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Response of paddy rice to fertilisation with pig slurry in northeast Spain: Strategies to optimise nitrogen use efficiency

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ABSTRACT

The increasing pig population in northeast Spain and the need to adequately manage the pig slurry (PS) generated demand the inclusion of PS in crop fertilisation plans. The aim of the present study was to maximise the amount of PS that can be applied to the crops without adverse environmental effects. Thus, a 3-year experiment was established to evaluate the response of flooded rice to different fertilisation strategies. The fertilisation strategies tested were two rates of PS applied before sowing: 170 kg NH_4-N ha^{-1} (PS170 strategy) that would cover the entire rice N requirements and 120 kg NH_4-N ha^{-1} (PS120 strategy) that would theoretically require N as top-dressing to reach maximum yields. These strategies were compared to the rate of mineral fertiliser applied before sowing at 120 kg NH_4-N ha^{-1}. Plant density; the presence of weeds, pests and diseases; head rice yield; and rice quality were not affected by the N source (PS or mineral). Maximum rice yields (5567–8235 kg ha^{-1}) varied between years and were attained with the two PS fertilisation strategies. Maximum yields with the PS170 strategy were reached without top-dressing application in the three years, but nitrogen (N) as top-dressing was necessary to reach maximum yields with the PS120 strategy. The nitrogen fertiliser replacement value (NFRV) of the two PS strategies, 87% (PS170) and 96% (PS120) of ammonium N applied, were not significantly different. The high PS NFRV suggests that PS is an excellent N source and rates should be established considering PS ammonium N content. Agronomic and recovery N use efficiencies and unaccounted N were not significantly different between mineral and PS strategies when the same ammonium N rate was applied; however, when the total N was considered, N use efficiencies decreased, indicating that organic N is not taken up by the crop during the crop season.

1. Introduction

Spain is the largest pig producer in the European Union (approximately 28 million heads), with 19% of the total production (EUROSTAT, 2015) and a production of approximately 50 million tonnes of pig slurry (PS) per year. More than half (51%) the country's pig production is concentrated in northeast Spain (Aragon and Catalonia regions, MAGRAMA, 2015a). Traditionally, PS has been applied to field crops, at very high rates in many cases, which may have resulted in negative environmental impacts on the soil, water and atmosphere. PS has been traditionally applied to winter cereals (barley and wheat) and maize crops. With a growing pig population, PS fertilisation should extend to alternative crops such as alfalfa (Salmerón et al., 2010) and rice to more efficiently recycle the increasing amounts of nutrients produced in the farms.

Rice is one of the most important crops in the world. The total cultivated area of rice is approximately 163 million ha, with 88% of this area in Asia. In Europe, rice is mostly cultivated in the Mediterranean countries, with a total harvested area of approximately 642,000 ha, and 17% of this area is in Spain (FAOSTAT, 2014). The rice extension in northeast Spain represents 25% (MAGRAMA, 2015b) of the crop surface in Spain. To improve the recycling of nutrients in agriculture, the integration of PS in the N fertilisation schedule for this crop is a necessity.

Poor N fertiliser use efficiency is characteristic of paddy rice systems. Low N efficiency is attributed to rapid losses of applied N due

Abbreviations: PS, pig slurry; N, nitrogen; NFRV, nitrogen fertiliser replacement value; NH_4-N, ammonium nitrogen; NO_3-N, nitrate nitrogen; AE_{NH4}, agronomic efficiency of N, considering only the ammonium N content of PS; RE_{NH4}, recovery efficiency of N, considering only the ammonium N content of PS; AE_{NT}, agronomic efficiency of N, considering the total N content of PS; RE_{NT}, recovery efficiency of N, considering the total N content of PS; DM, dry matter; EC_e, electrical conductivity of saturated paste extract.

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to ammonia volatilisation, denitrification (Cassman et al., 1998) and nitrate leaching. The particular conditions experienced by a rice crop, *i.e.* flooding interspersed with periods of drainage, contribute to these losses, especially to the gaseous losses due to denitrification (Cai et al., 1997; Wang et al., 2011; Zheng et al., 2000; Zou et al., 2005) and leaching, which can reach 60–70% of the applied N (Tinarelli, 1989).

Different studies in different parts of the world have evaluated the response of rice to mineral fertilisers (Xie et al., 2007; Biloni and Bocchi, 2003) or organic fertilisers such as cow and poultry manure (Myint et al., 2010a, 2010b), anaerobically digested cattle manure (Nishikawa et al., 2012), anaerobically digested PS (Lu et al., 2012; Zhang et al., 2015), pig manure (Pan et al., 2009), farmyard manure (Gu et al., 2009) or dairy manure (Xue et al., 2014b). However, most of these studies have not evaluated the fertiliser value of the N in these organic products for rice, and in some of these studies, even the nutrient composition of the organic fertiliser is unknown. Studies of PS application to rice have focussed on gaseous emissions (Maris et al., 2016) or soil properties (Goyal et al., 2006), but studies focussing on the fertiliser value of PS N have not been found in the literature, and such information is essential for integrating slurry management into the N fertilisation schedule of this crop.

In areas saturated with pig production, a premise is to maximise the amount of PS that can be applied to the crops without adverse environmental effects. In other summer crops, such as maize, pre-sowing application of PS at low rates, complemented with mineral N as side-dressing, is the most efficient strategy for PS fertilisation to avoid decreased N efficiencies and N losses to the environment while adhering to EU regulations (Berenguer et al., 2008; Yagüe and Quílez, 2010). We hypothesised that because of flooding conditions, rice can be fertilised with a single PS application (up to 100% of crop N requirement) before sowing with lower N losses than in other summer crops. In addition, we hypothesised that organic N is unlikely to be used by the crop during the year of application as anaerobic conditions delay the PS organic N mineralisation process (Aulakh et al., 2000; Ethan, 2015; Olk et al., 2007).

Therefore, the aim of this study was to investigate three fertilisation strategies in rice flooding irrigation systems in northeast Spain: a PS rate that would cover the total crop N requirements (170 kg NH_4-N ha^{-1}), a PS rate with ammonium N content below the N requirements for rice (120 kg NH_4-N ha^{-1}), and a mineral rate of 120 kg N ha^{-1} applied as a mineral fertiliser (M120). The three strategies were complemented with mineral N as top-dressing. We evaluated and compared the crop response, N use efficiency, rice quality and N budget.

The experimental treatments were established considering the nitrogen recommendation of approximately 170 kg N ha^{-1} for rice (to obtain a potential yield of 7–8 Mg ha^{-1}) (Pérez, 2006), and PS rates were established according to the ammonium N content of the PS.

2. Material and methods

2.1. Field experiment and design

A field experiment was conducted in Villanueva de Sigena (Huesca) in northeast Spain (41°45′31.87″ N, 0°2′18.16″ W) on silt loam-textured soil (the soil physicochemical characteristics are in Table 1) during three consecutive years (April 2011 to October 2013). The climate of the region is semiarid continental Mediterranean, with high temperatures during the summer and low precipitation (average summer temperature = 15.0 °C and average annual precipitation = 349 mm over the period 1980–2010). Figure S1 shows the average temperatures, rainfall and solar radiation for the three experimental years. The field had been cultivated with rice in 2010 and with barley in the previous years.

The fertilisation strategies applied were two rates of PS equivalent to 170 kg NH_4-N ha^{-1} (PS170 strategy) and 120 kg NH_4-N ha^{-1} (PS120 strategy) compared with 120 kg NH_4-N ha^{-1} of mineral fertiliser (M120), all three applied at pre-sowing. Theoretically, PS170 rate would cover the whole rice N requirements, whilst PS120 and M120 would need top-dressing N to achieve maximum yields. PS120 will allow identifying whether the N provided by the mineralisation of PS organic N is used by the crop in the year of application. These strategies of fertilisation at pre-sowing were combined with six N rates as top-dressing to obtain the yield response to top-dressing N and establish the N rate necessary to reach optimum yields with each strategy. The top-dressing mineral N rates (kg N ha^{-1}) were as follows: 0 (M0), 30 (M30), 60 (M60), 90 (M90), 120 (M120) and 150 (M150) (Table 2). The experimental design was a split plot with four replications. Additional mineral treatments (Table 2) were included to obtain the nitrogen fertiliser replacement value (NFRV) of the two PS strategies. The additional treatments were a control treatment without N application (M0) and five rates of mineral N at pre-sowing: 30 kg N ha^{-1} (M30), 60 kg N ha^{-1} (M60), 90 kg N ha^{-1} (M90), 120 kg N ha^{-1} (M120) and 150 kg N ha^{-1} (M150). The mineral fertiliser was ammonium sulphate (in 2011, ammonium nitrate was erroneously applied before sowing).

The experimental plots were 6 m wide by 12 m long for the PS treatments (6 subplots per main plot) and 6 m wide by 5 m long for the M treatments (10 subplots). The treatments were randomised in the first year (2011) and then repeated in the same plots for the next two years.

2.2. Agricultural practices

Typical land preparation (two passes of disc plough and two passes of rotavator) was conducted by a farmer in April–May every year before fertilisation, sowing and flooding.

PS was collected from a fattening farm near the experimental field. The application rates were established according to the ammonium N concentration of the PS, which was measured *in situ* using Quantofix and by conductimetry using the methodology of Yagüe and Quílez (2012), and slurry samples were collected for further analysis in the laboratory.

The ammonium and total N content in PS ranged between 3 and 3.8 kg NH_4-N Mg^{-1} and 4.2 and 6.3 kg N Mg^{-1}, respectively, and the P and K content ranged between 0.7 and 1.8 kg P Mg^{-1} and 3.1 and 4.1 kg K Mg^{-1}, respectively (Table S1).

PS was band spread on 16 May 2011, 15 May 2012 and 9 May 2013. On the same days, the basal mineral N fertiliser (ammonium sulphate) was applied to the plots of mineral treatments at the corresponding rates together with P (100 kg P_2O_5 ha^{-1}) and K (100 kg K_2O ha^{-1}) to avoid a P or K deficiency. Slurry and mineral fertilisers were then incorporated into the soil using a rotavator in the afternoon of the same day.

Prior to the PS application, the machinery was calibrated to apply the target N rates; however, applying the appropriate amounts of PS to reach target rates was difficult, as pointed out by Daudén and Quílez (2004). Therefore, in each application, the slurry tank was weighed before and after application to determine the actual PS rates (30–36 Mg ha^{-1} for PS120 and 49–54 Mg ha^{-1} for PS170) and the actual N rates (Table 3).

Rice (*Oryza sativa* L. spp *Japónica* cv. Guadiamar) was broadcast seeded on 17 May 2011, 16 May 2012 and 15 May 2013 at a seed rate of 180 kg ha^{-1}, and the field was immediately flooded, except in 2013 when flooding preceded rice seeding. Water was continuously flowing in and out of the plot. A water layer of 5 cm was maintained during the initial days to improve rice germination; after that, a water layer of 10 cm was maintained until approximately 1 month