrigation amounting to about 60 mm $year^{-1}$. Schröder et al. (2005) studied the residual effects of cattle slurry on silage maize and ryegrass under rainfed conditions on a sandy soil in the Netherlands. Schröder et al. (2007) also studied the residual effects of different manures on grasslands on sandy soils in the Netherlands. However, there is less available information regarding the PSRE on the soil and on the following crops under irrigated semiarid conditions in Southern Europe. In Spain, Yagüe and Quílez (2010) reported the residual effect of one application of pig slurry to wheat on the following wheat crop. In turn, Daudén et al. (2004), also working in Spain, evaluated the residual effects of pig slurry applied to maize for 3 consecutive years on the following wheat crop.

Given the limited data on PSRE, agronomists face uncertainties when recommending N fertilizer rates for crops seeded in soils that previously had received pig slurry. Hence, further information concerning PSRE and mineral N fertilizer residual effect (MRE)

Abbreviations: SMN, Soil mineral nitrogen; FNUE, Fertilizer N use efficiency; PSRE, Residual effect of pig slurry; MRE, Residual effect of mineral N fertilizer; RE_{INO}, Residual effect per kg of inorganic N applied to maize.

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Table 1
Amounts of *inorganic* N and *total* N (*inorganic* plus *organic*) applied to the maize through the different treatments.

Maize treatment		Whole period (2002-2007)		Average year	
Pig slurry rate (m^3 ha^{-1} $year^{-1}$)	Mineral N rate (kg N ha^{-1})	Inorganic N[a] (kg N ha^{-1})	Total N (kg N ha^{-1})	Inorganic N[a] (kg N ha^{-1} $year^{-1}$)	Total N (kg N ha^{-1} $year^{-1}$)
PS0	N0	0	0	0	0
	N100	600	600	100	100
	N200	1200	1200	200	200
	N300	1800	1800	300	300
PS30	N0	810	1193	135	199
	N100	1410	1793	235	299
	N200	2010	2393	335	399
PS50	N0	1446	2125	241	354
	N100	2046	2725	341	454
	N200	2646	3325	441	554

[a] Inorganic N refers to ammonium-N in the case of pig slurry and to ammonium nitrate in the case of mineral N fertilizer.

is needed for irrigated semiarid conditions. A better assessment of PSRE and MRE on the subsequent crop would help to improve nitrogen fertilizer use efficiency (FNUE) within the crop rotation and to reduce the possibility of N losses associated with unnecessary N applications. This last point is particularly important in nitrate vulnerable zones (Anonymous, 1991), where N leaching control is very critical to reduce water pollution with nitrates. The objective of this study was to quantify the residual effects of pig slurry and mineral N applied to maize on the subsequent wheat and on the soil mineral N content.

2. Materials and methods

2.1. Previous maize monoculture (2002–2007)

The present study was established following a N-fertilization trial conducted over 6 consecutive years (Berenguer et al., 2008a,b). A maize monoculture was grown from 2002 to 2007 in Gimenells, Northeast Spain (41°65′N, 0°39′E), on a Petrocalcic Calcixerept soil (Soil Survey Staff, 1998). The climate of the region is semiarid continental Mediterranean, with low annual precipitations (374 mm), low average air temperatures in winter (5.4 °C), and high average air temperatures in summer (22.5 °C). The experimental design was a split-plot, with three pig slurry rates as the main plots: 0, 30, and 50 m^3 ha^{-1} per year, referred to as PS0, PS30, and PS50, respectively. Each pig slurry treatment was combined with three mineral N fertilizer rates as subplots: 0, 100, and 200 kg N ha^{-1} per year, referred to as N0, N100, and N200, respectively. In addition, the PS0 treatment included an additional mineral N sub-treatment (300 kg N ha^{-1} per year), referred to as N300. The mineral N fertilizer was applied as ammonium nitrate (33.5%) in order to reduce the risk of ammonia loss. The fertilization treatments were randomized in the first year (2002) and thereafter they were applied to the same plots, every year, until 2007. Pig slurry was spread in March using a commercial splash plate spreader 3–4 weeks before maize seeding and was incorporated into the soil by disking within a few hours of application so as to minimize the risk of ammonia loss. Mineral P and K were annually applied to all plots at rates of 65 and 207 kg ha^{-1}, respectively, to ensure that there were no deficits in any of the treatments. Maize was sprinkler-irrigated with about 600 mm of water during each growing season. The irrigation water applied had no appreciable N content. The field was kept free of weeds, pests and diseases, following local practices. Each year, maize was harvested in late September-early October and the stover was removed from the field after harvest.

The amounts of *inorganic* N (ammonium N) and *total* N (*inorganic + organic*) applied to maize with the different treatments are presented in Table 1. The N treatments were chosen to reflect some of the most common amounts of N applied to maize by farmers in irrigated semiarid areas (Sisquella et al., 2004). A previous study conducted in this field (Berenguer et al., 2008a) reported that the PS30 + N100 rate covered maize-N requirements and only slightly exceeded the maximum amount of N derived from organic sources that can be applied to agricultural soils in Nitrate Vulnerable Zones (170 kg N ha^{-1}, Diari Oficial de la Generalitat de Catalunya, 2009). In turn, the PS50 + N0 rate covered maize-N requirements but would not be allowed in Nitrate Vulnerable Zones (Table 1). The treatments PS30 + N200, PS50 + N100, and PS50 + N200 resulted in a clear over-N fertilization of the previous maize monoculture (Berenguer et al., 2008a).

2.2. Wheat management

Following the maize experiment, bread wheat (cv. Califa Sur) was seeded in November 2007 at a rate of 450 seeds m^{-2}. At tillering, all the wheat plots were subdivided. One half-plot (size = 15 m × 5.5 m) was left unfertilized in order to evaluate the residual effects of the pig slurry and mineral N fertilizer treatments. The other half-plot was fertilized with 100 kg N ha^{-1} in the form of ammonium nitrate (33.5%) to test the possible need for additional N fertilization to attain maximum wheat yields. Wheat was sprinkler-irrigated from late March to early May 2008 with a total application of 120 mm. Wheat harvesting took place in mid July 2008.

The soil mineral N content was determined in October 2007, before wheat sowing (SMN_{2007}) and in August 2008, after wheat harvest (SMN_{2008}). Soil samples were taken from depths of 0 to 90 cm, in 30 cm increments, and each sample was composed of 4 mixed cores per plot. Soil nitrates were extracted using deionised water (soil/water ratio = 1:1) and were measured using test strips with a Nitrachek® device calibrated according to the standard procedure (Bischoff et al., 1996). The amount of ammonium was considered negligible (Villar-Mir et al., 2002) and was not taken into account. Wheat-grain yield was measured with an experimental combine (Wintersteiger, classic), by harvesting the central strip of each plot (1.5 m × 15 m) and was adjusted to 14% moisture. Grain-N concentration was determined by the combustion method (Dumas, 1931), and grain-N uptake was calculated by multiplying grain dry yield by grain-N concentration.

2.3. Residual effects of pig slurry and mineral N fertilizer

The average response of wheat in the control plots (PS0 + N0) was defined as the apparent soil effect, following Daudén et al. (2004). The apparent pig slurry residual effect (PSRE, Eq. (1)) and the apparent mineral N fertilizer residual effect (MRE, Eq. (2)) on wheat grain yield and on grain-N uptake were calculated in unfertilized