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Long term effects of tillage practices and N fertilization in rainfed Mediterranean cropping systems: durum wheat, sunflower and maize grain yield

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ABSTRACT

Long term investigations on the combined effects of tillage systems and other agronomic practices such as mineral N fertilization under Mediterranean conditions on durum wheat are very scanty and findings are often contradictory. Moreover, no studies are available on the long term effect of the adoption of conservation tillage on grain yield of maize and sunflower grown in rotation with durum wheat under rainfed Mediterranean conditions. This paper reports the results of a 20-years experiment on a durum wheat-sunflower (7 years) and durum wheat–maize (13 years) two-year rotation, whose main objective was to quantify the long term effects of different tillage practices (CT = conventional tillage; MT = minimum tillage; NT = no tillage) combined with different nitrogen fertilizer rates (N0, N1, N2 corresponding to 0, 45 and 90 kg N ha^{-1} for sunflower, and 0, 90 and 180 kg N ha^{-1} for wheat and maize) on grain yield, yield components and yield stability for the three crops. In addition, the influence of meteorological factors on the interannual variability of studied variables was also assessed. For durum wheat, NT did not allow substantial yield benefits leading to comparable yields with respect to CT in ten out of twenty years. For both sunflower and maize, NT under rainfed conditions was not a viable options, because of the unsuitable (i.e., too wet) soil conditions of the clayish soil at sowing. Both spring crops performed well with MT. No significant N × tillage interaction was found for the three crops. As expected, the response of durum wheat and maize grain yield to N was remarkable, while sunflower grain yield was not significantly influenced by N rate. Wheat yield was constrained by high temperatures in January during tillering and drought in April during heading. The interannual yield variability of sunflower was mainly associated to soil water deficit at flowering and air temperature during seed filling. Heavy rains during this latter phase strongly constrained sunflower grain yield. Maize grain yield was negatively affected by high temperatures in June and drought in July, this latter factor was particularly important in the fertilized maize. Considering both yield and yield stability, durum wheat and sunflower performed better under MT and N1 while maize performed better under both CT and MT and with N2 rates. The results of this long term study are suitable for supporting policies on sustainable Mediterranean rainfed cropping systems and also for cropping system modelling.

1. Introduction

Rainfed cereal cropping systems based on rotations between wheat and a spring crop are widespread in Mediterranean Europe. In the southern Mediterranean countries, winter cereals are grown as monoculture or in rotation with other autumn–spring crops such as pulses, fallow pasture, hay crops or other minor cereals. In the

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northern Mediterranean countries, the rainfall regime and the high water holding capacity of the arable soils allow the cultivation of spring-summer crops such as sunflower, sorghum or maize under rainfed conditions.

Conservation agricultural practices (CA) such as reduced or no tillage, characterized by a low disturbance of soil, coupled with crop residues retention, are increasingly widespread for cultivating cereals and industrial crops in the regions with dry Mediterranean climate (Kassam et al., 2012). CA in the Mediterranean dry areas can have positive effects on crop productivity due to increased soil moisture and nutrient availability (López-Garrido et al., 2011) and can contribute to reduce soil erosion, nitrate leaching, greenhouse gas emissions and fuel costs (Kassam et al., 2012). Site specific effects of CA (i.e., related to soil and climate types) on soil water retention (e.g., De Vita et al., 2007), soil aggregation stability (e.g., Hernanz et al., 2002), microbial activity (Pastorelli et al., 2013) and weed dynamics (De Sanctis et al., 2012) can largely explain the various impacts of CA on crop yields. However, evidences on long term effects of CA practices on crop yield and stability are less frequent and sometimes contradictory.

More than 50% of durum wheat cultivated worldwide lies in the Mediterranean region (Bozzini, 1988) where it represents one of the most important crops in rainfed cropping systems. In these areas, wheat grain yield is characterized by a high interannual variability due to erratic seasonal weather patterns, particularly irregular rainfall distribution and high temperatures during the grain filling stage (Lopez-Bellido et al., 1996). Under rainfed semi-arid Mediterranean conditions, Amato et al. (2013) and Ruisi et al. (2014) showed that durum wheat yield was higher under no tillage than conventional tillage only when water stress was high and that N fertilizer requirements increase with no tillage compared with conventional tillage, because of changes in N cycling that lead to a reduction in plant-available soil N. Sunflower, together with other oilseed crops, is recently drawing a renewed commercial and scientific attention because of its role as energy crop in the cereal-based cropping systems (Barontini et al., 2015 and references therein). Under Mediterranean rainfed conditions, sunflower production is heavily constrained by summer water stress, hence it is practiced as a rainfed crop only in the clayey soil of the northern areas, where the spring-summer rainfall regime is favorable and soil water holding capacity can buffer crop water availability. Under Mediterranean rainfed conditions in southern Spain, CA did not exert a beneficial influence on sunflower grain yields (López-Bellido et al., 2003; Murillo et al., 1998), although a high interannual variability was observed, mainly influenced by soil water conditions throughout the crop cycle.

CA practices may have site-specific impacts on rainfed grain maize yields. CA practices in well drained soils and under high N fertilization inputs and crop rotation may improve maize yield, and yield stability seems to be not significantly affected by reduced tillage (Rusinamhodzi et al., 2011). Rainfall was confirmed as the most important determinant of maize yield under rainfed conditions. The meta analysis of Rusinamhodzi et al. (2011) clearly revealed that the success of CA in improving maize yields depends on the adoption of other good agronomic practices such as targeted site-specific fertilizer application, timely weeding and crop rotations.

To our knowledge, no studies are available on the long term effect of conservation tillage on the productivity of rainfed maize and sunflower under Mediterranean conditions. The duration of such studies on sunflower ranged from one (Lopez-Garrido et al., 2014) to four years (López-Bellido et al., 2003). In the case of grain maize, the available long term studies on the role of tillage systems on yields are referred to a range of climate conditions, from a typical Northern-Central USA climate (Karlen et al., 2013), to the subhumid temperate climate in the Pampas of Argentina (Diaz-Zorita et al., 2002), to the semi-arid, subtropical climate of highlands of Central Mexico (Verhulst et al., 2011) and to the cold semi-arid and humid subtropical climate of Northern China (Wang et al., 2012), none of which comparable to the Mediterranean climate type.

The long-term impact of conservation tillage practices for durum wheat under Mediterranean conditions was instead analysed by several scholars (e.g., Amato et al., 2013; Lopez-Bellido et al., 1996, 2000, 2001; Mazzoncini et al., 2008). However, findings were often contradictory due to differences among the experimental sites in terms of climatic conditions, soil type, management practices, agronomic history and duration of experiments. Hence the effectiveness of various tillage systems is highly site specific and the impact of yield-limiting factors may vary significantly depending on the environmental conditions and on the interactions between them and the management practices (Subedi and Ma, 2009).

Moreover, very few long term investigations have been conducted to study the combined effects of tillage systems and other agronomic practices such as mineral N fertilization under Mediterranean conditions (Lopez-Bellido et al., 1996, 2001).

In the context of rainfed cereal cropping systems of the clayey hills of central Italy, in approximately 300,000 ha of arable hillslope land, the rotation of wheat and a spring-summer crop such as sunflower or maize implies about 8–9 months of intercropping period between the wheat harvest (early July) and the seeding of sunflower (March) or maize (April). Because of the high soil clay content (up to 50%) and the seasonal ranfall/evapotranspiration regime, the main tillage under the conventional practice (i.e., 30–40 cm deep ploughing) is made in the summer, in order to exploit the structuring effect of thermal and water regimes in the soil during autumn–winter. Moreover, tillage practices during autumn may be difficult due to the high plasticity of the clayey soils when autumn is wet. Further harrowing is practiced during intercropping to prepare the maize or sunflower seedbed. Therefore, the conventional practice exposes the bare soil to soil erosion (Roggero and Toderi, 2002) and nitrate leaching (De Sanctis et al., 2009) during the wet and cool season. CA techniques including no tillage and reduced N fertilization rates can provide options to mitigate such undesirable processes, but are considered by farmers as not reliable enough to ensure yield targets and stability, particularly in the case of the spring–summer crops.

In this paper we explore the implications for adopting CA practices from a Long Term Experiment (LTE) based on a two-year rotation of durum wheat and sunflower or maize under rainfed Mediterranean conditions and heavy clayey soils.

The aims of this study were to (i) assess the long term influence of tillage systems and N fertilization rates on yield, yield components and stability of durum wheat, sunflower and maize under Mediterranean rainfed conditions of the hilly areas of Central Italy and (ii) analyse at what extent the meteorological factors can influence the interannual variability of yield for the three crops.

2. Materials and methods

2.1. Experimental site

The LTE is located at the "Pasquale Rosati" experimental farm of the Polytechnic University of Marche in Agugliano, Italy (43°32′N, 13°22′E, 100 m a.s.l.), on a silty-clay soil classified as Calcaric Gleyic Cambisols (FAO, 2006), almost free of gravel, with a high clay (49%) and calcium carbonate (31%) content, pH of 8.3, a low soil organic carbon (SOC) content (0.7%) and a slope of about 10%.

The climate of the experimental site is Mediterranean (Fig. 1), with a mean annual rainfall of 820 mm, mostly distributed in the autumn and winter (54%) and in the spring (24%). The mean air