How to combine crop production and environmental quality? A decision support system to quantify best agri-environmental measures in the Veneto Region, Italy

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Summary

Efforts have been made in Europe to support the adoption of agri-environmental measures (AEMs), with the ambition to combine both high standards of crop productivity and environmental quality. However, benefits from AEMs have been poorly quantified at the spatial scale, despite the increasing demand for a spatial-targeting approach that link site-specific payments with AEMs performance. The aim of this work was to develop an integrated model-GIS platform that was used as decision support system to evaluate best AEMs in terms of agronomic performance and agro-ecosystem quality. The study site was the Veneto Region, where the AEMs were applied from 2007 to 2013 according to the Rural Development Programme. Results showed that in general the continuous soil cover yielded both agronomic benefits and the improvement of environmental quality, while a change from mineral to organic fertilizations was effective in the long-term and in the loose soils of southern and western Veneto, improving the soil-water balance and the nutrients availability to the crops. These estimates provide a good starting point for decision-makers aiming to implement a spatial targeting approach that effectively evaluate the ecological effectiveness of agri-environmental policies.

Keywords: rural development programme; modelling; biogeochemical fluxes.

JEL Classification codes: Q15

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1. INTRODUCTION

The way to reach the goals of biomass production and simultaneously to minimize the environmental pollution is debated, highlighting the importance of the subtle balance between productive agriculture and environmental quality (Dillon et al., 2016) in a perspective of sustainable intensification (Garnett et al. 2013). The adoption of agri-environmental measures (AEMs) is sustained across Europe in an attempt to combine competitive agricultural productions with reduced environmental impacts. However, in spite of the success of this approach that led to about 20% of used agricultural areas (in the EU-27) being under some agri-environmental agreement, the cost-effectiveness of adopting AEMs is questioned because it is based on a "management-oriented" scheme, where farmers are paid just for the adoption of specific measures (Uthes and Matzdorf, 2013). Conversely the environmental benefits are poorly quantified. Recently, a "result-oriented" scheme has been proposed with the aim to quantify the outcomes of EU agri-environmental policies, supporting any specific measure with a scientifically-based and site-specific evaluation. Although the result-oriented scheme is still in its infancy, the spatial targeting methodology has already been identified as a key aspect for improving the cost-effectiveness of AEMs (Burton and Schwarz, 2013). With the aim of evaluating their effectiveness, an integrated model-GIS platform was developed. By including both agronomic and environmental factors, we evaluated the most effective agri-environmental measures to improve soil and water quality as well as reduce greenhouse gas emissions across the Veneto Region, Italy.

2. MATERIAL AND METHODS

The study site was the Veneto Region. Most of the area is occupied by the Venetian plain (55%), where highly intensive agriculture coexists with one of the most densely populated and industrialised area of the country.

DAYCENT model, after calibration with field data, was coupled with geographical and alphanumeric data to evaluate the impacts of the AEMs that have been adopted at local scale (organic farming, conservation agriculture, farmyard manure input, etc.). In particular the pedo-climatic database (meteorological conditions, soil properties, etc.) was combined with the spatial extension of cropping systems and land use management information (N and P fertilizations, farmyard manure and slurry inputs, cropping systems, etc.), providing 1343 polygonal units covering the regional territory. The impact of AEMs application on arable lands throughout the region was quantified by simulating two different scenarios as follows: 1) a Standard scenario, which simulated conventional farming systems without the adoption of any specific agri-environmental policy; 2) an AEM scenario, which was based on the spatial distribution data of AEMs for the period 2007-2013, according to the implementation of the Rural Development Programme (Table 1). A total of about 45,000 unique simulations, covering the Veneto territory, were performed. Modelled used agricultural areas that were subjected to some AEMs accounted for a total of 44,065.3 ha. In this study, only arable land areas were considered for analysis, thus excluding pastures and meadows.

Table 1. Agri-environment measures (AEMs) simulated using DAYCENT model (source: elaboration from Dal Ferro et al., 2018).

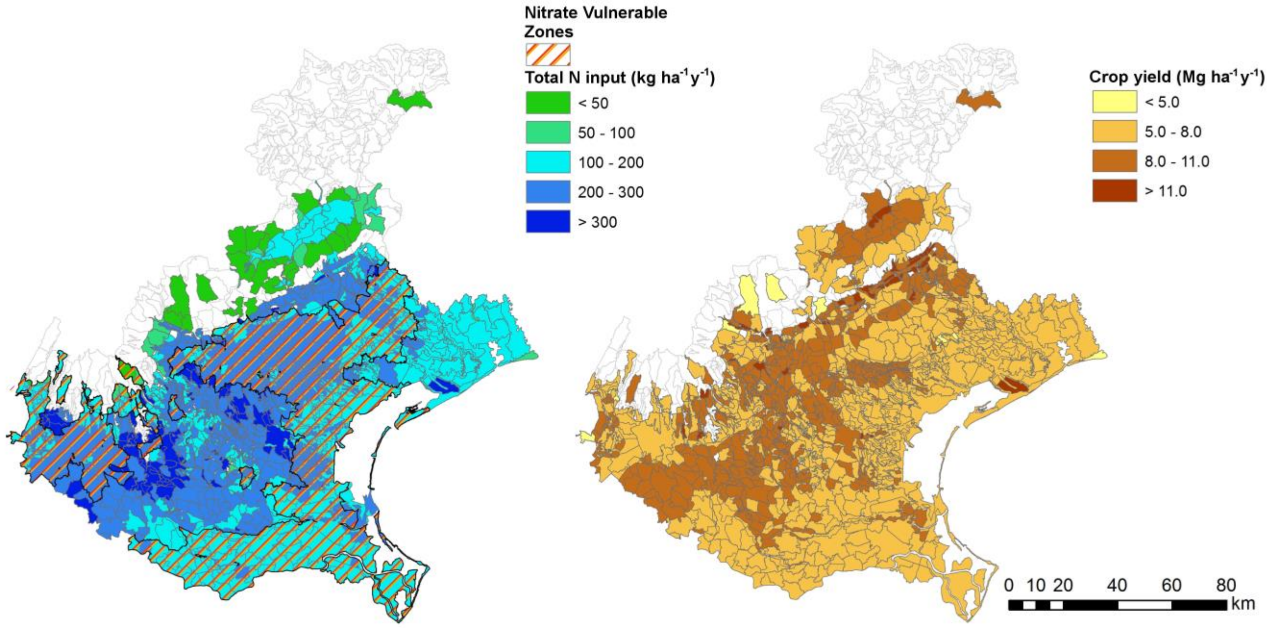
AEMs	Main management aspects	ID	Simulated hectares
Increase of SOM through farmyard manure input	Organic input = 130 kg N ha^{-1} y^{-1} + mineral	FMY	4760.7
Organic farming – new systems	Only organic instead of mineral input	OF_{New}	1373.9
Organic farming – maintenance of existing systems	Only organic instead of mineral input	OF_{Maint}	5151.1
Permanent meadows in arable lands – new systems	No fertilizers input allowed	MEAD	821.6
Conservation agriculture	No tillage, permanent soil cover, maintenance of residues on soil surface, crop rotations	CA	2300.1
Continuous soil cover with cover crops	Permanent soil cover, green manure	CC	1466.7
Optimization of irrigation in irrigated systems	Irrigation -25%	IRR_{Opt}	7705.5
Optimization of fertilization in rainfed systems	Mineral fertilization -30% compared to benchmark values	$FERT_{Opt}$	20485.7

Agronomic outcomes from the adoption of AEMs were evaluated in terms of standardized yields, quantified as the difference between agro-ecosystems that adopted – and did not adopt – AEMs, and nitrogen use efficiency (NUE), defined as the ratio between N removed as yield and the total amount of N inputs. Moreover, the environmental impacts on water (e.g., N leaching), air (e.g., N_2O emissions), and soil quality (e.g., SOC content), were quantified by considering the changes on the biogeochemical fluxes. Water, air and soil environmental indicators were successively integrated to construct AEM performance maps in ArcGIS 10.2 and to evaluate the overall effectiveness of AEMs in improving the agro-ecosystems quality. Soil, water and air indicators were classified in each geographical unit as representing high (H), medium (M) or low (L) environmental quality (Dal Ferro et al., 2018).

3. RESULTS AND DISCUSSION

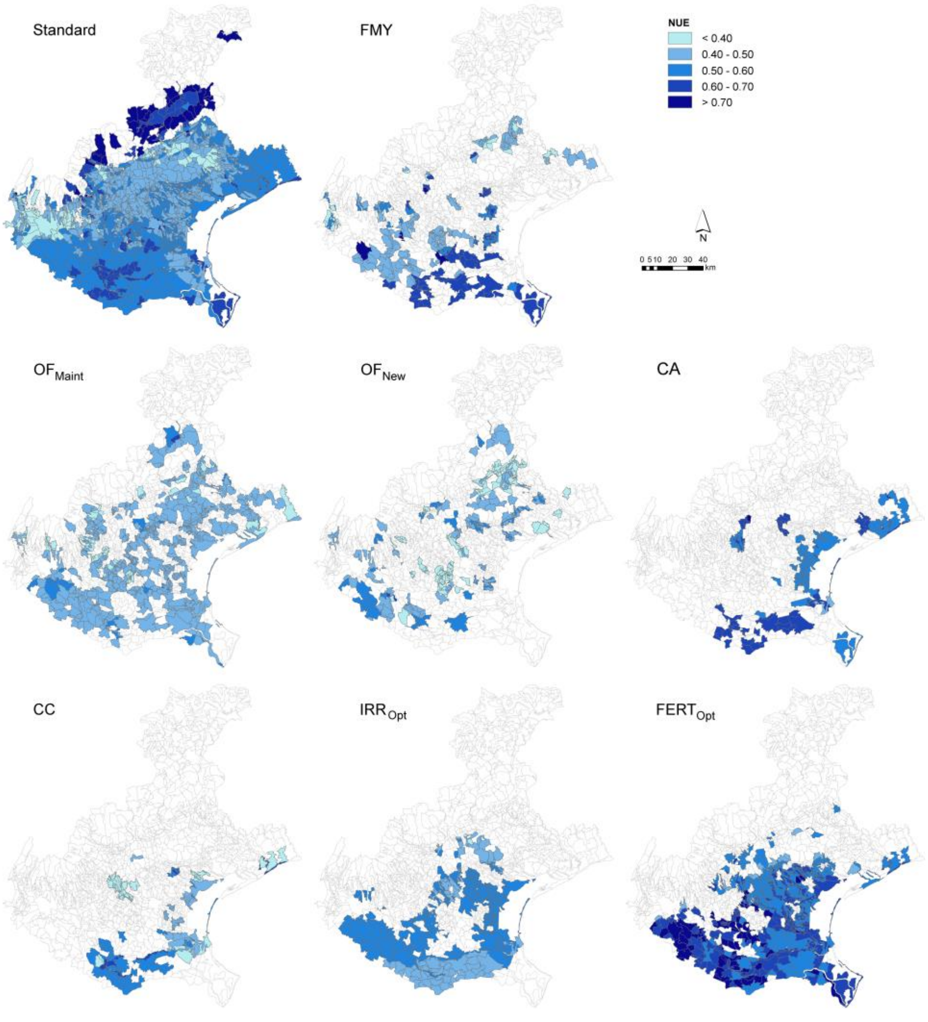
Modelling results of crop yields with DAYCENT in the standard scenario ranged between 3.3 Mg ha^{-1} y^{-1} and 21.4 Mg ha^{-1} y^{-1}, with a median of 7.7 of Mg ha^{-1} y^{-1}. The highest simulated yields were found where silage maize was highly fertilized and irrigated (> 20 Mg ha^{-1} y^{-1}), whereas the lowest were found where rapeseed was the main cultivated crop (< 3.5 Mg ha^{-1} y^{-1}). Agricultural systems that showed the highest yield values were observed in the central-northern plain areas, where the interaction between pedo-climatic and management conditions (e.g., high dose of N input) favoured optimal crop growth (Figure 1). Nitrogen use efficiency (NUE) varied widely between 0.3 and 0.7, with median values of 0.51. Among simulated AEMs, a reduction of NUE was observed after a change from mineral to organic nitrogen fertilization until median values of 0.47, 0.45 and 0.42 that were specifically associated with the introduction of farmyard manure input, and organic farming in the long and short term, respectively (Figure 2). By contrast, adopted strategies of N mineral fertilization reductions increased NUE, but conversely they led to reductions of crop yields.

Figure 1: Total N loads (kg ha^{-1} y^{-1}) inside and outside the Nitrate Vulnerable Zones (left) and average crop yields (dry matter) across the study area (right), predicted with DAYCENT model.



According to Oenema et al. (2015), the agronomic efficiency of some AEMs reduced NUE, leading to risks of inefficient N use when applying only organic amendments. However, some modelled differences in NUE were also observed between winter and summer crops, suggesting that more detailed evaluations are required to define crop-specific guidelines. A combination of organic and mineral fertilizers, as well as their integration with cover crops, should be suggested to improve the AEMs efficiency, especially on the low-lying Venetian plain that is characterized by loose soils (especially sandy loam and silt loam) and a shallow water table that is vulnerable to N leaching. Water quality, evaluated in terms of N leaching, was generally improved by adopting AEMs that provided a continuous soil cover, such as the conservation agriculture measure, the conversion from croplands to grasslands, and the use of cover crops, which were also associated to an improvement of NUE. At regional scale, DAYCENT model simulations estimated a decrease in total N of around 9.0 kg ha^{-1} y^{-1}, corresponding to a total reduction of 575 t y^{-1} across Veneto Region. In terms of soil quality, AEM strategies that support the organic input alone were not sufficient to increase the SOC content across Veneto. Indeed, the simulated adoption of only organic inputs (e.g. in organic farming) partly reduced promptly available nutrients as per mineral fertilizers, thus decreasing endogen soil C inputs (roots and residues) that was due to reduced biomass production. Instead, a notable increase of SOC content was observed in the long term, when a legacy-induced effect on nutrients availability to crops may be hypothesized that favoured biomass production (Lin et al., 2016).

Figure 2: Spatial visualisation of nitrogen use efficiency (NUE) in the Standard and AEM scenarios.



Positive effects from improvements of NUE affected N_2O emissions into the atmosphere, that decreased from 1.59 kg N-N_2O ha^{-1} y^{-1}, as predicted in the Standard scenario, to values < 0.5 kg N-N_2O ha^{-1} y^{-1} with both conservation agriculture and cover crop practices. By contrast, some increase of N_2O emissions was predicted after the adoption of organic inputs, especially in irrigated systems, that were likely due to anaerobic conditions as associated with labile C availability that is needed for denitrification (López-Fernández et al., 2007). Overall, AEMs that imply the continuous soil cover (CA and CC) and that are maintained in the long term (OF_{Maint}) were the most effective for improving the agro-ecosystem quality (Table 2): more than 60% of the simulated used agricultural areas showed "high" environmental quality, whereas the Standard scenario, as well as IRR_{Opt}, $FERT_{Opt}$ and FMY measures, generally produced a "medium" overall environmental quality. Despite the benefits that have been modelled by conservation agriculture and cover crop practices, their adoption across the Veneto Region is still poor and concentrated in the south/south-eastern areas of Veneto, while on the central and northern plains, where for instance N loads are high due mostly to livestock concentrations, they were rarely implemented, minimising their potential benefits at the regional scale. Moreover, these practices were adopted in just 1.2% of total hectares under conventional practices, despite DAYCENT predictions suggesting both agronomic and environmental improvements. Several factors likely hindered their application: 1) little investments due to relatively small size of the farms; 2) little innovation as a result of low generational change; 3) uncertainties on farm incomes, especially in the short term.

Table 2. Percentage area of Standard and AEM scenarios as characterized by the combination of agro-ecosystems environmental quality parameters (H = high, M = medium, L = Low).

Rank	Standard scenario	AEM scenarios							
		FMY	OF_{Maint}	OF_{New}	MEAD	CA	CC	IRR_{Opt}	$Fert_{Opt}$
L-L-L	0.1%								
M-L-L	15.6%	2.9%		9.6%				1.1%	1.4%
M-M-L	83.9%	90.5%		61.4%				63.5%	98.4%
M-M-M	0.0%	1.8%		9.0%	0.1%			31.2%	
H-M-L	0.4%	4.8%	21.6%	12.9%	39.8%			2.4%	0.2%
H-M-M	0.0%		16.3%	2.1%	13.2%		9.5%	0.8%	
H-H-L			0.1%	4.8%		21.5%	11.3%		
H-H-M			61.5%	0.1%	43.3%	78.5%	79.3%	2.6%	
H-H-H			0.4%		3.5%			0.2%	
	100%	100%	100%	100%		100%	100%	100%	100%

4. CONCLUSIONS

The proposed model-GIS platform proved its feasibility for a spatial evaluation of AEMs because it was able to combine both agronomic results, evaluated in terms of crop productivity and nitrogen use efficiency, and environmental factors, evaluated in terms of biogeochemical fluxes in the agro-ecosystems of the Veneto Region. As a decision support system, this method was able to evaluate different AEMs at the local scale with a result-oriented approach, disentangling which adopted strategies might be the most promising and should be strongly valorized and sustained. In particular, it was observed that better agronomic and environmental performances were associated with the continuous soil cover and the application of AEMs in the long term: in particular, the maintenance of organic farming was particularly effective in the sandy soils with natural low SOM content of south-western Veneto, whereas a generalized improvement was associated with CA and CC practices across the region.

These estimates provide a good starting point for decision-makers aiming to implement a spatial targeting approach that effectively evaluate the ecological effectiveness of agri-environmental policies.

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