ARTICLE IN PRESS
STOTEN-24319; No of Pages 12
Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect
Science of the Total Environment
journal homepage: www.elsevier.com/locate/scitotenv

Assessing cover crop management under actual and climate change conditions

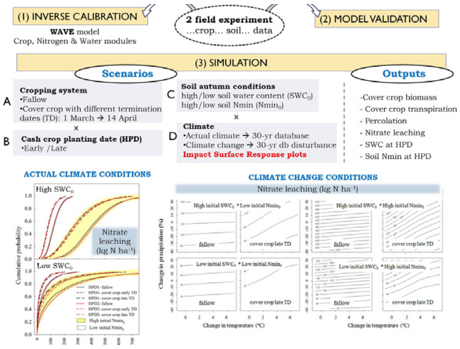
María Alonso-Ayuso [a], Miguel Quemada [a], Marnik Vanclooster [b], Margarita Ruiz-Ramos [a], Alfredo Rodriguez [a,c], José Luis Gabriel [d,*]

[a] *Dpto. Producción Agraria, Universidad Politécnica de Madrid, 28040 Madrid, Spain*
[b] *Earth and Life Institute, Université Catholique de Louvain, Croix du Sud 2, B-1348 Louvain-la-Neuve, Belgium*
[c] *Dpto. Análisis Económico y Finanzas, Universidad de Castilla-La Mancha, 45071 Toledo, Spain*
[d] *Dpto. Medio Ambiente, Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, Ctra. de la Coruña km 7.5, 28040 Madrid*

HIGHLIGHTS

- WAVE model was inverse calibrated and validated with field measurements.
- Impact response surface approach was used to assess future climate scenarios.
- Late cover crop termination reduced leaching but increased competition risk.
- The cash crop planting date was a tool to control preemptive competition.
- Under climate change conditions, cover crop management becomes crucial.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 4 August 2017
Received in revised form 9 October 2017
Accepted 10 October 2017
Available online xxxx

Editor: D. Barcelo

Keywords:
Inverse model calibration
Killing date
Nitrogen
Preemptive competition
Termination date
Water

ABSTRACT

The termination date is recognized as a key management factor to enhance cover crops for multiple benefits and to avoid competition with the following cash crop. However, the optimum date depends on annual meteorological conditions, and climate variability induces uncertainty in a decision that needs to be taken every year. One of the most important cover crop benefits is reducing nitrate leaching, a major concern for irrigated agricultural systems and highly affected by the termination date. This study aimed to determine the effects of cover crops and their termination date on the water and N balances of an irrigated Mediterranean agroecosystem under present and future climate conditions. For that purpose, two field experiments were used for inverse calibration and validation of the WAVE model (Water and Agrochemicals in the soil and Vadose Environment), based on continuous soil water content data, soil nitrogen content and crop measurements. The calibrated and validated model was subsequently used in advanced scenario analysis under present and climate change conditions. Under present conditions, a late termination date increased cover crop biomass and subsequently soil water and N depletion. Hence, preemptive competition risk with the main crop was enhanced, but a reduction of nitrate leaching also occurred. The hypothetical planting date of the following cash crop was also an important tool to reduce preemptive competition. Under climate change conditions, the simulations showed that the termination date will be even more important to reduce preemptive competition and nitrate leaching.

---

[*] Corresponding author.
E-mail address: gabriel.jose@inia.es (J.L. Gabriel).

https://doi.org/10.1016/j.scitotenv.2017.10.095

Please cite this article as: Alonso-Ayuso, M., et al., Assessing cover crop management under actual and climate change conditions, Sci Total Environ (2017), https://doi.org/10.1016/j.scitotenv.2017.10.095

1. Introduction

Nitrate leaching from the root zone of agricultural crops puts a major constraint on modern agriculture. Nitrate leaching induces pressure on groundwater systems in agricultural basins and reduces nutrient use efficiency of the agricultural crops. Nitrate leaching is also a specific concern for irrigated agriculture (Causapé et al., 2004; Díez et al., 1997). Even when the fertilization and the irrigation are adjusted to crop demand, it is difficult to obtain N use efficiencies higher than 60% (Dinnes et al., 2002). A great amount of residual nitrate may remain in the soil after harvest (Bundy and Andraski, 2005; Gabriel and Quemada, 2011). This nitrate will then be prone to leaching during the subsequent fallow period. The environmental performance of an irrigated agroecosystem would therefore be considerably improved if nitrate leaching between two cash crops could be reduced.

Replacing the fallow period between two cash crops with cover crops is one of the techniques that is advocated to reduce nitrate leaching in both dry and humid regions (Gabriel et al., 2012b; Hargrove, 1991; McCracken et al., 1994; Thorup-Kristensen et al., 2003). The reduction of nitrate leaching with cover cropping is due mainly to an increased retention of N in the cover crop biomass, the reduction of the nitrate concentration in the percolating water, and/or the reduction of the percolating water flux (Kramberger et al., 2014; Thorup-Kristensen et al., 2003). However, the use of cover crops is still not very popular in arid and semiarid regions because a cover crop is suspected of competing for water and nutrients with the cash crop (Unger and Vigil, 1998). Cover crop management is crucial to avoid such competition, particularly deciding the appropriate termination date (Alonso-Ayuso et al., 2014).

Guidelines for cover crop management are not yet well elaborated (Clark et al., 2007; Krueger et al., 2011). Choosing a termination date, for instance, should consider the balance between often conflicting objectives. On the one hand, a reasonable water and nutrient extraction should be achieved by delaying the termination date, which would reduce nitrate leaching, provide nutrient recycling after residue mineralization, and cover the soil, hence avoiding direct evaporation of the topsoil (Clark et al., 2007). However, as this is a complex system, there is not a universal recommendation for cover crop management (Clark et al., 2007; Krueger et al., 2011). On the other hand, the water and nutrient extraction by the cover crop should be limited by advancing the termination date to avoid competition with the subsequent cash crop. Under various climate scenarios, the uncertainty of the decision taken is expected to increase. Because of that indecision, quantification of potential advantages and disadvantages of various termination dates may contribute to the best practice for cover cropping.

The in situ experimental assessment of the role of cover crops on water and nutrient balances is complicated. This assessment is particularly linked to the difficulty of measuring water and nutrient fluxes in the soil crop continuum (Gehl et al., 2005; Webster et al., 1993). In addition, the experimental approach does not allow evaluation of the possible impacts of cover crops in future changing environments. Hence, as an alternative, water and nutrient balance modeling is often presented to evaluate the effect of different crop management techniques on the functioning of the agroecosystem (Muñoz-Carpena et al., 2008; Tribouillois et al., 2016). The calibration of all the parameters involved in the water and nutrient fate models remains, however, a challenge (Simunek et al., 1999). However, this challenge can be partially addressed by inverse modeling techniques, as well as the combination of field data with modeling techniques (Paramasivam et al., 2001, Ritter et al., 2003).

When appropriately calibrated, field scale water nutrient balance models can be used to evaluate the impact of different cover crop strategies on agroecosystem functioning in an environment where the climate is changing. The evaluation of the impact of climate change on agroecosystem functioning is particularly important for Mediterranean agriculture as the Mediterranean region is considered a hotspot for climate change. Moreover, an accurate simulation of water and N balances relies on accurate precipitation data. The uncertainty of precipitation projections currently associated with climate model outputs makes exploiting these precipitation projections difficult for many impact studies (Ruiz-Ramos et al., 2016). Other approaches are needed for dealing with this uncertainty, as, for instance, the impact and adaptation response surfaces that provide a wide range of impact responses for a plausible range of futures (Pirttioja et al., 2015; Ruiz-Ramos et al., 2017).

The main goal of this paper is to study the effects of cover crops on the water and N balances of an irrigated Mediterranean agroecosystem under present and future climate conditions. The specific sub-objectives are: i) to calibrate and validate the water and N balance model WAVE (Water and Agrochemicals in the soil and Vadose Environment; Gabriel et al., 2012b; Vanclooster et al., 1996), ii) to analyze the effect of the cover crop termination date and interannual climate variability on potential nitrate leaching and the following cash crop competition; and iii) to analyze the effect of different future climate scenarios on this cover crop effect.

2. Materials and methods

2.1. Field experimental setup

The model was calibrated and validated based on field data from two different experiments. Both experiments were conducted in an experimental field station located in Aranjuez (Madrid, Spain) in the Tajo River basin. The soil was analyzed at the beginning of the experiment (Gabriel et al., 2010) and classified as a *Typic Calcixerept* (silty clay loam) based on Soil Survey Staff (2014). The climate was characterized as a Mediterranean semi-arid climate based on Papadakis (1966). Annual weather information (temperature, humidity, wind speed, precipitation and solar radiation) were recorded hourly with a weather station (Campbell Scientific Inc., Logan, UT, USA) placed in the experimental field.

The first experiment consisted of a 4-year cover crop-maize rotation with three treatments and lasted from October 2006 to October 2010. The treatments considered barley (*Hordeum vulgare* L.), vetch (*Vicia villosa* L.) and fallow during the cover crop period, keeping the maize (*Zea mays* L.) as the main crop during the three summers included in the study. The treatments were randomly distributed in twelve 144 m^2 plots with four replications, keeping plots constant for the 4 years. The cover crops were sown around the first week of October and terminated with one application of glyphosate between the second and the third week of March. During their growth, cover crops did not receive fertilization or irrigation. A more detailed description of the experimental site and design can be found in Gabriel and Quemada (2011) and Gabriel et al. (2012b).

The second experiment consisted of a 2-year cover crop system (from October 2011 to October 2013) compared with fallow. In this case, the cover crop consisted of a barley-vetch mixture, and the treatments used two different cover crop termination dates: mid-March and mid-April. A cover crop mixture was also sown around the first week of October in twelve 180 m^2 plots (again randomly distributed with four replications). The termination was made by a glyphosate application, keeping residues over the soil surface. Similarly, cover crops were not fertilized or irrigated. A more detailed description of the experiment is available in Alonso-Ayuso et al. (2014).

2.2. Field measurements

Both plant and soil variables were measured. The cover crop plant measurements in both field experiments consisted of the crop soil coverage (measured every 15 days at five permanent points per plot by taking digital images from a nadir perspective at a 1.5 m height; Ramírez-García et al., 2012), crop phenology, final aerial biomass production and final N concentration in the aerial biomass, to obtain the total N

Please cite this article as: Alonso-Ayuso, M., et al., Assessing cover crop management under actual and climate change conditions, Sci Total Environ (2017), https://doi.org/10.1016/j.scitotenv.2017.10.095