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Greenhouse gases mitigation policies in the agriculture of Aragon, Spain

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Abstract. Climate change is an important threat to human society. Agriculture is a source of greenhouse gases (GHG), but it also provides alternatives to confront climate change. The expansion of intensive agriculture around the world during recent decades has generated significant environmental damages from pollution emissions. The spatial distribution of emissions is important for the design of local abatement measures. This study makes an assessment of GHG emissions in an intensive agricultural area of Aragon (Spain), and then an economic optimization model is developed to analyze several GHG mitigation measures. The results indicate that adequate management of manure, emissions limits, and animal production restrictions are appropriate measures to abate pollution. Economic instruments such as input and emission taxes could be only ancillary measures to address nonpoint pollution problems. Suitable pollution abatement policies should be based on institutional instruments adapted to local conditions, and involve the cooperation of stakeholders.

Key words. GHG emissions, Economic modelling, Mitigation policies, Effectiveness, Abatement costs

Jel Codes. Q54, D78, C61

1. Introduction

The impacts of climate change on the human society and the environment have been the subject of widespread discussions and social concern during recent decades. Several studies indicate that arid and semiarid regions will sustain large negative effects from climate variability. Suitable climate conditions for cultivation are expected to move northwards in the northern hemisphere, resulting in more frequent and severe droughts in the southern region. Recent climate change projections for the end of the twenty-first century indicate that in arid and semiarid regions including the South of Europe and the Mediterranean basin, there would be large reductions in water availability, huge increase of water withdrawals, pressures on food production systems with falling crop productivity, and harmful damages to aquatic ecosystems (FAO, 2011).

Climate change projections for the end of the twenty-first century in Spain indicate that temperature and evapotranspiration increase by about 4 °C and 21%, respectively,

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while precipitation decreases by 17%. These changes reduce crop yields, increase the water requirements of irrigation, and intensify the spread of pests and diseases (CEDEX, 2010). Water scarcity would worsen in most Spanish basins, with water availability falling up to 40 percent in some basins and drought recurrence increasing by a factor of ten (Lehner, 2005; Iglesias, 2009).

The increase of the greenhouse gas (GHG) concentrations is largely determining the current and projected climate changes in the earth (Houghton, 2001). Anthropogenic global GHG emissions have risen 70% between 1970 and 2004, due to fossil fuel use, land use changes, and agriculture intensification (IPCC, 2007). The Stern review estimates that without the implementation of GHG mitigation policies, the impacts of climate change could result in damages equivalent to 5% of global GDP per year, while the costs of mitigation policies could be limited to around 1% (Stern, 2007).

Agriculture is a significant source of GHG emissions and the main source of non-CO₂ emissions such as methane (CH₄) and nitrous oxide (N₂O). The sources of these emissions are nitrogen fertilization in cultivated soils, large animal production facilities, and nitrogen pollution loads in rivers and water streams. Agriculture accounts for around 14 percent of global anthropogenic GHG emissions (IPCC, 2007). But agriculture is also a source of low cost alternatives to mitigate climate change, by adequate management of forests, woody vegetation and soils to enhance carbon sequestration, and by using good agricultural practices to reduce GHG emissions.

In Spain, GHG emissions from agriculture are close to 39 million t CO₂eq, which represent approximately 11 percent of Spain anthropogenic emissions. About 46 percent of all agricultural GHG emissions are from soil fertilization management. About 33% of emissions are methane from enteric fermentation from livestock, and 21% are nitrous oxide and methane from manure handling and storage. Land Use, Land Use Change and Forestry (LULUCF) activities may improve the total GHG emission budget by 8% (29 million t CO₂eq), by using reduced emissions and carbon sequestration measures (MARM, 2011a).

The European Union (EU) is committed by the Kyoto Protocol to reduce GHG emissions by 8% in the commitment period (2008-2012), over the 1990 baseline. Member states are required to limit or reduce their GHG emissions in the sectors covered by the EU emission trading scheme (EU-ETS), and they could increase their emission budget through the flexible mechanisms and the LULUCF activities (EEA, 2010). Consequently, the emission limits established for the regulated sectors and the LULUCF activities are an indirect mechanism to place emission limits on diffuse sectors not covered by the EU-ETS, such as agriculture and transport. The emission reduction target for the diffuse sectors in the EU is a 10% reduction in 2020 compared to the 2005 baseline. This overall emission reduction target is shared by all European countries with different individual targets depending on their emission level. Spain is required to reduce its GHG emissions from diffuse sectors by 10% (OJ, 2009).

Climate change mitigation issues have been recently included in European agricultural and environmental policies. The purpose is to provide policy instruments to reduce emissions from agricultural sources without damaging the economic viability of production activities. These policies are basically the Common Agricultural Policy (CAP), the Integrated Pollution Prevention and Control Directive (IPPC), the Water Framework Directive (WFD), and the Nitrates Directive (ND).

The CAP shapes the evolution of European agriculture. Recent reforms of the CAP promote the sustainability of agriculture, the protection of the environment, and better animal health and welfare conditions. The main changes to protect the environment and curb climate change are the agro-environment measures, the decoupled income support and cross-compliance, the compulsory modulation, and the setting of farm advisory systems. The CAP after 2013 would include climate specific measures to further explore agriculture potential to mitigate GHG emissions and adapt to the adverse impact of climate change (EC, 2009 and 2010).

The IPPC Directive is oriented to reduce pollution emissions from industrial and agricultural sources. This Directive regulates industrial and agricultural activities with a high pollution potential, such as the energy, chemical and livestock sectors. These production activities follow an authorization procedure with minimum requirements included in all permits, especially pollution emissions. The Directive includes livestock facilities for intensive rearing of poultry and pigs. The main recommendations to reduce pollution from livestock facilities are the use of the best available technologies to prevent pollution, the efficient use of energy, setting emission limits, and measures for waste management.

The WFD regulates water resources in Europe. The objectives are to achieve the good ecological status of all water bodies, protect all continental, coastal and subsurface waters, and advance the sustainable use of water. The Directive promotes water pricing policies, the combination of emission limits and water quality standards, and also the participative management of basins. The improvement of water management could have a positive effect on GHG emissions. The Directive is considered a key tool for climate change adaptation and mitigation.

The ND aims to protect water quality across Europe by preventing nitrates from agricultural sources to pollute ground and surface waters. The main measures are the identification of vulnerable zones to nitrate pollution, the design and implementation of good farming practices, and the setting of fertilization limits. The objectives are the abatement of nitrate pollution in water bodies and mitigation of GHG emissions generated by excessive nitrogen fertilization and manure surplus. Moreover, the use of good farming practices such as reduced tillage, crop rotations, soil winter cover, and catch crops enhances carbon sequestration by soils and vegetation (Smith, 2004).

At the Spanish level, the government has developed a strategy for climate change (MARM, 2007). The strategy sets up an emission limit for the whole Spanish economy for the period 2008-2012, when GHG emissions should not exceed 37% over the 1990 baseline, and provides guidelines for the design of mitigation measures by sector. The strategy calls for the cooperation of regional governments and local administrations to reduce GHG emissions and comply with the Spanish commitments.

The objectives for the agricultural sector are to reduce GHG emissions from cultivation and livestock sources, but without a specific reduction target for the whole sector, and to increase carbon sequestration by 2% for the period 2008-2012. The measures to mitigate agricultural GHG emissions are to improve information and knowledge on production processes, reduce nitrogen fertilization and better manure management, promote organic farming, biodigestion of manure, improve the energy efficiency in irrigated agriculture, increase the land area of energy producing crops, and renew agricultural machinery.

The purpose of this study is to contribute to the ongoing policy discussion about GHG mitigation in agriculture. The study analyzes first the GHG emission sources linked to agricultural production activities in an intensive agricultural area of Aragon (Spain). Then, the cost-effectiveness of several GHG mitigation measures at local scale is evaluated. Specific local measures to mitigate GHG emissions are important for policy design.

The study is organized as follows. First, a review of the economic literature about GHG mitigation policies is presented in section 2. Section 3 describes the methodology and the study area, and section 4 presents the results. Section 5 concludes with the summary and policy recommendations.

2. Literature review

There are several studies in the economic literature about climate change that analyze GHG emissions released by agricultural activities, and the cost-effectiveness of policies to mitigate emissions (De Cara *et al.*, 2005; Neufeldt and Schäfer, 2008; Pérez *et al.*, 2009; MacLeod *et al.*, 2010; Lengers and Britz, 2012; Kahil and Albiac, 2012). The economic impacts of mitigation policies are important determinants of whether or not policies are implemented. Smith *et al.* (2007) indicate that economic constraints may limit global agricultural GHG mitigation to around 35 percent of the total biophysical potential for mitigation.

Some studies estimate GHG abatement costs and the welfare implications of abatement measures (De Cara *et al.*, 2005; MacLeod *et al.*, 2010). Other studies consider also the indirect effects of these policies and the trade-offs between environmental externalities (Neufeldt and Schäfer, 2008). Different methodological approaches have been used, such as partial or general equilibrium models, econometric models, or more integrated models that couple a socioeconomic core with environmental and agricultural sector components (Povellato *et al.*, 2007).

The studies evaluate abatement policies such as emission trading, inputs taxes, and emission standards. A single instrument is not sufficient to mitigate emissions, rather a combination of adequate regulatory instruments is highly recommended to achieve climate stabilization in a cost-effective way. Results indicate also the importance of identifying the main emission sources, and then designing policy instruments adapted to local conditions. The design of instruments should consider the biophysical, socioeconomic and political heterogeneity of producing areas, in order to achieve the collective action of stakeholders (MacLeod *et al.*, 2010; Kahil and Albiac, 2012).

Some studies point out that the inclusion of agriculture in GHG regulatory systems could contribute to climate stabilization in a cost-effective way, and provides also opportunities to reduce GHG mitigation efforts in other sectors where abatement costs are higher (De Cara *et al.*, 2005; Pérez *et al.*, 2009). The main hypothesis behind these results is that the response of agricultural pollution to policy intervention is similar to the response of urban and industrial pollution, ignoring the nonpoint characteristics of agricultural pollution. Agricultural pollution is linked to an important problem of information and knowledge, because of the impossibility of identifying the agents generating the emissions, the precise spatial location of sources, and the amount of emission loads at the source.

Several issues arise in the design and implementation of policies to control nonpoint pollution. These issues are linked to uncertainties about sources and controlling factors,

the complexity and randomness of biophysical processes, and the strategic behavior of stakeholders facing abatement measures. All these factors make the measurement of emissions, and the design and enforcement of policies to control GHG emissions from agriculture costly and complicated (Tomasi *et al.*, 1994; Weersink *et al.*, 1998; Shortle and Horan, 2001; Albiac, 2009). Lengers and Britz (2012) indicate the difficulty to measure agricultural GHG emissions and implement economic instruments for mitigation. Their empirical results in dairy farms in Germany show that abatement strategies of farmers and the related costs would depend on the particular performance indicator for emissions chosen by the regulator, creating incentives for free-riding. DEFRA (2009) indicates that the problem of implementing economic instruments to mitigate GHG emissions is the high transaction costs for small farmers.

Abatement policies could entail negative impacts on agricultural income and rural development, or could produce unintended environmental damages (Neufeldt and Schäfer, 2008). Smith *et al.* (2007) present a review of policy and technological constraints to implement GHG mitigation measures in agriculture. They point out that suitable policies must provide benefits for climate, but they also emphasize that their effective implementation requires that the outcomes from these policies are sustainable from the economic, social and environment perspectives.

In a previous work by Kahil and Albiac (2012), several policy instruments to mitigate GHG emissions from cultivation are analyzed. Results indicate that standards limiting nitrogen fertilization and investments in irrigation modernization are appropriate mitigation measures to abate emissions. Another finding is that economic instruments are not very well suited measures to abate agricultural nonpoint pollution. Results show also the importance of forests as carbon sinks, and the potential of reforestation. However, reforestation could have negative effects on water balances in watersheds under acute water scarcity in arid and semiarid regions.

3. Methodology

The study analyzes agricultural activities in Aragon, a region located in the middle Ebro basin in north-eastern Spain. The region has an important irrigated area covering 450,000 ha, and a large swine herd close to 5 million heads.

Agriculture in Aragon releases almost 3.6 million t CO₂eq of GHG, representing 20% of the total emissions of the region, which is above the percentage of emissions in Spain (11%). The GHG emissions from livestock are 1.9 million t CO₂eq, including methane (CH₄) from enteric fermentation, and nitrous oxide (N₂O) from manure management. The GHG emissions from crop cultivation are close to 1.7 million t CO₂eq, of nitrous oxide (N₂O) from crop and soil management (EACCEL, 2011).

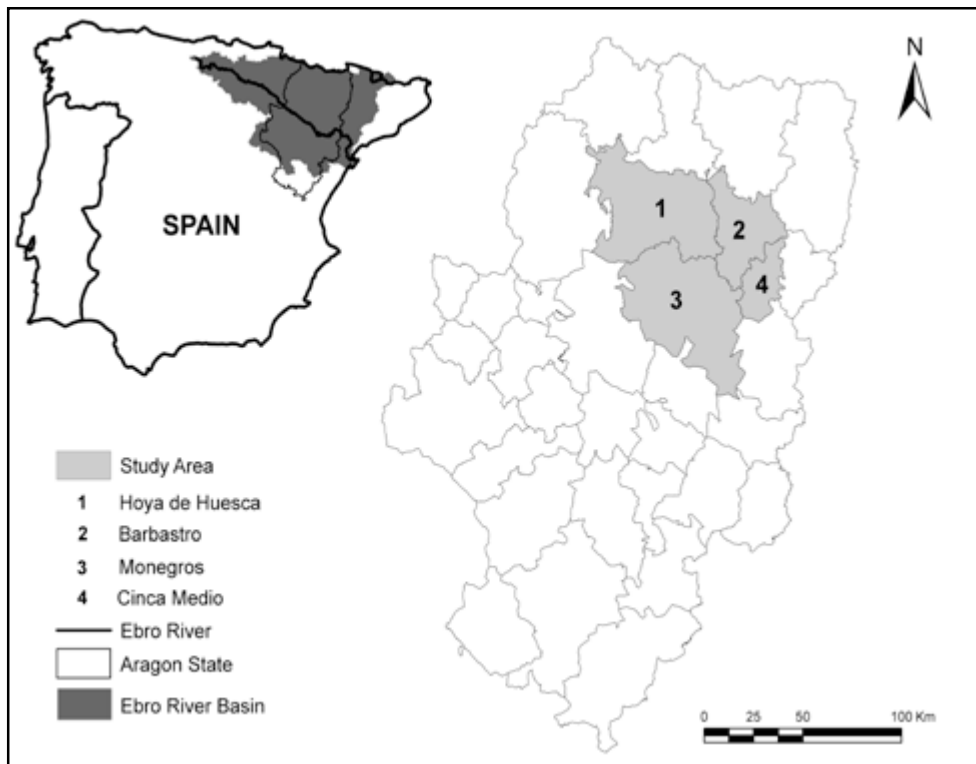
Agricultural pollution is a negative externality that causes harmful environmental and socioeconomic impacts. The control of nonpoint emissions from agriculture is very different from the control of point emissions from industrial and urban activities. The main features of diffuse pollution are the lack of knowledge and randomness of biophysical processes, and the asymmetric information between regulators and polluters.

These features impose important difficulties for regulation, which make the task of finding adequate policy measures quite complex. Perman *et al.* (2003) analyze the avail-

able policy instruments to control agricultural pollution. These instruments are classified into three groups: command and control instruments (input or output control, emission or concentration limits, etc), economic instruments (input or output based taxes, subsidies for control practices, emission trading, etc), and institutional instruments (management organizations, liability rules, education and social programmes, etc). The present study considers alternative abatement measures from the three groups of instruments.

The study analyzes the cultivation and livestock activities in four counties of Aragon: Barbastro, Cinca Medio, Hoya de Huesca and Monegros (Figure 1). This area includes about 138,000 ha of crop land and more than 2 million heads of swine. The main cultivated crops are barley (77,000 ha), alfalfa (20,000 ha), corn (16,000 ha) and wheat (10,000 ha) among field crops, and olives (2,300 ha) and vineyards (1,900 ha) among fruit trees (Gobierno de Aragón 2009).

Figure 1. Map of the study area.



3.1 Economic model

The analysis of agricultural GHG mitigation measures is based on the development of a regional economic optimization model that includes cultivation and livestock activities. The programming technique is linear programming, and the main advantage of using this

procedure is the possibility to introduce a large set of biophysical and economic information in a suitable level of disaggregation.

Linear programming models have been used in the literature to analyse climate change issues (De Cara *et al.*, 2005; Schneider *et al.*, 2007; Povellato *et al.*, 2007). These models can simulate policy responses at a detailed activity level, and taking into account the spatial heterogeneity of production processes.

The model maximizes the social welfare from cultivation and livestock production activities, subject to technical and resource constraints. A Leontief production function technology is assumed with fixed input and output prices, where farmers are price takers. The optimization problem is stated as:

$$\text{Max} \left[\left(\sum_{i=1}^{28} C_i \cdot X_i + \sum_{j=1}^5 C_j \cdot X_j \right) - (\lambda \cdot E) \right]$$

Subject to:

$$\sum_{i=1}^{28} X_i \leq d_s \quad [1]$$

$$\sum_{i=1}^{23} W_{mi} \cdot X_i + \sum_{j=1}^5 W_{mj} \cdot X_j \leq d_{wm} \quad [2]$$

$$\sum_{i=1}^{28} O_{mi} \cdot X_i + \sum_{j=1}^5 O_{mj} \cdot X_j \leq d_{om} \quad [3]$$

$$X_i = \sum_{n=1}^5 \alpha_n \cdot X_{in} ; \sum_{n=1}^5 \alpha_n = 1 ; \alpha_n \geq 0 \quad [4]$$

$$X_j / Pl_j \leq L_j \quad [5]$$

$$X_i, X_j \geq 0 ; i = 1, \dots, 28 ; j = 1, \dots, 5$$

The first equation is the objective function of social welfare from production activities, which is defined by the difference between farmers' net income and environmental damages (Perman *et al.*, 2003; Koundouri and Christou, 2006; Esteban and Albiac, 2011). Farmers' net income is equal to the sum of the net income for each crop i ($i=1, \dots, 28$) and each animal category j ($j=1, \dots, 5$). The net income C_i and C_j of each activity are equal to revenue minus direct and indirect costs, and depreciation. Environmental damages are approximated by a linear function of GHG emissions E , where the unit emission cost λ is

assumed to be equal to 25 €/t CO₂eq which is the average price of the emission allowance in the European Trading Scheme (MARM, 2010a). The decision variables in the optimization problem are X_i and X_j , corresponding to crop area and livestock herd numbers.

The land use constraint [1] represents the available land area d_s of rainfed and irrigated crops. The water constraint [2] represents the monthly water availability d_{wm} . The coefficients W_{mi} and W_{mj} are the monthly water requirements of each irrigated crop i ($i=1, \dots, 23$) and each animal category j ($j=1, \dots, 5$), respectively. The labor constraint [3] represents the monthly labor availability d_{om} . The coefficients O_{mi} and O_{mj} are the monthly labor requirements of each crop i and animal category j , respectively.

The aggregation constraint [4] forces crop production activities X_i to fall within a convex combination of historically observed crop mixes X_{in} . The index n indicates the number of years of the observed crop mixes. Variables α_n are non-negative weights assigned to each historical observed crop mix and are determined endogenously during the optimization process. Once the weight variables are determined, the optimal aggregate supply response will be determined as a weighted sum of the corresponding historical crop mixes (Önal and McCarl, 1989 and 1991).

When performing an analysis at regional-level instead of at individual farm-level, there is an aggregation problem because farms in a region are different. Ideally, a model could include a component for every individual farm, but this is unfeasible for a regional model (Hazell and Norton, 1986). The convex combination approach solves the aggregation problem using theoretical results from linear programming. The optimum solutions of linear programs (e.g. crop production decisions at the farm level) occur at corner solutions (extreme points). Önal and McCarl (1989 and 1991) using the mathematical programming theory of Dantzig and Wolfe (1961) prove that the optimum solution of an aggregate linear program is formed by stacking the optimum solutions of the farm level models. Therefore, this approach eliminates the need for full information about micro-level input-output data and extreme points of the individual farm problems. Rather, what is needed is only a set of observed aggregate supply responses, namely historical crop mixes that characterize the decision space of the aggregate producer, which can easily be obtained from publicly available statistics and other data sources.

The convex combination approach embodies individual farm resource constraints, crop rotation considerations, farmers' conservative behavior (risk aversion) against price, yield uncertainty, and a variety of natural conditions (Chen and Önal, 2012). There are other procedures to address the aggregation problem in regional models, such as the representative farm approach (Day, 1963) and positive mathematical programming (Howitt, 1995).²

The livestock facilities constraint [5] represents the available number of places L_j for each animal category j . Pl_j is the maximum number of heads per place in one year (1 head for sows, 2.3 heads for fattening pigs, 1 head for cattle). In order to account for the quasi-fixed nature of livestock-related capital, the variation of animal numbers for each animal

² The representative farm approach requires that all individual farms have the same production possibilities, the same type of resources and constraints, and the same level of technology and managerial ability. Also, the matrix of technical coefficients has to be identical for all farms, and the availability of resources and the coefficients of the objective function have to be proportional (Day 1963). These requirements are very demanding and implausible for regional models.

category does not exceed ± 15 percent of the initial animal numbers in the corresponding animal category (De Cara *et al.*, 2005).

Biophysical and economic information specific to the study area has been collected and introduced in the model: land and water use, fertilizers, labor, and revenues and costs of crop and livestock production activities (Table 1). This information has been taken from a large number of primary and secondary data sources (Mema 2006, Gobierno de Aragón 2009, MARM 2009, Orús *et al.* 2011, Kahil and Albiac 2012).

Table 1. Parameters of the model.

Parameters	Value	Unit
Total crop area	138	10 ³ ha
Irrigated area/Total crop area	60	%
Rainfed area/Total crop area	40	%
Field crop area/Total crop area	95	%
Fruit trees area/Total crop area	5	%
Flood irrigation area/ Irrigated area	52	%
Sprinkler irrigation area/ Irrigated area	46	%
Drip irrigation area/ Irrigated area	2	%
Water use	567	Mm ³
Mineral nitrogen use	16,640	t N
Organic nitrogen use	3,080	t N
Nitrogen leaching	5,900	t N
Irrigation water price	0.05	€/m ³
Nitrogen fertilizers price	1	€/kg N
Swine place numbers	875	10 ³ places
Cattle place numbers	50	10 ³ places
Swine nitrogen excretion	8.3	Kg N/place
Cattle nitrogen excretion	48.7	Kg N/place
Crops net income	39	10 ⁶ €
Livestock net income	28	10 ⁶ €

An important component of the empirical model is the estimation of GHG emissions generated by cultivation and livestock production. The method used to assess agricultural GHG emissions follows the approach of the Intergovernmental Panel on Climate Change (IPCC, 1996). This method combines the use of emission factors per activity unit, and the regional-specific data on crop area, fertilizers use, animal numbers, nitrogen excretion, manure management systems, and historical Spanish emission data.

The model simulates different policy scenarios, and provides results on social welfare, environmental damages, farmers' net income, inputs use, pollution loads, crop area, and swine herd size. Results show the abatement potential and cost, welfare effects, and environment impacts of each mitigation measure. This information is used to classify measures by their cost-effectiveness. The model has been developed using the GAMS package (General Algebraic Modelling System).

4. Results

4.1 Assessment of agricultural GHG emissions

The study area contributes significantly to the final agricultural production of Aragon, as well as to employment and rural development (MARM, 2009). However, these activities generate environmental damages by releasing GHG emissions, nitrogen loads in rivers and streams, and manure surplus, which contribute to global warming and the degradation of water resources.

The net income of farmers in the study area is close to 67 million Euros, with 39 million from cultivation activities and 28 million from livestock. Field crop cultivation is the main activity generating 31 million Euros of net income from the large cultivated area (131,000 ha). By county, Monegros generates the largest net income (30 million €), while net income in Barbastro, Cinca Medio, and Hoya de Huesca ranges between 10 and 14 million Euros (Table 2).

Table 2. GHG emissions and farmers' net income from agricultural production activities.

	Barbastro	Cinca Medio	Hoya de Huesca	Monegros	Total study area
N ₂ O direct emission (10 ³ t CO ₂ eq)	16	12	20	45	93
N ₂ O indirect emission (10 ³ t CO ₂ eq)	10	7	12	27	56
N ₂ O manure management (10 ³ t CO ₂ eq)	3	8	5	9	25
CH ₄ manure management (10 ³ t CO ₂ eq)	63	88	45	246	442
CH ₄ enteric fermentation (10 ³ t CO ₂ eq)	15	32	17	47	111
Total emissions (10³ t CO₂eq)	107	147	99	374	727
Crop net income (10 ⁶ €)	9	8	5	17	39
Livestock net income (10 ⁶ €)	4	6	5	13	28
Total net income (10⁶ €)	13	14	10	30	67
Emission intensity (Kg CO₂eq/€)	8	11	10	13	11

Agricultural activities in the study area contribute to GHG emissions through four main gas-emitting processes: direct and indirect nitrous oxide (N₂O) emissions from agricultural soils, nitrous oxide (N₂O) emissions from manure management, methane (CH₄) emissions from manure management, and methane (CH₄) emissions from enteric fermentation.³ Emissions in the four counties are estimated at 727,000 t CO₂eq, which represent 20 percent of the agricultural emissions in Aragon. Manure management is the main source of emissions (65%) because of the large concentration of swine herd in the area.

³ Direct N₂O emissions from agricultural soils occur through the nitrification and denitrification of nitrogen in soils from mineral and organic fertilizers, while indirect N₂O emissions arise from nitrogen leaching and run-off from agricultural soils (IPCC, 1996).

Monegros generates around half of emissions in the area (374,000 t CO₂eq). In terms of emission intensity, Monegros is the most intensive (13 kg CO₂eq/€), followed by Cinca Medio, Hoya de Huesca and Barbastro.⁴ The difference in emission intensity by county is related to the heterogeneity of production systems, land use and management practices. One factor is the prevailing irrigation technology used in each county, which influences the emission intensity. Sprinkler and drip irrigation are more efficient than flood because they use less nitrogen and water to produce the same output, so both water percolation and pollution loads are smaller. Also the extent of rainfed crop area influences emission intensity, because rainfed land is used to dump manure surplus and there is no strict control on these fertilization loads. The study area is quite intensive in emissions (11 kg CO₂eq/€) compared to the emission intensity of the whole agricultural sector in Aragon (3 kg CO₂eq/€) (Kahil and Albiac 2012).

4.2 Policy scenarios

Policy measures for GHG mitigation have been widely studied in the literature during the last decade (IPCC 2007). Measures are linked to improved or optimized fertilization, such as adjusting nitrogen inputs to crop requirements, better use of organic fertilizers, setting organic fertilization standards, using more precise manure spreading technologies, and the promotion of no-till cultivation methods. For livestock, recommendations are limits on livestock densities, production quotas, improving the feeding and housing of animals, and better on-farm manure storage and processing.

Several mitigation measures recommended in the literature are evaluated by their cost-effectiveness. Three types of measures are considered: economic instruments (emission tax, inputs-based taxes), emission limits (GHG emissions limit, limit on nitrogen leaching in irrigation water returns), and control of inputs and production (standards limiting nitrogen fertilization, improved feed of swine, reduction of the swine herd, reduction of irrigation water) (Tables 3 and 4).

The baseline scenario represents the current conditions of land use, inputs use, yields, and revenues and costs. Social welfare in the baseline scenario is 49 million Euros, the difference between farmers' net income (67 million €) and environmental damages (18 million €) from GHG emissions (727,000 t CO₂eq). Agricultural activities create large pressures on water resources, with water extractions around 600 Mm³ and nitrogen leaching loads around 6,000 t N. The high livestock density in the area generates also a large amount of manure with nitrogen loads around 10,600 t N. Only 30 percent of this manure is used in crop fertilization (MARM 2011b), and therefore this manure surplus results in large GHG emissions and considerable pollution loads on water bodies and streams.

Economic instruments

The first scenario evaluates the first best measure of taxing GHG emissions by 25 €/t CO₂eq.⁵ This measure achieves the maximum social welfare (+37% over the base-

⁴ The emission intensity is measured in kilograms of GHG emission loads per Euro of net income. The higher is the value of the emission intensity, the more emission intensive is the production within an area.

⁵ The emission tax is the first best measure that achieves the maximum social welfare and the optimum level of

Table 3. Social welfare, net income and land use under each scenario.*

Scenarios	Welfare (10 ⁶ €)	Farmers' net income (10 ⁶ €)	Environmental damages (10 ⁶ €)	Crop area (10 ³ ha)	Swine herd (10 ³ heads)
Baseline	49	67	18	134	2,050
<i>Economic instruments</i>					
Emission tax ($t_e=25$ €/t CO ₂ eq)	67	49	18	136	1,940
Nitrogen tax ($t_n=0.5$ €/kg N)	48	58	17	114	2,050
Nitrogen tax ($t_n=1$ €/kg N)	48	51	17	111	2,050
Water tax ($t_w=0.02$ €/m ³)	48	57	18	119	2,050
Water tax ($t_w=0.05$ €/m ³)	47	43	18	117	2,050
<i>Emission limits</i>					
Limit on GHG emissions (10%)	49	65	16	130	1,769
Limit on nitrogen leaching (10%)	48	65	17	100	2,050
<i>Control of inputs and production</i>					
Fertilization standards	55	71	16	134	2,050
Improved feed	46	64	18	134	2,050
Swine herd reduction (15%)	48	64	16	134	1,746
Reduction of irrigation water (25%)	43	61	18	118	2,050

* For nitrogen, water and emission tax instruments, social welfare is set equal to farmers' net income minus environmental damages, plus taxes.

Table 4. GHG emissions, inputs use and pollution loads under each scenario.

Scenarios	GHG emissions (10 ³ t CO ₂ eq)	Water use (Mm ³)	Nitrogen Fertilization (t N)	Manure surplus * (t N)	Nitrogen leaching (t N)
Baseline	727	567	19,720	7,500	5,900
<i>Economic instruments</i>					
Emission tax ($t_e=25$ €/t CO ₂ eq)	700	569	19,900	7,100	6,000
Nitrogen tax ($t_n=0.5$ €/kg N)	694	505	16,890	9,400	4,700
Nitrogen tax ($t_n=1$ €/kg N)	690	497	16,300	9,600	4,500
Water tax ($t_w=0.02$ €/m ³)	706	492	16,800	8,100	5,050
Water tax ($t_w=0.05$ €/m ³)	709	437	18,240	7,600	5,200
<i>Emission limits</i>					
Limit on GHG emissions (10%)	655	549	19,080	6,700	5,700
Limit on nitrogen leaching (10%)	677	503	13,140	8,800	3,950
<i>Control of inputs and production</i>					
Fertilization standards	653	567	10,751	2,200	2,700
Improved feed	726	567	19,720	4,650	5,900
Swine herd reduction (15%)	655	558	19,720	6,300	5,900
Reduction of irrigation water (25%)	711	506	17,470	7,800	5,200

* Manure surplus is the difference between manure availability from livestock (swine and cattle) and manure use in crop fertilization.

line) with the desirable level of GHG emissions. Manure surplus falls by 5 percent, with a decrease in livestock production and a slight increase in crop production. The reason of the decrease in livestock production is that the GHG marginal abatement costs are lower for livestock than for crop production.

Proposals of taxing agricultural emissions have been strongly rejected by farmers in previous experiences in countries such as Denmark, Ireland and New Zealand, given the substantial losses in income and employment resulting from the tax instrument (Kasterine and Vanzetti, 2010). In addition, taxing individual farmers would result in very low levels of pollution abatement because farmers equate their individual marginal costs of abatement with their individual marginal benefits of abatement. This is a non-cooperative solution or Nash equilibrium. When there is cooperation among farmers, the condition for efficient provision of public goods applies (in this case pollution abatement), and then each farmer equates the individual marginal costs of abatement with the total marginal benefits of abatement (Perman *et al.*, 2003). The cooperative solution requires the support of stakeholders. Therefore, the pollution abatement efforts should focus on nurturing this collective action by providing the right institutional setting to support it (Ostrom, 2010).

The second scenario considers taxing nitrogen fertilizers with two tax rates following the “polluter pays” principle. Tax ranges have been chosen taking into account the findings from the literature, which indicate that relatively high nitrogen taxes are needed to abate pollution (Martínez and Albiac, 2006). The implementation of this measure reduces the use of nitrogen fertilizers and abates GHG emissions up to 5 percent for a high tax rate (1 €/kg N). This measure has a positive effect on nitrogen leaching, which falls 24%, but the high tax reduces strongly farmers’ net income causing the abandonment of crop cultivation. The nitrogen use-based tax could increase manure surplus given the fall of crop area where manure is spread.

The third scenario considers taxes on irrigation water. Water taxes increase water prices towards “full recovery costs” and spread the water scarcity signal to any potential water markets that may appear. This water pricing is the measure of choice for water savings promoted by the WFD, and in fact the high tax rate (0.05 €/m³) saves 75 Mm³ of water. However, water pricing results in very low abatement of GHG emissions (2-3%) and very high losses of net income (15-36%). The tax instrument is quite ineffective to abate emissions and looks politically unfeasible.

Taxes would be opposed by farmers because irrigation water is at present a common pool resource (rival and non-excludable good) and not a private good. Taxing water is equivalent to introduce water markets, and the current institutional setting of water allocation would have to be dismantled in order to introduce taxes or water markets, and the common pool resource would have to be transformed into a private good. The implication is that water pricing doesn’t seem to be the best instrument to allocate irrigation water and abate emissions.⁶

emission. However, implementation of the first best measure is almost impossible because of the complexity of biophysical processes and the heterogeneity of pollution functions among agents (Perman *et al.* 2003).

⁶ Bosworth *et al.* (2002), Cornish and Perry (2003), and Cornish *et al.* (2004) present compelling results from the literature and from field cases that show the difficulties of allocating irrigation water through water pricing. See Martínez and Albiac (2004 and 2006) for arguments on the ineffectiveness of water pricing in abating nonpoint pollution.

Emission limits

The first scenario limits GHG emissions by 10 percent, which is the emission reduction target for the Spanish diffuse sectors. Net income losses under this scenario are quite small and social welfare remains unchanged, while manure surplus falls by 11%. However, the measurement, monitoring and enforcement of emission limits at the source are quite complicated tasks and entail very large transaction costs (Shortle and Horan, 2001).

Since observing pollution at the source is impossible or very costly, an alternative is to design measures to control ambient pollution (Segerson, 1988). So, the alternative is to control nitrogen leaching in irrigation water returns, which generates indirect nitrous oxide (N_2O) emissions. The control of nitrogen content of water returns gives an indication on the use of nitrogen fertilizers, and could be used to estimate the overall direct and indirect N_2O emissions at the source. This measure is feasible because there is already a network of pollution measurement stations in the main irrigation districts in the Ebro river basin (CHE, 2010). Under this measure, a limit of nitrogen leaching is set up at 39 kg N/ha, which is 10 percent less than the baseline scenario. This measure cuts GHG emissions by 7% and reduces nitrate pollution by 30 percent, but manure surplus increases 17%. There is a small decline of farmers' net income and social welfare, and also a fall in cultivated area.

Limiting nitrogen leaching in irrigation return flows is a cooperative solution, because farmers choose the pollution abatement level that could be reached collectively by equating their marginal individual costs from abatement to the total marginal benefits of abatement. This finding is in agreement with the results by Esteban (2010), which indicate that the best instruments to abate agricultural pollution are those that induce farmers' cooperation based on measurable pollution load limits, within the appropriate institutional setting.

Control of inputs and production

One problem derived from crop production is the overuse and mismanagement of nitrogen fertilizers. Recent estimations in Aragon indicate that nitrogen fertilization from mineral and organic sources exceeds crop requirements by 24%. The consequence is a nitrogen surplus of 42,000 t N (MARM, 2011b), which damages the environment. In addition, estimations of nitrogen content from manure reveal that the nitrogen available could cover up to 80% of the nitrogen requirements of crops. This would reduce the use of mineral fertilizers, saving costs, solving manure disposal problems, and abating pollution. In Aragon, farmers do not take advantage of the large amount of manure available, because of the high costs of transportation and spreading, the difficulties of management, and the uncertainty of the impact on crop yields (Orús *et al.*, 2011).

Several studies in the Ebro river basin indicate that an adequate manure use could achieve satisfactory yields for crops such as corn, wheat and barley, substituting mineral fertilization partially or completely, and achieving lower nitrogen losses (Daudén and Quilez, 2004). The transport and spreading costs of manure are lower than the costs of mineral fertilizers, when the distance from the manure source to the application site is small.⁷

Since nitrogen can readily change form and is highly mobile in soil, a strategy for

⁷ The average cost of applying manure is estimated at about 0.8 €/kg N when the distance to the application site is less than 33 km (Iguácel *et al.*, 2010).

reducing GHG emissions from nitrogen fertilization is to improve its overall use efficiency. This would reduce the amount of nitrogen in the soil available to pollute the environment. One important factor affecting nitrogen use efficiency is the application rate. Nitrogen losses are often enhanced where available nitrogen from mineral and organic fertilization exceeds crop requirements. Therefore adjusting the application rates during the growing season with precise estimations of crop nitrogen requirements and nitrogen content of all sources would reduce the losses of all forms of nitrogen (Orús *et al.*, 2011).

In the study area, nitrogen available from manure, biologic fixation, and organic matter is around 14,000 t N, which covers the entire nitrogen requirements of field crops that are 12,000 t N. However, some additional mineral fertilization is required for other nutrients. Nutrient balance results indicate that there is a large nitrogen surplus in Cinca Medio and Monegros, while additional potassium is needed. In Barbastro and Hoya de Huesca, there is a deficit of nitrogen and potassium that requires additional mineral fertilization (Table 5).

The fertilization standard scenario combines mineral and organic fertilization at adequate rates supplying enough nitrogen to meet expected yields. This scenario increases net income up to 71 million Euros (+6% over the baseline), while social welfare goes up to 55 million € (+12% over the baseline). GHG emissions fall 10 percent and nitrate pollution is cut by half. Manure surplus falls significantly down to 2,200 t N (-70%). This measure is “win-win measure” that enhances income while reducing pollution, benefiting both farmers and the environment. However, its implementation requires the support of extension services for effective control mechanisms and changes in the current environmental regulation.

The second scenario considers the improvement of swine herd feeding, a recommendation of the IPPC Directive. The improvement of swine feeding consists in matching feeds more closely to animal requirements at various production stages, thus reducing the nitrogen excretion of animals and the nitrogen content of manure. The cost of this measure for farmers is 2.6 €/place/year, using the best available technologies (MARM, 2010b). The impact of this measure on social welfare is slight, and its emission abatement potential is quite low. However, there is an important decrease in manure surplus (38%) with positive ancillary effects on ammonia and phosphorus pollution abatement. Moreover, the improved feeding of swine could be linked with other measures such as better animal housing to enhance pollution abatement.

The reduction of the swine herd size is another measure to mitigate GHG emission from livestock that could be imposed in the future by the new CAP. This measure is also recommended by the Spanish strategy for climate change to abate pollution from livestock. The measure could enhance the balance between cultivation and livestock activities in some regions with high livestock densities. The reduction of the swine herd by 15% reduces GHG emissions by 10%, and achieves the reduction target of the European Union for the Spanish diffuse sectors. Manure surplus is reduced by 16%, lessening the risk of pollution. The economic impact of this measure is slight, with decreases in social welfare and farmers' net income by 2 and 5%, respectively.

The last scenario is the reduction of water supply by the water authority. A large reduction of 25% results in less cultivated area and water savings amounting to 130 Mm³ (-23%). This measure reduces the land area of water-intensive crops such as alfalfa, rice and corn, but maintains the area of fruit trees. This is the strategy followed by the Ebro

Table 5. Nutrient balance in the study area.^a

Nutrients	Barbastro			Cinca Medio			Hoya de Huesca			Monegros			Total study area		
	N ^b	P ₂ O ₅ ^c	K ₂ O ^d	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
Crop requirements (t)	2,018	1,005	2,085	1,605	953	2,537	2,757	1,328	2,783	5,680	3,251	8,025	12,060	6,537	14,429
Nutrient availability (t)	1,845	1,518	914	2,932	2,361	1,713	1,988	1,666	1,062	7,136	5,681	3,252	13,900	11,226	6,940
Nutrient balance (t)	-173	+513	-1,171	+1,327	+1,408	-824	-769	+338	-1,721	+1,456	+2,430	-4,773	+1,840	+4,689	-8,489

^a Estimation is based on work by Orús et al. (2011). Nutrient balance is considered the physical difference between nutrient available from manure, biologic fixation and organic matter to the agricultural system and the uptake of nutrient by field crops. A positive value indicates a surplus while a negative one indicates a deficit.

^b Nitrogen, ^c Phosphorus, ^d Potassium

basin drought plan (CHE, 2007), where the basin authority reduces water supply and farmers adapt their land use to water scarcity. The net income losses are only 9% and the GHG abatement potential is very limited (3%). Nitrogen leaching falls 12% while manure surplus increases by more than 1%.

4.3 Evaluation of policy scenarios

The policy measures are evaluated by comparing the welfare effects and the abatement costs sustained by farmers under each measure. The first best measure of taxing GHG emissions increases social welfare by 18 million Euros (+37%). Nevertheless, this measure is not feasible because it requires information on the emission loads from each individual parcel, and the cost of this information is prohibitive (Martínez and Albiac, 2006). Besides, taxing GHG emissions has unintended negative effects in the area, since the measure increases nitrogen leaching and the use of irrigation water. Another problem is that the measure does not induce farmers' cooperation, which is a necessary condition to avoid policy failure in abating agricultural nonpoint pollution (Byström and Bromley, 1998).

Among second best measures, standards limiting nitrogen fertilization improve social welfare by 6 million Euros (+12%) achieving a considerable abatement of GHG (-10%). The main obstacle for implementing quantitative limits on nitrogen fertilization is the difficulty to verify farmers' compliance. The solution is to give the responsibility of control to the irrigation user associations, coupled with measurements of the water quality of return flows from irrigation districts by the basin authority. This collaboration between irrigation districts and the basin authority is a feasible option to achieve the collective action of farmers.

The control of nitrogen fertilization sought by the Nitrates Directive was initially based on spreading information and voluntary compliance, and more recently farmers have been required to keep an individual nitrogen balance book. Enforcement

is based on inspections of farms drawn by chance, where noncompliant farms are penalized in their CAP payments. However, control is limited to cultivation areas located over aquifers or streams declared officially vulnerable to nitrate pollution. The usefulness of this fertilization control mechanism remains to be seen because it ignores cultivation over the whole basin, rainfed lands, and very polluting crops that are not receiving subsidies such as vegetables or fruit trees. Also, this control mechanism does not promote cooperation among farmers (Kahil and Albiac, 2012).⁸

The measure of limiting GHG emissions at the source by 10% achieves the GHG reduction target of the European Union for the Spanish diffuse sectors, and maintains social welfare unchanged. This measure could be acceptable from a social point of view, but requires enforcement mechanisms and entails transaction costs. The reduction of the swine herd is another measure that reduces GHG emissions (-10%) with a slight loss of social welfare (-2%). This measure could be a suitable instrument to lessen large swine concentrations and the ensuing pollution in selected counties.

All measures, except fertilization standards, show large abatement costs for farmers, between 28 and 3,000 €/t CO₂eq. This range is well above the abatement cost threshold of 20 €/t CO₂eq recommended by the European Climate Change Program for GHG mitigation (ECCP, 2003).

Table 6. GHG abatement potential and cost of measures.

Scenarios	GHG abatement potential (t CO ₂ eq)	GHG abatement cost (€/t CO ₂ eq)
Fertilization standards	74,000	-54
Limit on GHG emissions (10%)	72,000	28
Limit on nitrogen leaching (10%)	50,000	40
Swine herd reduction (15%)	72,000	42
Nitrogen tax ($t_n=0.5$ €/kg N)	33,000	273
Reduction of irrigation water (25%)	18,000	333
Nitrogen tax ($t_n=1$ €/kg N)	37,000	432
Water tax ($t_w=0.02$ €/m ³)	16,000	625
Emission tax ($t_e=25$ €/t CO ₂ eq)	27,000	667
Water tax ($t_w=0.05$ €/m ³)	21,000	1,143
Improved feed	1,000	3,000

The implementation of fertilization standards increases farmers' net income and achieves the highest GHG abatement. This cost-effective and win-win measure shows that there is a considerable mitigation potential in agriculture. This result is in agreement with MacLeod *et al.* (2010), which find that the improved management of fertilization achieves a considerable GHG abatement in the agriculture of the UK at a negative cost.

⁸ The current organic fertilization limit established by the ND is 210 kg N/ha in cultivation areas outside vulnerable zones, with no limits on mineral fertilizers use. The organic limit is excessive compared to average nitrogen requirements of crops in Aragon which are below 100 kg N/ha (Orús *et al.*, 2011).

Economic instruments for mitigating agricultural GHG emissions are taxes on irrigation water, nitrogen fertilizer or emissions. Although they follow the “polluter pays” principle, their implementation has an important barrier. Farmers will oppose this type of measures rather than cooperating, because they sustain very high abatement costs under these taxes, and policy failure would be quite likely. The empirical results in the study area indicate high abatement costs, between 273 and 1,143 €/t CO₂eq, achieving very small pollution abatement, below 5%. These results confirm the ineffectiveness of economic instruments to control agricultural nonpoint pollution.

Certainly, properly designed economic instruments promote behavioural changes in agents. Esteban (2010), De Cara *et al.* (2005) and Pérez *et al.* (2009) analyze these behavioural changes in agriculture following the economic theory of demand and supply of private goods. Esteban (2010) shows how non-uniform water taxes induce heterogeneous farmers to adopt advanced irrigation technologies which abate pollution. De Cara *et al.* (2005) and Pérez *et al.* (2009) state the advantage of using market-based instruments to reduce agricultural GHG emissions.

However, the policy evidence seems to question these results. Shortle (2012) reviews several agricultural emission trading schemes in the United States, Canada and New Zealand. Most of these schemes are from the United States with demonstration pilot projects subsidized by the administration. Emission trading takes place between urban or industrial point sources which have pollution limits, and agricultural nonpoint pollution sources without pollution limits. Shortle acknowledges that the outcomes from these emission trading experiences are unconvincing, and explains the reasons for the difficulty of emission trading as a policy to control agricultural nonpoint pollution. Emission trading is an economic instrument with serious difficulties to be effective because it is market based. GHG emissions abatement is a public good requiring collective action through the cooperation of farmers and other stakeholders. Under these circumstances, economic instruments such as taxes and subsidies are likely to fail (Ostrom, 2010).

The measure of improving the feeding of swine results in very large abatement costs, with a quite small abatement potential. However, this measure involves other positive environmental effects such as abatement of water pollution by nitrate and phosphorus. Therefore, these effects may compensate the abatement costs of improved feeding and advance its feasibility.

The results of evaluating the measures for mitigation of GHG emissions in the agriculture of Aragon indicate that a combination of institutional instruments and command and control instruments could result in significant cost savings compared to economic instruments. However, these measures face a number of obstacles, such as high transaction costs, difficulties to enforce quantitative limits, and problems with the current environmental legislation. These shortcomings can be overcome by promoting the involvement of private and public stakeholders, and this will be the key driver to change the farmers’ behavior in addressing climate change mitigation.

5. Conclusions

Climate change is a negative externality from the economic activities that is already damaging the natural environment and its ecosystems, and could endanger seriously the

human well being in the coming decades. The large growth in wealth and population since the industrial revolution, based in accelerated technological developments, have largely increased atmospheric GHG concentrations. These emissions are changing the energy balance of the earth and the climate system, and threatening with a future of higher temperatures, lower precipitations in arid and semiarid regions, rises of the sea level, and more severe and frequent extreme events (IPCC, 2007).

Agriculture is an important sector for implementing climate change mitigation policies. Agriculture is a significant source of GHG emissions and the main source of non- CO_2 emissions. Besides, climate change would also have large harmful effects on agricultural activities, especially in arid and semiarid regions. The design of adequate mitigation policies for the agricultural sector is needed, and these policies require the cooperation of farmers through the right institutional setting.

This study evaluates the GHG emissions from an intensive agricultural area in Aragon, located in the middle Ebro basin. Emissions are estimated at 727,000 t CO_2eq , which represent 20% of the agricultural emissions in the Aragon region. The emission intensity in the area is 11 kg $\text{CO}_2\text{eq}/\text{€}$, well above the average emission intensity of the agriculture in Aragon. This type of information is important because the spatial dimension of emissions contributes to the adequate design and implementation of GHG mitigation policies adjusted to local conditions.

The analysis of GHG mitigation measures in agriculture indicates that there is not a unique preferred measure, and that no single instrument can address the mitigation of GHG emissions. A combination of suitable measures is needed to contribute towards climate stabilization while achieving cost-effectiveness. The choice of measures depends on the objectives of decision-makers, but also on the availability of biophysical and economic information. Local characteristics, economic and environmental effects, and social acceptability have to be considered in the design of measures. Policies have to be legitimate, because enforcement cannot be achieved without the support of stakeholders.

Inappropriate GHG abatement measures could indirectly increase the nitrogen loads into water resources, through increased leaching and runoff from crop cultivation and manure surplus. A comprehensive nutrient management planning is needed to reduce nitrogen pollution loads, by considering the whole nitrogen cycle, sources and sinks when implementing measures to reduce GHG emissions.

In the case of Aragon, more attention has to be paid to manure management in order to make a better use of this waste. Manure could eventually become a resource if properly managed, reducing at the same time its GHG emissions. Empirical results show that a combined and balanced organic and mineral fertilization of crops is a good second best policy, achieving almost the same welfare (82%) than the first best policy. Although manure management is an important aspect of the Nitrates Directive, its achievements are quite poor, and manure regulation needs revision to be more effective and adapted to local conditions.

The results of this study indicate that economic instruments that follow the “polluter pays” principle are quite ineffective in abating agricultural nonpoint pollution. Economic instruments display very high abatement costs for farmers and mostly negative welfare effects. The alternative is using institutional instruments, where stakeholders cooperate for a better land use planning and protection of environment assets. Cooperation is needed

for a reasonable allocation of resources and for achieving significant nonpoint pollution abatement efforts.

The empirical findings challenge the design of mitigation policies using pure economic instruments, and call for policy efforts focused on nurturing stakeholders' collective action and on supporting the necessary institutional setting. This study shows some measures that could induce farmers' cooperation in abating emissions. Also, preparation for climate change calls for more coordination between environmental policies, adaptation to spatial conditions, and enforcement supported by the involvement of local stakeholders.

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