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Soil tillage and residues management in wheat continuous cropping in Southern Italy: A model application for agronomic and soil fertility assessment

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ABSTRACT

The intensive agricultural practices are the main causes of soil organic matter decline that generates the desertification process, mainly in Mediterranean areas, characterized by a semi-desertic climate.

The central aim of this work was to simulate and assess the consequences of different crop residue management in durum wheat cultivation in Basilicata region (Southern Italy).

CropSyst model was applied in the 6 main traditional production areas of Basilicata of durum wheat for a total of 15 soil profiles. For this simulation study, 13 years of continuous wheat in 6 different management scenarios were simulated. The compared treatments were: Conventional, Conventional plus residues, Minimum Tillage, No-Tillage, Conservative and Conservative with rotation. The evaluated output variables were biomass and grain yield, water used and percolated, soil organic carbon content. Simulations covered a period over 13 years (from 2001 to 2013) using daily climatic data recorded by 6 weather stations located less than 30 km far from the soils used in the simulation.

The highest yield production resulted in Lavello site, the lowest in Potenza one. Conventional management (residues burning, ploughing and supplemental soil tillage) ensured the best crop performance (3430 kg ha^{-1}), comparable to the other treatments where the straw was left on the soil and highest if compared to the reduced input tillage and straw removal. Burning of straw caused a reduction of the soil organic carbon content (−137 kg ha^{-1} y^{-1}), whereas the other practices allowed an increase in the soil carbon stock, especially when straw was left on the soil and ranging from 1756 kg ha^{-1} y^{-1} in conservative management to 86 kg ha^{-1} y^{-1} in minimum tillage.

CropSyst model indicated an improvement in *SOC* under reduced and no tillage treatments, but the highest soil carbon stock enrichment was achieved when the straw was left on the soil. Anyway, the increment in *SOC* did not lead to an improvement in grain yield, and for this a financial support to the farmers is still necessary.

1. Introduction

Crop management can be adopted as mitigation strategy to take away CO_2 from the atmosphere and incorporate it in agricultural soils (Smith and Olesen, 2010). Indeed conventional soil management characterized by high energetic input on soils, release large amount of CO_2 as a consequence of soil carbon degradation. Increase in greenhouse gas emissions, impoverishment of soil fertility and desertification processes are the main consequences of the conventional soil practices (Reicosky, 2001; Six et al., 2000).

There are several ways to reverse this trend throughout alternative crop management such as: reduced or no-tillage soil management, organic instead of mineral fertilization, deep-rooting crops, adoption of crop rotation instead of intensive farming, residue left or incorporated into soil.

The latter is a simple way to increase soil organic carbon as underlined by Freibauer et al. (2004) who reported as the increment in the soil carbon stock could range from 0.21 to 0.69 t ha^{-1} y^{-1} depending on experimental conditions.

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Residue burning is the most common practice adopted by farmers in Southern Italy, including durum wheat cropping system, with the aforementioned environmental impact other than fire risk. The current environmental protection measures provided by New Common Agricultural Policy (CAP 2014–2020), states that the farmers have to align to Standards of Good Agricultural and Environmental Condition (GAEC) for claiming the founding. In GAEC guidelines, burning of wheat residues is prohibited to avoid the risk of fires and air pollution, keeping good soil organic carbon content to preserve soil fertility. GAEC were implemented via Regional Rural Development Plans (PSR) (EC Regulation No. 1782/03).

In Mediterranean area durum wheat (*Triticum durum* Desf.) cultivation is one of the main income source for farmers and Italy is one of the leader in the world with 1.2 million ha of cultivated surface and 4.2 million tons of grain production (ISTAT, 2013): Basilicata is the third region in Italy for durum wheat production. The growing season of this crop in this environment takes place during the autumn-winter period, for exploiting the rainfall of this period; no irrigation is scheduled, so moderate water stress, which is becoming more frequent because of global warming, can compromise the grain yield.

In Basilicata (Southern Italy), agricultural soils underwent continuous degradation during the last century due to the highly erodible nature of outcropping terrains and to the anthropic pressure favored by the introduction of Common Agricultural Policy (CAP) measures, which, especially in the last 30 years, has led to the reclamation of scrub lands and badlands for durum wheat cultivation (Capolongo et al., 2008). This practice of reclamation, known as 'remodelling', increases soil erosion, implying an enlargement of the surface area exposed to physical phenomena of erosion. An appropriate soil tillage and residues management could help to significantly reduce soil erosion.

With rising awareness of problems related to degradation of land and decreased production, efforts have been undertaken recently in Southern Italy to experience alternative crop management in order to replace the resource-depleting tillage and preserve the soil fertility. Conservation agriculture (*CA*), is seen as a promising way to address the issue facing three main issues: no tillage or zero tillage, crop residue management to preserve the soil organic matter as long as possible in the field, and crop diversification/rotation (Hobbs et al., 2008).

One key point of *CA* is the increment in plant available water of soil by increasing soil water infiltration, reduce runoff (Scopel et al., 2005; Thierfelder et al., 2005) and soil evaporation (Bescansa et al., 2006). Water scarcity, land degradation and soil erosion are issues that occur frequently in the semi-arid areas of Mediterranean countries; investigations are needed to assess the mitigation effects of *CA* in these areas.

The boosting on yield and soil fertility of *CA* is a "long-term" property and, therefore, studies that require long time must take in place for highlighting these effects. In addition, results obtained in a site could not be confirmed under different pedo-climatic conditions that can be encountered in other cultivation areas.

To overcome these issues the crop simulation models are tools that after the proper calibration and validation process can provide quick and reliable answers with low cost, even if with an approximation which must be previously put into account.

Crop growth simulation models have been widely used to simulate long-term responses of crops to different pedo-climatic conditions and crop management. A multitude of crop software models have been developed for wheat, as reported in the study of Asseng et al. (2013) for which were experienced 27 wheat crop growth models, with the most widely used DSSAT (Decision Support System for Agrotechnology Transfer), APSIM (Agricultural Production Systems Simulator), EPIC (Environmental Policy Integrated Climate model), STICS (Simulateur Multidisciplinaire pour les Cultures Standard) and CropSyst (Cropping Systems Simulation Model) to simulate the wheat response under different management and locations.

Simulation studies were performed also to investigate long-term dynamic of soil organic carbon in Mediterranean areas: Gabrielle et al. (2002) compared the response of four crop models on soil carbon dynamics, other studies were carried out to compare conventional and conservative soil management for several crop rotations (Lugato et al., 2006); other investigations were finalized to assess the consequences of residue removal on soil organic carbon content (Saffih-Hdadia and Mary, 2008; Alvaro-Fuentes et al., 2009).

CropSyst model (Stöckle et al., 2003) has been applied on wheat in several environments, as Washington (USA) in response to different fallow and tillage management practices (including no-till; Pannkuk et al., 1998), Central Anatolia Plateau Turkey, (Benli et al., 2007), northwest Uzbekistan (Djumaniyazova et al., 2010) and northern Syria (Pala et al., 1996). Simulations with CropSyst took place for a wide range of purposes, such as: to estimate drainage and nitrogen leaching resulting from different soil-weather-management scenarios in Po Valley, Italy (Donatelli et al., 1999; Meinke et al., 2001); to develop a decision support system for nitrogen fertilization strategies (Ferrer-Alegre and Stockle, 1999); to evaluate the amount and dynamics of nitrate leaching from a typical irrigated potato-/winter wheat-/maize rotation in this area (Peralta and Stockle, 2001). Long-term simulations with CropSyst were carried out to explore the performance of several cropping systems with different input levels (Donatelli et al., 1997; Morari et al., 2000; Garofalo et al., 2009).

The most part of the simulation studies on long term simulation of soil organic carbon (*SOC*) have been focused in UK (Falloon et al., 2006), China (Guo et al., 2007) Australian (Skjemstad et al., 2004), France (Gabrielle et al., 2002) and African (Badini et al., 2007) pedo-climatic conditions, but scarce works are reported in Mediterranean environment as Southern Italy. In this area of Italy, CropSyst was previously calibrated and validated to simulate a wheat-faba bean rotation (Garofalo et al., 2009) and in view of this, this software was chosen as reference crop model in our study.

In this study, CropSyst was used with the aim of simulating durum wheat response to different straw and soil management, under the pedo-climatic conditions of Basilicata, in order to analyze the long-term effects on crop productivity and soil carbon stock dynamics.

2. Materials and methods

2.1. Locations

The study area is located in two provinces of "Basilicata" region (Southern Italy; 9992 km^2), Potenza and Matera (Fig. 1) in a predominantly mountainous area. The area consists of mountains (areas above 700 m a.s.l.) and hills (areas between 201 and 700 m a.s.l.) by 47% and 45% respectively, whereas the remaining area is flat surface.

Vegetation is strongly influenced by climatic conditions of the zone which can be divided in two parts. The Western part, along the strip of the Apennines, is characterized by soils plenty covered with vegetation, with many woods and fields cultivated with vineyards and olive groves. The Eastern part of the region, instead, is characterized by bare and arid soils where durum wheat is the predominant cultivated crop in the flat and hilly areas (Fig. 1). Lavello, Matera, Potenza, Val d'Agri, Vulture and medium basin of Agri-Sauro rivers were the inspected areas for this study.