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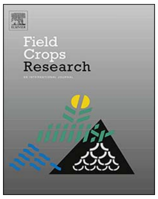

Switching from conventional tillage to no-tillage: Soil N availability, N uptake, ^{15}N fertilizer recovery, and grain yield of durum wheat

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ABSTRACT

This 2-year study, performed in a typical Mediterranean environment on three soil types (two Inceptisols and one Vertisol), aimed to improve understanding of the factors that play a major role in determining crop response when soil management shifts from conventional tillage (CT) to no-tillage (NT). The effects of NT on the soil nitrogen (N) availability, N uptake, ^{15}N fertilizer recovery, and grain yield of durum wheat were evaluated in comparison to CT under five different N fertilization rates (0, 40, 80, 120, and 160 kg N ha^{-1}).

Compared to CT, NT negatively affected grain yield in one of the two years but only in the two Inceptisols. On average, a considerable grain yield advantage of CT over NT (approximately +0.6 Mg ha^{-1} of grain) was observed with no N fertilization. This benefit decreased progressively when N fertilizer rate increased to the point that at 120 kg ha^{-1} of N applied differences between CT and NT were negligible. The differences between the two tillage systems in both grain yield and N uptake were attributable more to differences in the native soil mineral N (that materialized already during the vegetative phase of the crop cycle) than to differences between CT plants and NT plants in efficiency in taking up N from fertilizer. The differences between CT and NT for many of the traits observed in durum wheat plants increased with decreasing soil fertility and in particular with decreasing soil total N. In conclusion, the shift from CT to NT, which should be accompanied in any case by an increase in the N fertilization rate to take into account the reduction in soil N available for the crop, was less problematic in the Vertisol, which is more fertile and better structured than the two Inceptisols.

1. Introduction

No-tillage (NT) is widely recognized as a viable soil management technique in sustainable agriculture (Derpsch, 2008). Compared to conventional tillage (CT; usually based on moldboard plowing), NT helps to protect the soil from erosion (Scopel et al., 2005); enhances aggregation and aggregate stability (Madari et al., 2005); improves soil hydraulic characteristics (Kay and VandenBygaart, 2002); preserves soil macro- and microfauna (Uri et al., 1999); enhances soil microbial activity (Sharifi et al., 2008); reduces fuel consumption, and saves labor and time (Kirkegaard, 1995). Moreover, NT tends to preserve soil water better than CT, which results in huge advantages for the cropping systems in arid and semiarid areas; this is generally attributed to the change in the soil porosity (into more small pores and fewer large pores), to the creation of a more continuous pore system (from decaying roots and soil macrofauna activity), and above all to the minor soil water evaporation in NT as a consequence of both the presence of crop residues on the soil surface and the minor soil surface roughness generated by soil cultivation (Blevins and Frye, 1993; Lampurlanés and Cantero-Martínez, 2006). Such potential benefits suggest that NT is advantageous for cereal-based systems in Mediterranean environments, where water scarcity during the spring is often the main factor limiting

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Abbreviations: NT, no-tillage; CT, conventional tillage; OM, organic matter; %$^{15}N_{REC}$, percentage of ^{15}N fertilizer recovery; CNRG, contribution of N remobilization to grain N yield; N0, no N fertilization; N40, N80, N120, and N160, fertilization with 40, 80, 120, and 160 kg N ha^{-1}; CDA, canonical discriminant analysis

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the growth and productivity of rainfed crops (Lampurlanés et al., 2002) and where soils are particularly prone to erosion because of their characteristics and morphology (45% of the Mediterranean region has slopes greater than 8%), of cultivation even in steep slopes, and of the high frequency of intense rainfall events in fall and winter (García-Ruiz et al., 2013; Raclot et al., 2016). Several studies carried out under Mediterranean conditions have confirmed the benefits of NT over CT in terms of both a reduction in soil erosion (García-Orenes et al., 2009) and a crop yield advantage, particularly in dry areas/years (Amato et al., 2013; Ruisi et al., 2014). Despite these benefits, however, NT systems are used rarely in the Mediterranean, being practiced on approximately 2% of the total cropland (FAO AQUASTAT, 2013). There are several reasons for this, such as a lack of policies encouraging the adoption of NT and likely also the resistance on the part of farmers, as its positive effects are often not immediately apparent but can only be seen after a new equilibrium in the soil has been established (Stubbs et al., 2004). Such benefits in fact are directly or indirectly attributable to the increase in soil carbon sequestration and storage that, under NT, occurs gradually over time (West and Marland, 2002; West and Post, 2002; González-Sánchez et al., 2012; Badagliacca et al., 2018) depending on several factors, including climatic conditions, soil characteristics, crop rotation, and other crop management practices. As a consequence, the shift from CT to NT can be thorny; the farmer often has to completely reorganize the production system to resolve the problems that will inevitably arise before a new equilibrium is reached. For example, application of NT can markedly affect the population of weeds (Sosnoskie et al., 2006; Giambalvo et al., 2012; Ruisi et al., 2015a,b) and the incidence of pests and diseases (Paulitz et al., 2002), requiring adjustments to control strategies. At the same time, even from the first years of application, NT can result in considerable changes in organic matter (OM) mineralization rates, nitrogen (N) immobilization, N availability, and N-use efficiency of the crop (Gao et al., 2009; Stagnari et al., 2014). Obviously, these effects can vary greatly depending on the context in which NT is implemented (e.g., in terms of climatic conditions, soil type and fertility, crop rotation, crop management, and duration of application); this explains the inconsistent findings in the literature (Franzluebbers et al., 1995; McCarty et al., 1998; Peigné et al., 2007).

Although several studies have been conducted in the Mediterranean environment on the effects of the continuous application of NT over a high number of years on soil N dynamics and the crop response (e.g., Ruisi et al., 2016), relatively few studies have evaluated the effects of NT on soil N dynamics and the fate of the N fertilizer applied during the first year switch from CT to NT, which, as already said, can be thorny so much to induce in some cases the farmer to abandon NT. This knowledge is important to plan cropping management strategies sustainable from both the agronomic and environmental standpoints. Thus, the present study aimed to address the following questions: i) How, and to what extent, does switching from CT to NT alter the availability of soil N for crops and the fate of the N fertilizer applied? ii) How much do these changes vary by soil type and climatic conditions? To this end, we studied the effects of NT on soil N dynamics and crop growth and yield in comparison with CT by applying these two techniques to three soil types differing in physical and chemical characteristics. The experiment was conducted in a semiarid Mediterranean environment and replicated over 2 years. Durum wheat (*Triticum durum* Desf.) was used as the model plant because of its importance as a crop plant in arid and semiarid areas of the Mediterranean basin.

2. Materials and methods

2.1. Site characteristics

Field experiments were performed during two growing seasons (2011–2012 and 2012–2013; hereafter referred to as 2012 and 2013, respectively) at three sites (highly representative of arable soils of the Sicilian inland), all located within the Pietranera farm, which is located about 30 km north of Agrigento, Sicily, Italy (37°30′N, 13°31′E; 178 m a.s.l.). The farm covers approximately 700 ha and includes a variety of soil types, morphologies, and orographies. The cropping systems of the farm are based on cereal crops (mainly durum wheat) in rotation with legumes (grain and fodder crops). Soil tillage management is based on moldboard plowing (followed by secondary tillage operations) for cereal crops or on minimum tillage for legume crops. Soil characteristics (referring to the 0- to 0.40-m layer) of the three experimental sites are reported in Table 1. The first soil, classified as Typic Calcixerept (Soil Survey Staff, 2006), is deep, with a clayey texture and a low to moderate OM content; it has a sub-angular structure and a sub-alkaline reaction. The second soil is a Vertic Haploxerept evolved on recent alluvial deposits. The soil is deep, with a sandy clay texture and a very low OM content; it has a granular structure, good drainage, and a sub-alkaline reaction. The third soil, classified as Chromic Haploxerert, is a fine-clayey, calcareous, mixed, xeric Vertisol that developed on Mio-Pliocenic clayey substrata. It is especially rich in montmorillonitic clays that promote swelling and shrinking in the soil; it can be considered the most productive soil because of its high natural fertility.

Table 1
Physical and chemical characteristics of the top layer (0–40 cm) of the three soil types where the experiment was conducted.

		Soil type (St)		
	Unit	St 1 Typic Calcixerept (Inceptisol)	St 2 Vertic Haploxerept (Inceptisol)	St 3 Chromic Haploxerert (Vertisol)
Altitude	m a.s.l.	245	150	175
Particle size analysis:				
Clay	$g\ kg^{-1}$	558	267	525
Silt	$g\ kg^{-1}$	197	247	227
Sand	$g\ kg^{-1}$	245	486	248
pH (1:2.5 H_2O)	–	8.0	8.0	8.2
Total C (Walkley Black)	$g\ kg^{-1}$	10.6	6.3	16.8
Total N (Kjeldahl)	$g\ kg^{-1}$	0.61	0.86	1.78
Available P (Olsen)	$mg\ kg^{-1}$	28.8	55.9	40.1
Cation exchange capacity	$cmol+\ kg^{-1}$	28.1	26.8	35.0
Water content at:				
field capacity	$cm^3\ cm^{-3}$	0.35	0.28	0.37
permanent wilting point	$cm^3\ cm^{-3}$	0.19	0.19	0.20

The climate is semiarid Mediterranean, with a mean annual rainfall of 581 mm, mostly in autumn/winter (74%) and in spring (18%), and a mean annual PET of about 1100 mm (calculated using the Penman–Monteith method). The dry period is from May to September. The mean air temperature is 15.9 °C in autumn, 9.8 °C in winter, and 16.5 °C in spring. The average minimum and maximum annual temperatures are 10.0 °C and 23.3 °C, respectively.

2.2. Experimental design and crop management

The experiments were set up as a split-plot design with four replications. The main plots (90 m^2 each) were the soil tillage techniques: CT or NT. Each subplot received a different level of N fertilizer: 0, 40, 80, 120 or 160 $kg\ N\ ha^{-1}$ (hereafter referred to as "N0", "N40", "N80", "N120" and "N160," respectively). The size of each subplot was 18 m^2 (16 rows, each 6.0 m long, spaced at 0.1875 m). In both 2012 and 2013, the previous crop was berseem clover (*Trifolium alexandrinum* L.) in all three sites; before berseem clover was sown, soils were always managed