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Best management practices of tillage and nitrogen fertilization in Mediterranean rainfed conditions: Combining field and modelling approaches

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ABSTRACT

In this work, appropriate management practices for crop production under the variable climate conditions of the Mediterranean region, in particular rainfall, were tested with the use of a modelling system applied to long-term (i.e. 18 years) field data. The calibration of the CropSyst model was performed using data collected from 1996 to 1999 at three different Mediterranean locations (i.e., HYP-Guissona, MYP-Agramunt and LYP-Candasnos, i.e. high, medium and low yield potential, respectively) within a degree of yield potential. The model simulated reasonably well barley growth and yield to different tillage and N fertilization strategies.

Simulations of barley performance over 50 years with generated weather data showed that yields were often greater and never smaller under no-tillage compared to conventional tillage with a mean increase of 36%, 63% and 18% for HYP-Guissona, MYP-Agramunt and LYP-Candasnos. In MYP-Agramunt, the long-term data showed a 40% increase in grain yields when using no-tillage compared to conventional tillage, as an average of 18 years.

The model also predicted that greater N applications in no-tillage were appropriate to take advantage of additional water supply. Taking into account the limited amount of soil water available, overall N fertilizer applications could be reduced to about half of the traditional rate applied by the farmers without yield loss. The 50-yr simulation, confirmed by the long-term experimental data, identified no-tillage as the most appropriate tillage practice for the rainfed Mediterranean areas. Also, N fertilization must be reduced significantly when tillage is used or when increasing aridity. Our work demonstrates the usefulness of the combination of long-term field experimentation and modelling as a tool to identify the best agricultural management practices. It also highlights the importance of posterior analysis with long-term observed field data to determine the performance of simulation results.

1. Introduction

In the semiarid Mediterranean region of the Ebro river valley (northeast Spain), dryland agriculture is based on continuous cropping of winter cereals (mainly barley and wheat). In these areas, rainfall is usually low and erratic with significant high evapotranspiration rates. These typical climate characteristics constrain crop productivity due to the shortage of available water during prolonged periods (Austin et al., 1998; Ryan et al., 2006). Consequently, attending to these highly variable climatic conditions, it is difficult to recommend suitable agronomic strategies (Stewart and Robinson 1997; Giambalvo et al., 2012) and specially based on short-term experimentation (Peterson et al., 2011).

Two management practices, tillage and nitrogen (N) fertilization are, however, appropriate targets to improve profitability and reduce environmental impacts of cropping practices. First, they are important determinants of crop yield and are suitable technologies to be developed in Mediterranean areas (Cantero-Martínez and Gabiña, 2004; Ryan et al., 2009). As inputs, they account for more than 40–50% of the cost of crop production (Cantero-Martínez et al., 1995a). Second, the major environmental challenges in the region are to reduce soil erosion (Grove 1996) and N losses (Ryan et al.,

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2009). Reduced and no-tillage were introduced in the area 35 years ago, with evident success in controlling erosion but with limited acceptance by farmers since its adoption requires confidence in the long-term performance of the system, including adjustment of N fertilization due to modifications in the water and nitrogen balances (Moreno et al., 2010). According to this last, Pittelkow et al. (2014) stated in a meta-analysis the importance and interest of those soil management systems and the need to determine locally their suitability.

Few years ago, the impact of tillage and N fertilization management on crop performance was analysed in Mediterranean dryland conditions (Cantero-Martínez et al., 2003; Angás et al., 2006; Morell et al., 2011). Though these studies provided valuable observed data during three growing seasons, the conclusions and recommendations obtained were taken with caution. The short length of the experimental period (only three growing seasons) limited the possibility of obtaining robust conclusions in these areas with highly-variable climate conditions, making difficult the establishment of appropriate cropping strategies with only few years of experimental data. According to this, in dryland Mediterranean conditions, strong recommendations for crop management would require a large number of experimental years with time and cost associated. The combination of experimental work with the use of crop simulation models may help to overtake this limitation. Crop simulation models that integrate the effects of crop, environment and management to predict crop yield can be used to evaluate different management options over long periods using historical or generated weather data. When evaluated over the long term, crop models can be used to build probability graphs to assess technology options and to analyse their interactions regarding the productivity and sustainability of agricultural systems.

CropSyst (Stöckle and Nelson, 1998) is a crop model suitable for simulating yield, taking into account crop characteristics and the relevant crop and soil processes. CropSyst includes ClimGen that is a complement which is able to generate long-term daily weather data by reproducing the observed variability in short-term climate data (Acutis et al., 1999). CropSyst and Climgen have been successfully used for various crop-environment combinations in semiarid conditions, e.g. Pala et al. (1996) for durum wheat in northern Syria (3 years simulation), Donatelli et al. (1997) for crop rotations at two locations in Italy (6 years simulation), Ferrer-Alegre et al. (1999) for irrigated corn in the Ebro river valley in Spain (30 years simulation), Marcos et al. (1999) for a number of crops in dryland conditions in the western United States (2 years simulation), Díaz-Ambrona et al. (1999) for a winter cereal-legumes rotation in the central dryland area of Spain (15 years simulation), and Sadras (2002) in southern Australia to evaluate the problem of terminal drought during grain filling (40 years simulation). All of them with moderate success in the performance of the CropSyst model, but no previous attempt has been made to use CropSyst to predict crop yield under different tillage and N fertilization strategies in this Mediterranean conditions.

The objectives of this work were: (i) to evaluate the ability of the CropSyst model to simulate growth, yield and water use in a barley monocropping dryland system under various tillage and N fertilization regimes; and (ii) to analyse the best tillage and N fertilization combinations that might form the basis of recommended long-term cropping strategies in Mediterranean dryland areas.

2. Materials and methods

2.1. Location and selected sites

The Ebro river valley (about 40,000 km^2) is a wide region in northeast Spain, highly representative of the arid and semiarid Mediterranean area. Mean annual rainfall ranges from 250 to 500 mm, 60% of which occurs between September and January. Generally, soils are loamy and clay loamy with available soil water capacity ranging between 80 and 250 mm depending on site and soil depth. Mean annual air temperature ranges between 13.0 and 14.5 °C.

In this study, three sites located within the Ebro river valley were selected. These three sites covered the main climate and soil conditions of the area. They represented the major cropping systems in the region covering the gradient of yield potential of the area.

2.2. Field experiments

Experimental data from three field experiments and three growing seasons (i.e., 1996–1999) were used to evaluate the performance of the model. A detailed description of the field experiments, their agronomic evaluation and the physical and chemical characteristics of the soils were provided in Cantero-Martínez et al. (2003). The three experimental fields were established in 1996. Briefly, field experiments were located at Guissona (41°46′N, 1°16′E, 490 m.a.s.l), Agramunt (41°48′N, 1°07′E, 330 m.a.s.l) and Candasnos (41°30′N, 0°08′E, 280 m.a.s.l), which vary in the amount of rainfall and water holding capacity of their soils, representing a decreasing gradient of yield potential (Table 1). According to this gradient, Guissona, Agramunt and Candasnos were considered as representative sites of high (HYP), medium (MYP) and low (LYP) yield potential, respectively. The experimental field located in Agramunt was maintained under the same conditions and with the same treatments until the 2013–2014 growing season. The 18-year dataset of the Agramunt experiment was used to evaluate the ability of the model as a decision tool for management practices over the long-term.

In all three experimental fields, three tillage systems (i.e., conventional tillage, CT; minimum tillage, MT, and no-tillage, NT) and three mineral N fertilization rates were tested. The three N fertilization rates consisted in high (150, 120 and 100 kg N ha^{-1}), medium (75, 60 and 50 kg N ha^{-1}), and control (no N applied) rates at HYP, MYP and LYP locations, respectively. On each area, the traditional N fertilizer rates applied by farmers correspond to the high rates tested in the corresponding field experiment. Presowing applications were carried out with ammonium sulphate while ammonium nitrate was used at tillering. For this study, only CT and NT treatments were considered. The CT treatment consisted of one mouldboard plow pass (25–30 cm depth) plus one or two cultivator passes (15 cm depth) before sowing, during August and September depending on soil moisture. In the NT treatment, sowing was performed by direct drilling after spraying with herbicide (1.5 L 36% glyphosate [*N*-(phosphonomethyl)-glycine] plus 1 L of 40% MCPA (2-(4-chloro 2-metilfenoxi) acetic acid) per ha). In the CT treatment and at all three sites, crop residues were incorporated into the soil with tillage operations and the soil remained bare after tillage. Under NT, crop residues were maintained throughout the study period, and at MYP and LYP locations stubble was left and straw was chopped and spread on the soil. At HYP, however, due to the high amount of crop residues, the stubble was left but the straw was removed after harvest in order to facilitate the establishment of the next crop. Daily maximum and minimum temperatures and rainfall were collected from the nearest weather stations (1–6 km far) of the National Weather Institute of Spain (INM). Representative soil data from the upper 25 cm layer used for the simulations are shown in Table 1. Stoniness (30%) was taken into account at LYP location to calculate the actual soil water content.