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Cover crops effect on farm benefits and nitrate leaching: Linking economic and environmental analysis

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ABSTRACT

Introducing cover crops (CC) interspersed with intensively fertilized crops in rotation has the potential to reduce nitrate leaching. This paper evaluates various strategies involving CC between maize and compares the economic and environmental results with respect to a typical maize–fallow rotation. The comparison is performed through stochastic (Monte-Carlo) simulation models of farms' profits using probability distribution functions (pdfs) of yield and N fertilizer saving fitted with data collected from various field trials and pdfs of crop prices and the cost of fertilizer fitted from statistical sources. Stochastic dominance relationships are obtained to rank the most profitable strategies from a farm financial perspective. A two-criterion comparison scheme is proposed to rank alternative strategies based on farm profit and nitrate leaching levels, taking the baseline scenario as the maize–fallow rotation. The results show that when CC biomass is sold as forage instead of keeping it in the soil, greater profit and less leaching of nitrates are achieved than in the baseline scenario. While the fertilizer saving will be lower if CC is sold than if it is kept in the soil, the revenue obtained from the sale of the CC compensates for the reduced fertilizer savings. The results show that CC would perhaps provide a double dividend of greater profit and reduced nitrate leaching in intensive irrigated cropping systems in Mediterranean regions.

1. Introduction

There are very few studies that combine economic and environmental approaches to analyse the adoption of agricultural techniques using experimental data and actual economic evaluations at farm level. Nowak (1992) claims that farmers fail to adopt new technologies because they are either unwilling or unable, although adoption reluctance is frequently rooted in low economic profitability or poor knowledge. Economic analyses permit a comparison between the profit that farmers obtain from agricultural products and the cost of adopting specific agricultural techniques. Environmental studies are complex, and evaluating the indicators that are representative of the environmental impact of an agricultural system is a complex task that is conducted by specialized groups and methodologies. Multidisciplinary studies might help to develop reliable approaches that would contribute to choosing the best agricultural strategies based on linking economic and environmental benefits.

Cover cropping was chosen for this study because, despite the evident environmental services provided and the range of agronomic benefits documented in the literature, farmers' adoption of the technique is still limited (Thorup-Kristensen et al., 2003). Growing cover crops (CC) could lead to extra costs for the farm in three different forms: direct, indirect, and opportunity costs (Snapp et al., 2005). Direct CC costs include the cost of establishment, seed, killing, and harvesting, but in some cases they replace other costs such as costs of tillage or herbicide applied when fallow. This means that only incremental costs should be considered. The indirect component is associated with hindering the establishment of the succeeding cash crop by slow soil warming, water depletion, or delayed organic N release. Other indirect costs are associated with factors that reduce expected benefits such as weather conditions, over-vigorous CC, or hard-to-kill CC acting as weeds. Lastly, the forgone benefits of producing another cash crop, a clear opportunity cost, during CC time could perhaps be the greatest cost. However, in most regions, CC are usually grown, replacing fallow between two cash crops, when time or environmental limitations do not allow for planting another profitable cash crop, so the choice is between fallow and CC. Differences in climatic conditions generate a great variability in CC growth, which, combined with price volatility, increases the variability of

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farmers' incomes. Risk analyses of economic scenarios based on probability distributions might help to compare the different alternatives.

Excess nitrates in water bodies causing non-point pollution are one of the major environmental problems related to agricultural systems. Meeting the ambitious goal of reducing nitrate pollution in the entire EU would entail reducing the welfare of the farm sector by 25% (Oenema et al., 2009). However, at farm level some studies suggest that potential improvements could be made to recommendations regarding N fertilizer (Deen, 2007). In Spain, Kahil and Albiac (2011) identified strategies to reduce emissions in agriculture, estimating a cost of 2 € per kilogram of reduction in N leaching. Mikkelsen et al. (2009) obtained the same cost for Denmark, whereas Hoogeveen et al. (2008) obtained a range of 3–8 € per kg of reduced N leaching for The Netherlands, and in the evaluation of Oenema et al. (2009) the figure was 4 €. Particularly, irrigated agriculture contributes to crops' productivity and diversification but has a large potential for nitrate contamination of groundwater (Vázquez et al., 2006). Replacing intercrop fallow with CC has been reported to reduce NO_3^- leaching in irrigated agriculture by increasing the retention of post-harvest surplus inorganic N and improving the efficiency of N use (Salmerón et al., 2011; Gabriel et al., 2012). The challenge is to identify CC management strategies that could reduce nitrate leaching in irrigated systems and increase, or at least not impair, farm profits, without government aids.

The goal of this paper was to evaluate the economic impact of replacing the usual winter fallow with CC in irrigated systems using stochastic Monte-Carlo simulations of key farms' financial performance indicators. In an attempt to relate economic and environmental criteria, the nitrate leaching was plotted versus the economic benefit for the scenarios where data were available. Strategies are thus judged on their joint effects on the farm economy and the nitrate leaching reduction.

2. Materials and methods

2.1. Soil and site characteristics

The field studies were conducted from October 2006 to April 2011 at La Chimenea Field Station (40°03′N, 03°31′W, 550 m a.s.l.) in Aranjuez (Madrid, Spain). Located in the central Tagus river basin, this site has a Mediterranean semiarid climate (Papadakis, 1966). Rainfall is 347 mm per year, with a dry period including June to September, and it is therefore classified as *Thermomediterranean* (UNESCO, 1979). The soil at the field site is a silty clay loam *Typic Calcixerept* (Soil Survey Staff, 2003), which is alkaline and rich in organic matter and carbonates and contains a low stone content throughout the soil profile.

Observed data employed for the analysis were obtained from various experiments conducted in the same field station. The first experiment lasted from October 2006 to April 2011, and it will be referred to in the article as the 'midterm experiment'. In this trial a CC–maize rotation was repeated in the same plot during five CC periods and four maize crops to study the cumulative effect. The other three 'annual experiments', where maize was grown after fallow or various CC, were carried out in different fields separated by ~100 m each year (from October 2006 to October 2009). All experiments follow the same factorial design, with CC as the main factor. At the beginning of a trial, each field (3000 m^2) was split at random into sixteen plots (144 m^2), leaving borders to prevent side effects, and distributed in four replications for each of four treatments: barley (*Hordeum vulgare* L., cv. Vanessa), vetch (*Vicia villosa* L., cv. Vereda), rapeseed (*Brassica napus* L., cv. Licapo), and fallow. CC were sown in early October and killed in late winter (March), allowing maize seeding of the entire trial area three weeks later (early April) and harvesting in early October. The fields were left fallow for a minimum of 2 years, and had not received organic amendments or N fertilizer during four years prior to the beginning of the trial.

2.2. Cover crop biomass production and N uptake

Biomass production was measured in each plot and year of midterm and annual experiments ($n = 128$; Fig. 1). Four 0.5 m × 0.5 m squares were randomly harvested from each plot before killing the CC by applying glyphosate. Aerial biomass was cut by hand at soil level, dried, weighed, and ground. Subsamples of the dry material were analysed for N concentration by Dumas combustion method with a LECO FP-428 analyser (Leco, St. Joseph, MO, US), and N content in each plot was calculated as the product of biomass and N concentration.

The software @RISK (PALISADE, 2007) was used for constructing the histogram and fitting the best probability distribution function (pdf) for each CC biomass data set (Fig. 1). This software allowed a value sequence to be fitted to a pdf, giving its moments and characterization. Fifteen different models were fitted and the best was selected based on the χ^2 criterion. A truncation at 0 kg ha^{-1}, as the absolute minimum biomass, was imposed in the fitting of the pdf. The function was truncated too, as the maximum for these crops and conditions, at the maximum biomass observed in a simple square during the different years for each CC. The same procedure was used for constructing the histogram and fitting the best pdf to the set of CC N uptake data (Fig. 1). The functions were truncated again at 0 kg N ha^{-1}, as the absolute minimum N uptake, and at the maximum N uptake observed in a simple square during the different years for each CC for the fitting of the pdf.

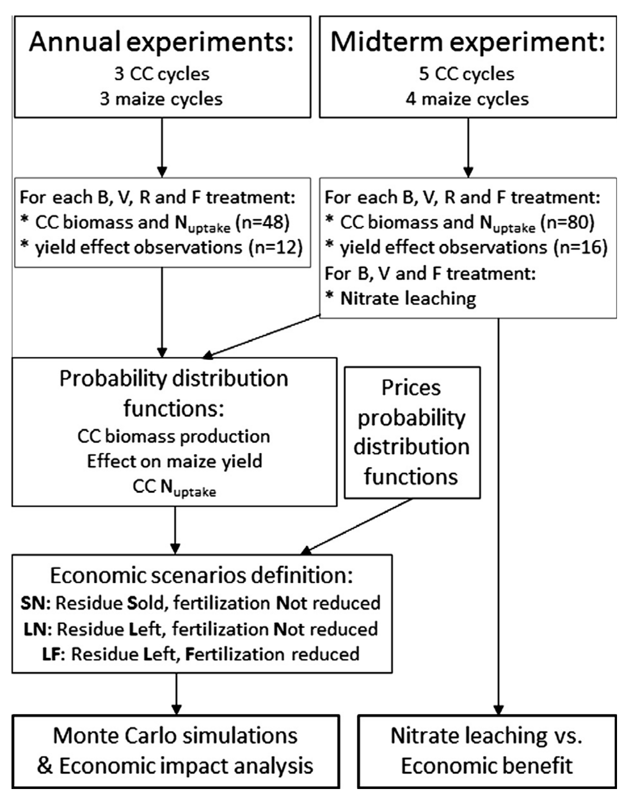

Fig. 1. Diagram of field data processing for both economic impact and economic-environmental analysis. Treatment considered were three cover crops (CC; barley (B), vetch (V) and rapeseed (R)) and fallow (F) as different land use between two following maize crops.