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Do no-till and pig slurry application improve barley yield and water and nitrogen use efficiencies in rainfed Mediterranean conditions?

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ABSTRACT

Tillage and N fertilization strategies including mineral and organic sources need to be studied in combination given their importance on the production cost that farmers face and their potential interaction on crop performance. A four-year (2010–2014) experiment based on barley monocropping was carried out in NE Spain in a typical rainfed Mediterranean area. Two tillage treatments (CT, conventional tillage; NT, no-tillage) and three rates of N fertilization (0; 75 kg N ha^{-1}, applied at top-dressing; 150 kg N ha^{-1}, applied at pre-sowing and at top-dressing at equal rate), with two types of fertilizers (ammonium-based mineral fertilizer and organic fertilizer with pig slurry), were compared in a randomized block design with three replications. Different soil (water and nitrate contents) and crop (above-ground biomass, grain yield, yield components and N concentration in biomass and grain) measurements were performed. Water- and nitrogen use efficiencies (WUE and NUE) as well as other N-related indexes (grain and above-ground biomass N uptake; NHI, nitrogen harvest index; NAR, apparent nitrogen recovery efficiency) were calculated. Barley above-ground biomass and grain yield were highly variable and depended on the rainfall received on each cropping season (ranging between 280 mm and 537 mm). Tillage and N fertilization treatments affected barley grain yields. No-tillage showed 1.0, 1.7 and 6.3 times greater grain yield than CT in three of the four cropping seasons as a result of the greater soil water storage until tillering. Water scarcity during the definition of the number of spikes per m^2 under CT would have compromised the compensation mechanism of the other two yield components. Pig slurry application led to the same (3 of 4 years) or higher (1 of 4 years) grain yield than an equivalent rate of mineral N fertilizer. Regardless the N origin, barley yield did not respond to the application of 150 kg N ha^{-1} split between pre-sowing and top-dressing compared to the 75 kg N ha^{-1} rate applied as top-dressing. A significant nitrate accumulation in the soil over the experimental period was observed under CT. Greater barley water use efficiency for yield (WUEy), N uptake and grain N content were found under NT than CT in three of the four cropping seasons studied. Moreover, for a given N rate, the use of organic fertilization increased significantly the WUEy as an average of CT and NT. When CT was used, a greater NHI was observed when using pig slurry compared with mineral N as an average of the four years studied. However, the use of different N fertilization treatments (rates or types) under CT or NT did not increase the NUE compared with the control. Our study demonstrates that the use of NT and the application of agronomic rates of N as pig slurry leads to greater barley yield and water- and nitrogen-use efficiencies than the traditional management based on CT and mineral N fertilization.

Abbreviations: CT, conventional tillage; HI, harvest index; NAR, apparent N recovery efficiency; NHI, nitrogen harvest index; NT, no tillage; NUE, nitrogen use efficiency; WUE_b, water-use efficiency for biomass; WUE_y, water-use efficiency for yield.

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1. Introduction

Rainfed Mediterranean cropping systems face a series of challenges related to different agronomic, environmental and socio-economic aspects. Crop productivity under Mediterranean conditions is highly dependent on the variable amount of precipitation received during the cropping season and the capacity of the soil to store water, leading to low yield potentials in many areas (Austin et al., 1998). Cropping intensity and crop diversification in the rainfed Mediterranean areas depends on the amount of water available. In the driest locations (i.e. <350 mm of annual rainfall), the traditional cropping system is the winter cereal-fallow rotation. In wetter semiarid areas (i.e. 350–450 mm) cropping systems are mainly based on winter cereals, namely barley and wheat, usually grown in monocropping. Finally, under sub-humid conditions (i.e. >450 mm and/or deeper soils) other crops such as grain legumes (e.g. vetch, peas, etc.) or canola are incorporated into the rotations.

Soil management and nitrogen (N) fertilization practices account for a great proportion of the production costs that farmers face (Cantero-Martínez et al., 1995) and have a wide margin for their improvement in semiarid areas such as the Mediterranean region (Carmona et al., 2015). Traditionally, soil management in Mediterranean areas has been based on conventional tillage (CT) with soil inversion (i.e. based on moldboard plowing). Although inversion systems are still used in many areas, a significant proportion of farmers have turned to reduced tillage systems based on vertical implements (e.g. chisel-type plows) or less intensive inversion systems (e.g. disk plows). No-tillage (NT), which began to be experienced more than three decades ago, continues to be increasingly adopted, even though many farmers are still reluctant to make the switch (Cantero-Martínez and Gabiña, 2004; Kassam et al., 2012). However, different studies have shown the benefits of NT compared to CT in rainfed semiarid areas regarding different agronomic (e.g. higher and more stable yields, Hernanz and Sánchez-Girón, 1988; Mrabet, 2000), environmental (e.g. improving soil physical quality, Fernández-Ugalde et al., 2009) and economic aspects (e.g. Sánchez-Girón et al., 2004).

Low profitability of rainfed cropping systems drives the farmers towards the diversification of revenues. In the dryland Mediterranean systems of NE Spain that process has led to the establishment of intensive livestock production, mainly pig (*Sus scrofa*) farming (Clar and Pinilla, 2011; Yagüe and Quílez, 2013). Recent statistics show that pig herd in NE Spain accounts for more than 13 million animals (MAGRAMA, 2013). The presence of that large swine production has led to a great availability of slurries that farmers spread on agricultural soils not always with the best synchronization with crop needs (Bosch-Serra et al., 2015). Furthermore, the need to empty the farm storage pits regularly and the costs of transporting large volumes of slurries with rather low N concentration per unit of volume have led to the contamination of groundwater with nitrates (Menció et al., 2016; Rebolledo et al., 2016). Traditionally, farmers of the area have tended to overdose the applications of N with mineral and/or organic fertilizers as a means to secure crop yields. This decision would be partly justified by the unpredictability of rainfall and water availability for the crops in rainfed Mediterranean areas. As a consequence, significant areas in NE Spain have been declared nitrate vulnerable zones according to the Nitrates Directive (91/676/EC) (European Union, 1991).

Previous works have evaluated the combined impact of tillage and mineral N fertilization on crop yields under rainfed Mediterranean conditions (López-Bellido et al., 1996; López-Bellido and López-Bellido, 2001; Angás et al., 2006; Lestingi et al., 2010; Cantero-Martínez et al., 2016; Seddaiu et al., 2016). Regarding to this point, Angás et al. (2006) stressed the need to reduce N applications due to their negative economic and environmental consequences independently of the type of tillage. In turn, Cantero-Martínez et al. (2016) pointed out the greater crop response to mineral N fertilizer under NT compared with CT. However, tillage × nitrogen fertilization experiments including the impact of organic fertilization are scanty since most have focused only on mineral N fertilizer.

Then, the aim of this experiment was to elucidate the impact of tillage and different sources and rates of nitrogen fertilization on cereal production and water and nitrogen use efficiencies under Mediterranean conditions. Our hypothesis was that the use of NT and medium rates of N fertilizer would led to greater productivities and resource use efficiencies.

Table 1
General and soil (0–30 cm) characteristics of the field site. Soil properties were measured at the beginning of the experiment (October 2010).

Site and soil characteristic	
Elevation (masl)	395
Annual precipitation (mm)	327
Mean annual air temperature (°C)	13.4
Annual PET (mm)	1197
Soil classification[a]	Typic calcixerept
pH (H_2O, 1:2.5)	8.0
$EC_{1.5}$ (dS m^{-1})	1.04
Organic C (g kg^{-1})	15.6
Organic N (g kg^{-1})	1.4
Particle size distribution (%)	
Sand (2000–50 μm)	6.2
Silt (50–2 μm)	63.3
Clay (<2 μm)	30.5

PET, potential evapotranspiration.
[a] According to the USDA classification (Soil Survey Staff, 2014).

2. Materials and methods

2.1. Experimental site and treatments

A field experiment was established in 2010 in Senés de Alcubierre (NE Spain, 41° 54′ 12″ N, 0° 30′ 15″ W) in a rainfed area with a temperate continental Mediterranean climate. Soil and climatic characteristics of the site are shown in Table 1 and Fig. 1, respectively.

The experimental design consisted of the combination of two tillage practices (CT, conventional tillage; NT, no-tillage) and three N fertilization rates (0, 75 and 150 kg N ha^{-1}) based on two different types of fertilizer (mineral N and organic N with pig slurry) in a randomized block design with three replications. Since the 1970s soil management at the site was based on the use of a subsoiler and a chisel. Four years before the establishment of the experiment (i.e. 2006) soil management was switched to NT. The cropping system during the experiment consisted of a barley (*Hordeum vulgare* L., cv. Meseta) monocropping. The CT treatment consisted of one pass of disk plow (15 cm depth) followed by a cultivator. However, due to the dry conditions of soil in 2011 two passes of chisel were used. A non-selective herbicide (1.5 L 36% glyphosate per hectare) was applied before sowing in the NT treatment. Sowing was carried out with a no-till seeder equipped with disk type furrow openers set to 2–4 cm depth. The combination of fertilizer types and N rates led to five fertilization treatments: 0, control, 75 Min and 75 Org, 75 kg N ha^{-1} with mineral and organic N at the beginning of tillering, respectively, and 150 Min and 150 Org, 150 kg N ha^{-1} with mineral and organic N applied at equal rates before sowing and at the beginning of tillering. For the mineral N treatments ammonium sulphate (21% N) and ammonium nitrate (33.5% N) were used before sowing and at the beginning of tillering, respectively. Mineral N applications were performed manually. The organic fertilization treatment consisted on the application of