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Effect of preceding crop on the agronomic and economic performance of durum wheat in the transition from conventional to reduced tillage

Laura Ercoli[a,*], Alessandro Masoni[b], Marco Mariotti[c], Silvia Pampana[b], Elisa Pellegrino[a], Iduna Arduini[b]

[a] Institute of Life Sciences, Scuola Superiore Sant'Anna, Piazza Martiri della Libertà 33, 56127 Pisa, Italy
[b] Department of Agriculture, Food and Environment, University of Pisa, via del Borghetto 80, 56124 Pisa, Italy
[c] Department of Veterinary Science, University of Pisa, viale delle Piaggie 2, 56124 Pisa, Italy

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ABSTRACT

Preceding crop greatly affects the agronomic and economic performance of durum wheat, but its interaction with tillage intensity was scarcely investigated at the early transition from conventional to reduced tillage. This work was aimed at studying how preceding crop determines the performance of durum wheat during the early transition from conventional to reduced tillage. To this end, the effect of four preceding crops (sunflower, durum wheat, alfalfa and maize) in interaction with two tillage systems without inversion (RT1 – chisel ploughing, disking twice, and harrowing and RT2 – disking twice and harrowing) and a conventional tillage (CT – mouldboard ploughing, disking twice, and harrowing) was studied on durum wheat in two years of cultivation. The effect of preceding crop on grain yield and yield components of durum wheat was different depending on tillage intensity, and this effect varied depending on the year of cultivation. Grain yield increased by 1.1–4.2 t ha^{-1} with the increase of the intensity of tillage in both years and all preceding crops, with the only exception of wheat crop following sunflower in 2009–2010 and following maize in 2010–2011. RT2 decreased wheat grain yield when compared with RT1 only with alfalfa as preceding crop. Differences in grain yield among tillage systems and crops preceding wheat in both years were mainly due to variations of mean kernel weight and number of spikes per unit area. The profitability of durum wheat varied according to the year of cultivation, the preceding crop and the tillage system. Overall, in both years profitability was lowest and negative following wheat under reduced tillage system, while it was highest and positive following alfalfa under CT. Reduced growth of durum wheat with reduced tillage systems was mainly consequence of weeds and volunteers plants development and nitrogen availability in soil resulting from nutrient immobilization. It can be concluded that potential yield penalties in durum wheat in the transition from conventional to reduced tillage can be alleviated by an appropriate selection of preceding crops.

1. Introduction

Durum wheat is a major crop for agricultural production in Italy, with a total area of 1,287,565 ha in 2014 (ISTAT, 2015). Since from 2013 European Union subsidies to agriculture production have been removed, the only way for producers to remain financially viable is through efficient production. Higher efficiency represents the ability to produce more output with the lowest invest in inputs (Coelli et al., 2005). Thus, producers need to achieve the economic optimal level of production, which is when the maximum difference between revenue and costs is attained (Tozer, 2010).

Conservation tillage involves soil management practices that minimise the disruption of the soil's structure, composition and natural biodiversity, thereby minimising erosion and degradation as well as water contamination (Lal et al., 1998; Holland, 2004). Conservation tillage encompasses any non-inversion soil cultivation technique that leaves sufficient crop residues in place to cover at least 30% of the soil surface after sowing (Lal, 2003), and it is often adopted for cost saving, because it decreases manpower and energy required for crop cultivation, and for soil conservation and moisture retention (Kassam et al., 2009).

Tillage affects soil physical, chemical and biological properties, as well as plant growth, root distribution into soil, and ulti-

* Corresponding author.
E-mail address: ercoli@sssup.it (L. Ercoli).

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mately crop yield (Holland et al., 2004). Owing to the intrinsic variability in climatic conditions, soil characteristics and management practices, contradictory yield results have been reported in comparisons between conservation and conventional tillage systems (e.g., Mazzoncini et al., 2008; Giacomini et al., 2010). Yield increases under reduced tillage were recorded in sandy soils and dry conditions due to higher soil water availability, whereas yield disadvantages in clay and loam soils and humid conditions due to reduced plant establishment and increased development of pests and weeds (Ercoli et al., 2006; Van den Putte et al., 2010; Giller et al., 2015). It is often reported that the positive effects of reduced tillage or no tillage on grain yield and soil properties only become apparent after several years (e.g., Hao et al., 2002; Madejon et al., 2009). In the long-term soil fertility is improved, but changes in C stock in soil occur slowly, being relevant only in the long-term (Lal et al., 1998; González-Prieto et al., 2013). However, recent evidences question the potential for C-sequestration of reduced tillage systems, as differences were limited to the distribution of soil organic carbon (SOC), with higher concentrations near the surface under conservation tillage and in deeper layers under conventional tillage (Baker et al., 2007; Powlson et al., 2011). By contrast, in the early transition stage, from standard to reduced tillage systems, variations in SOC following the change of soil management are not expected, but yield reductions can occur following the short-term nitrogen (N) immobilization and the reduced weed control (Karlen et al., 1994; Kong et al., 2009).

A considerable volume of the literature has addressed the effects of preceding crop on wheat (e.g. Bennett et al., 2012; Mazzilli et al., 2016), but the effect of preceding crop in interaction with tillage intensity was scarcely investigated both at the early transition from conventional to reduced tillage and in the long term. In the long tem grain yield following legumes and fallow was similar under no-tillage and conventional tillage, whereas following wheat no-till wheat was more productive (López-Bellido et al., 2007, 2012). In addition, at planting, soil water storage and nitrate content in soil were lower under no tillage following sunflower compared to fallow, legumes and wheat (López-Bellido et al., 2007, 2013).

Therefore, our research was carried out to study, during the transition from conventional to reduced tillage, the effects of different preceding crops (i.e., sunflower, durum wheat, alfalfa and maize) and tillage intensities on the agronomic and economic performance of durum wheat.

2. Materials and methods

2.1. Site description and climatic data

A field experiment was carried out at the experimental station of the Department of Agriculture, Food and Environment of the University of Pisa, Italy, which is located at a distance of approximately 3 km from the sea (43°40′N, 10°19′E) and 1 m above sea level.

Main soil physical and chemical properties were: 403 g kg^{-1} sand; 358 g kg^{-1} silt; 239 g kg^{-1} clay; 7.2 pH; 18.3 g kg^{-1} organic matter; 0.9 g kg^{-1} total N; 10.0 mg kg^{-1} available P (Olsen method); 166 mg kg^{-1} available K (Dirks-Sheffer method). Soil texture was loam and soil type Typic Xerofluvents, according to the USDA soil taxonomy (Soil Survey Staff, 2010).

At the experimental site, the climate was characterised as cold humid Mediterranean with 120-year average of mean annual maximum and minimum daily air temperatures of 20.2 °C and 9.5 °C, respectively, and annual precipitation of 971 mm, with 663 mm received during the period of durum wheat cultivation (from November to June). The weather data were collected from a weather station located within 500 m of the experimental site. Rainfall varied yearly over the two wheat-cropping seasons: in 2009–2010 it was similar to the 120-year average in the area (Moonen et al., 2002; Vallebona et al., 2014), whereas in 2010–2011 it was 45% lower than the 120-year average (Fig. 1). In 2009–2010, rainfall was well distributed through the wheat cycle and thus was more favourable for wheat growth and development. By contrast, the cropping season 2010–2011 was particularly dry, especially in the period following heading. Temperature was generally higher in 2009–2010. During the 10-days prior to anthesis, when active cell division in the ovary occurs, the mean maximum temperature was 24.2 °C in 2010 and 19.2 °C in 2011.

2.2. Experimental design

The experiment was established to evaluate the impact of preceding crop and tillage intensity on the production and profitability of durum wheat. In order to test the impact of the preceding crop, such as maize, sunflower, alfalfa and durum wheat, we utilised a long-term field study established in spring 2005 that compares in time and space at field level (ca. 2500 m^2 ha per field replicate, n = 3) two arable crop rotations (maize-durum wheat and sunflower-durum wheat), a fodder crop rotation (maize-durum wheat-alfalfa-alfalfa-alfalfa-durum wheat), and a continuous durum wheat. Sunflower, maize and durum wheat were grown for grain, whereas alfalfa was grown for hay with four cuts per year. The biomass left in the field was approximately 600, 500, 700 and 400 g m^{-2} of dry weight for sunflower, alfalfa, maize and durum wheat, respectively. Crops were managed following the common agronomical technique applied in the area, comprising conventional tillage (mouldboard ploughing, disking twice, and harrowing). Wheat was harvested in early July, maize in mid-September, sunflower in early August, and alfalfa was terminated in early October.

In the autumn before durum wheat sowing (2009-11-24 and 2010-12-16) two reduced tillage systems without inversion (RT1 – chisel ploughing, disking twice, and harrowing and RT2 – disking twice and harrowing) and a conventional tillage system (CT – mouldboard ploughing, disking twice, and harrowing) were set up in each field replicate previously cultivated with sunflower, durum wheat, alfalfa and maize. CT represents the control, where there was no transition from conventional to reduced tillage. The conventional tillage system was performed with a 3-bottom general purposed mouldboard plough equipped with share points ploughing to a nominal depth of 40 cm, followed by disking twice with a tandem disc to a nominal depth of 15 cm and surface rotary harrowing to a nominal depth of 20 cm for seedbed preparation. RT1 was performed with a chisel plough equipped with 40 cm sweeps followed by disking twice with a tandem disc to a nominal depth of 15 cm and surface rotary harrowing to a depth of 20 cm before sowing. RT2 consisted of disking twice and harrowing as above. Crop residues were not removed and were incorporated to a 40-cm depth under CT and RT1 and at 20-cm depth under RT2. The durum wheat variety Levante (Breeder: Produttori Sementi Spa, Bologna, Italy) was grown for the two years of cultivation (2009–2010 and 2010–2011) on all the combinations of preceding crop and tillage system. Levante is one of the most widely grown varieties in Central Italy, was released in 2002 and is medium maturing and is characterised by high yellow index, very high protein concentration and medium gluten quality.

In each year of cultivation, the experimental design was a two-factorial split-plot with three replications. The main plot factor was the preceding crop (sunflower, durum wheat, alfalfa and maize) and the subplot factor was the tillage system (CT, RT1, RT2). The area of each replicated subplot was 150 m^2.

Apart from tillage, management was the same in all the treatments. Phosphorus and K were applied immediately before soil tillage as triple mineral phosphate ($Ca(H_2PO_4)_2{\cdot}H_2O$) and potas-