Climate change adaptation and mitigation measures in the agriculture of Aragon

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RESUMEN

El cambio climático es una de las mayores amenazas ambientales, sociales y económicas a las que se enfrenta la sociedad humana. El sector agrícola es una fuente potencial de alternativas de bajo coste para la mitigación y adaptación al cambio climático. Sin embargo, la expansión de la agricultura intensiva en capital y otros inputs, esta generando daños ambientales importantes, debido a la carga de emisiones de gases de efecto invernadero (GEI), las pérdidas de nutrientes, y el uso de fitosanitarios. En este estudio se realiza una estimación de la carga de emisiones GEI y de emisiones de nitrógeno de origen agrario en Aragón. Estas emisiones alcanzan 3,5 Mt CO_2eq y 23.000 t N-NO_3^-, respectivamente. Se han examinado distintas medidas de mitigación y adaptación al cambio climático, utilizando en el análisis un modelo bioeconómico de las actividades de cultivo. Los resultados muestran que las mejores medidas sub-óptimas son los límites de fertilización y la modernización de regadíos. La medida óptima de impuestos sobre emisiones no puede alcanzarse por el carácter difuso de las emisiones agrarias. También se ha comprobado, que los instrumentos económicos son ineficientes para reducir la contaminación y que además causan una fuerte caída de la renta de los agricultores. El trabajo muestra además la importancia de los bosques en Aragón como sumideros de carbono, y su posible utilización para mitigar el cambio climático.

Palabras clave: Cambio climático, Modelización bioeconómica, Eficiencia de medidas, Instrumentos económicos, Sumidero de carbono.

1. INTRODUCTION

Climate change is an important threat to human society, with environmental, social and economic dimensions. Large variations in temperatures and precipitations are expected in the coming decades with severe impacts such as droughts, floods, snow melting, rise of the sea level, and more frequent extreme events (Houghton, 2001; EEA, 2007; IPCC, 2007). A large body of scientific evidence continues to accumulate, indicating that these changes respond to the increasing atmospheric greenhouse gas (GHG) concentrations, and warning about the agricultural production, ecosystems, and water resources (Wigley, 1999; Houghton, 2001).

The expansion during recent decades of the intensive type of agriculture worldwide, responds to large investments in advanced production technologies. But these production technologies entail significant pollution loads of nutrients and pesticides, with some of these pollutants being greenhouse gases. This agricultural nonpoint pollution is characterized by the high costs of generating information and knowledge on pollution processes, the randomness inherent to biophysical processes, and also by the asymmetric information on pollution sources among stakeholders. In Spain, GHG emissions from agriculture are close to 39 million t CO_2eq, which represent approximately 10% of Spain anthropogenic emissions, mainly as nitrous oxide (N_2O) and methane (CH_4) (MARM, 2010a), and there are serious problems of water availability and nitrate pollution in some regions with irrigation-intensive agriculture such as the Mediterranean coast, and several inland watersheds in the Jucar, Segura, Guadiana, Ebro, and Guadalquivir basins, with some locations reaching concentrations between 50-100 mg NO_3^-/l (Martínez and Albiac, 2004).

In the European Union, several policies have been implemented to protect water resources and aquatic ecosystems, such as the Nitrates Directive (1991) and the Water Framework Directive (2000). The Nitrates Directive aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices. The Water Framework Directive aims to reach the good ecological condition of water bodies, protect all continental, coastal and subsurface waters, and promote the sustainable use of water. The directive promotes water pricing principle to reach water use efficiency, and recommends the combination of emission limits and water quality standards, and also the participative management of watersheds. The goal is to improve water quality and ecosystems conditions.

The main water policies implemented in Spain to solve problems of water scarcity and drought and to curb pollution have been the National Hydrological Plan of 2001 modified with the AGUA Program, the National Irrigation Plan of 2002, the Upper Guadiana Plan of 2008, and the First and Second Sanitation Plans of 1995 and 2008. The National Hydrological Plan involves significant investments close to 19 billion €, aimed at assuring the sustainability of water resources use through desalinisation, treatment of wastewater and irrigation modernization. The National Irrigation Plan subsidizes the modernization of the largely obsolete irrigation systems, in order to save water resources and improve the competitiveness of agricultural production. This plan has supposed an investment of 6 billion € (including the Irrigation Crash Plan).

This study presents an assessment of GHG emissions and nitrogen emission loads in the agriculture of Aragon. The study includes also recommendations on climate change adaptation and mitigation measures for the agricultural and water resources sectors in Aragon. These recommendations take into account the IPCC proposals, and the Spanish and European agricultural and water policies.

2. METHODOLOGY

The study analyzes agricultural activities in the region of Aragon. Aragon is situated in north-eastern Spain in the middle Ebro basin. Most of the land in Aragon is used in agricultural and forest activities: land cultivation, livestock production and forestry. The study includes the main crops in the region: alfalfa, corn, rice, barley and wheat among field crops and olives, vineyards, almond and peach among fruit trees, covering 90% of the total area sown.

The model used in this study maximizes social welfare from crop production activities. Several climate change adaptation and mitigation policy measures are simulated with the model to find out the economic and environmental effects of the alternative scenarios. The optimization problem is stated as:

$$\underset{X_i}{Max} \sum_{i=1}^{26} \left[c_i - \left(\nu . E_i + \mu . L_i \right) \right] . X_i$$

subject to:

1) $\sum_i X_i \leq d_{os}$

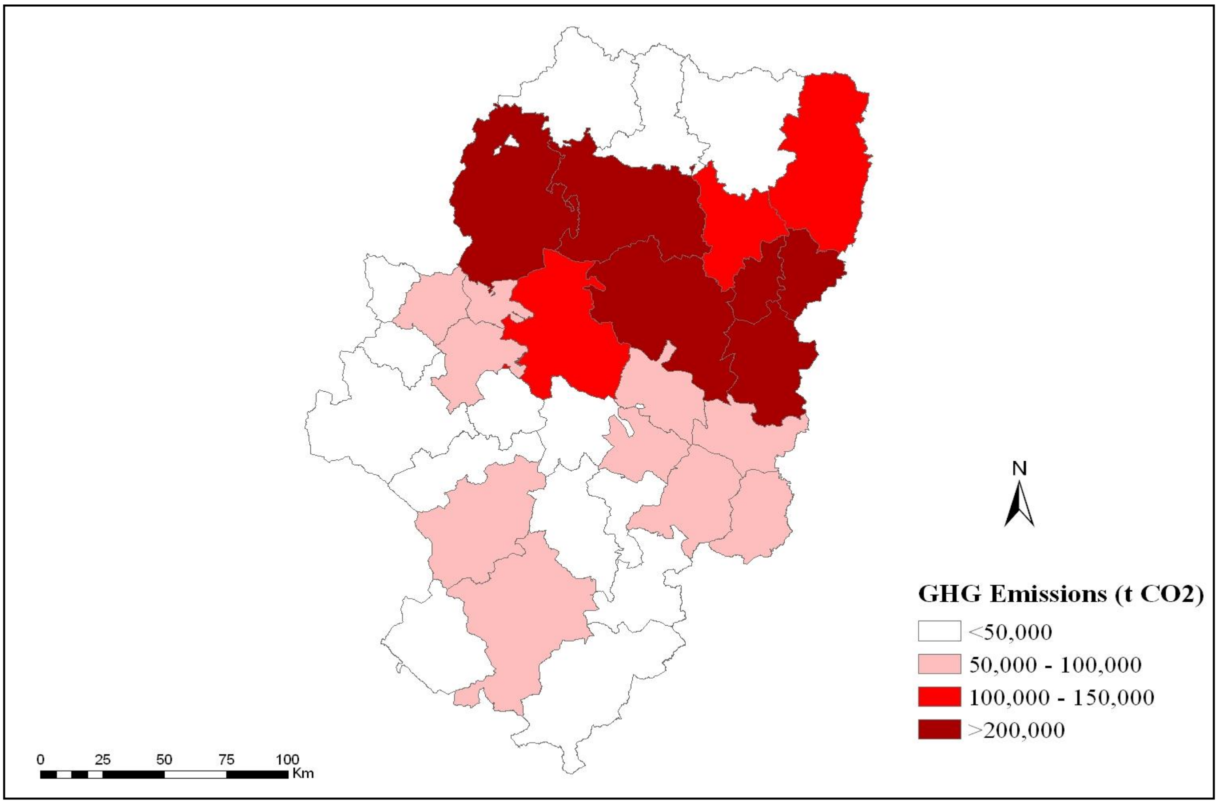
2) $\sum_{i=1}^{21} W_{mi} . X_i \leq d_{wm}$; $\sum_{i=1}^{12} d_{wm} \leq D_{wT}$

3) $\sum_{i=1}^{26} O_{mi} . X_i \leq d_{om}$; $\sum_{m=1}^{12} d_{om} \leq D_{oT}$

4) $X_i = \sum_{n=1}^{5} \alpha_n . X_{in}$; $\sum_{n=1}^{5} \alpha_n = 1$; $\alpha_n \geq 0$

$X_i \geq 0$, $i = 1,\ldots,26$

Figure 1. GHG emissions by county in Aragon (t CO_2/year).



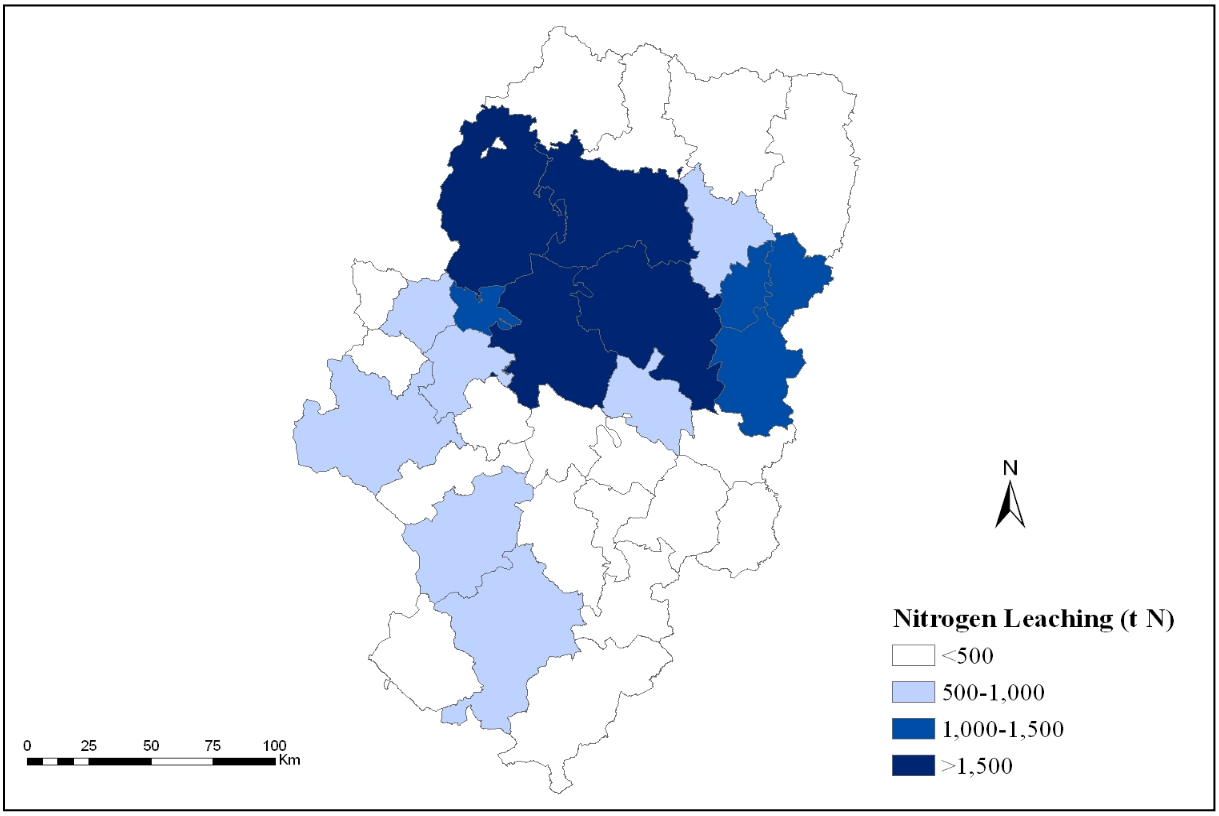
The first equation is the objective function of social welfare, which is the difference between the farmers' quasi-rent and the environmental damages. The quasi-rent is equal to the net return per hectare c multiplied by the acreage of each crop i (i=26), and the environmental damage is approximated by a linear function of GHG emissions and nitrogen emission loads, where the unit emission costs are ν and μ. Parameter ν is the cost of CO_2 emission and equals the prevailing in the European Trading Scheme (ETS) for the case of GHG emissions (ν= 22 €/t CO_2) (MARM, 2010b). Parameter μ is the cost of nitrogen emission and it is equal to the cost of removing nitrogen from water (μ= 1.3 €/kg N-NO_3^-) (Martínez and Albiac, 2006; Mema, 2006).

The land use constraints (1) represent the available acreage d_{os} of dry land and irrigated area. The water constraints (2) represent the monthly and yearly water availability, d_{wm} and D_{wT}, respectively. The coefficients W_{mi} are the monthly water requirements of each irrigated crop i (i=21). The labour constraints (3) represent the monthly and yearly labour availability, d_{om} y D_{oT}, respectively, where O_{mi} are the monthly labour requirement coefficients of each crop i (i=26).

The aggregation constraint (4) forces crop production activities X_i to fall within a convex combination of historically observed choices X_{in}. Based on decomposition and economic duality theory, Onal and McCarl (1991) show that historical crop mixes represent rational choices embodying the individual farm resource constraints, crop rotation considerations, perceived risk reactions, and a variety of natural conditions. In equation (4), the variables X_{in} are the observed crop mixes levels for the past 5 years.

The model simulations provide results on social welfare, farmers' quasi-rent, inputs use, pollution loads and acreage of crops at regional level. Several biophysical and economic data specific for each county of Aragon have been introduced in the model such as: the use of inputs water, nitrogen and labour; irrigation systems distribution; GHG and nitrogen emission loads; production costs; crops net return; and production historical data. This information has been taken from a large number of primary and secondary data sources.

Figure 2. Nitrogen emission loads by county in Aragon (t $N\text{-}NO_3^-$/year).



3. ASSESSMENT OF POLLUTANT EMISSION LOADS

The methodology used to estimate GHG emissions is a combination between methods used by the European Environmental Agency (EEA, 2006) and those used by the Intergovernmental Panel of Climate Change (IPCC, 1996a). These methods are based on the determination of emission factors per activity unit. For the nitrogen emission loads, estimation has been made using previous empirical studies conducted in the Ebro basin (Isidoro, 1999; Causapé et al., 2002; Cavero et al., 2003; Mema, 2006). Several data have been used to estimate emissions such as: emission factors; crops acreage; number of animals; use of fertilizers; Global Warming Potential (GWP); and historical European and Spanish emission data. Previous studies and opinion of experts were consulted to improve the results and minimize incertitude.

The agriculture of Aragon emits almost 3.5 million t CO_2eq of GHG, representing 15 percent of the total emissions of the region, which is above the national percentage (10%). The GHG emissions from livestock are 2.5 million t CO_2eq, including methane (CH_4) from enteric fermentation and nitrous oxide (N_2O) from manure management. The GHG emissions from crop cultivation are close to 1 million t CO_2eq, including nitrous oxide (N_2O) from crop and soil management. Nitrogen emission loads are estimated at around 23,000 t $N\text{-}NO_3^-$ from the use of fertilizers. The larger GHG emissions and nitrogen emission loads are located in the counties of Cinco Villas and Monegros, because of the large acreage of intensive irrigated crops (corn, rice, peach), and the large swine and cattle herd in these areas (Figure 1 and 2). Estimated pollution emission loads are used in the economic model as technical coefficients to evaluate the effect of several policy measures on these emissions.

Table 1. Results of alternative policy measures in Aragon.

Scenarios	Welfare (10^6 €)	Quasi-rent (10^6 €)	Nitrogen fertilization (10^3 t)	Nitrogen leaching (10^3 t)	N_2O emissions (10^3 t CO_2)	Crop acreage (10^3 ha)
Baseline	227	278	110	23	912	1,062
Emissions taxes	281	239	93	17	743	977
Fertilization standards	262	301	88	18	719	1,062
Water price: Pa=0,07 €/m^3	225	226	107	23	888	1,042
Water price: Pa=0,095 €/m^3	217	180	83	17	676	876
Irrigation modernization	238	281	93	21	773	867

4. RESULTS

The model is used to analyze the effects of various climate change mitigation and adaptation measures for the agricultural and water resources sectors in Aragon. These measures are then ranked by their cost-efficiency. The measures examined are emissions taxes, standards limiting nitrogen fertilization, higher irrigation water prices, investments in irrigation modernization, and forest management to increase carbon sequestration (Table 1, Figure 3).

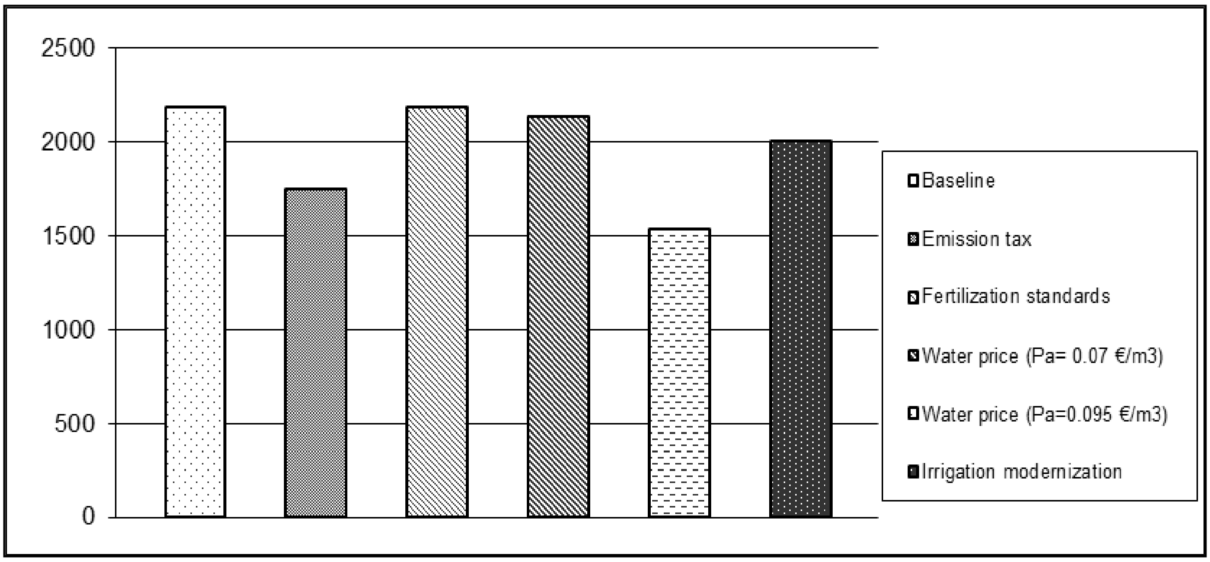
The baseline scenario approximates current conditions in the area related to land use, yields, crop and input prices, net income and costs. The price of irrigation water is 0.0475 €/m^3 and the price of nitrogen is 1.037 €/kg. Crop prices were collected from statistical data source for the period 2004-2008 (Gobierno de Aragón, 2010).

Total quasi-rent of the region is 278 million €, using 2,190 hm^3 of irrigation water and 110,000 t of nitrogen fertilizer, and generating 912,000 t CO_2eq of N_2O y 23,000 t N-NO_3^- of nitrogen emission loads. The environmental damage caused by the pollution emission is evaluated at 50 million €. The social welfare from crop production, which is the difference between farmers' quasi-rent and environmental damage, amount to 227 million €.

The first scenario considered is the first best instrument of taxing emissions, and it achieves the maximum social welfare and the optimum level of pollution. Emissions taxes represent environmental damages, and are equal to 22 €/t CO_2eq for N_2O emissions and 1.3 €/t N-NO_3^- for nitrogen emission loads. Results show that nitrogen fertilizer use is reduced to 93,000 t de N (-15%), and water use is reduced to 1,750 hm^3 (-20%). Taxes have an important effect on emissions, which decrease by 19 percent for N_2O and 26 percent for nitrogen loads. Farmers' quasi-rent decreases under the emission taxes around 14 percent. The social welfare reaches 281 million €, with an increase of 54 million € compared to the baseline scenario. This policy measure is not feasible because nonpoint pollution cannot be easily observed or controlled. However results could be used as a benchmark to compare alternative instruments.

In Aragon, there is an over-use of nitrogen fertilization between 20 and 50 percent above crop requirements (Orús et al., 2000). The second scenario introduces a limit or standard on applied nitrogen, following the Technical Information of the Government of Aragon (Orús, 2006). The advantage of this scenario is the benefits obtained, both in terms of farmer's quasi-rent and social welfare (8 and 15%, respectively). The use of nitrogen fertilizer is reduced to 88,000 t N, the abatement of N_2O is 21 percent, and the abatement of nitrogen emission loads is 22 percent. The environmental damage is evaluated at 39 million € which is below the baseline scenario.

Figure 3. Irrigation water use by alternative policy measures in Aragon (hm^3).



The third scenario considered is taxes on irrigation water, which increase irrigation water prices from 0.0475 to 0.07 and 0.095 €/m^3. The policy measure of increasing irrigation water prices is a recommendation of the Water Framework Directive. The European administration considers that setting water prices at "full recovery cost" causes a reduction of water use, improves the efficiency of using water, reduces irrigated acreage, and improves farming management following the conventional theory of supply and demand. Nevertheless, this hypothesis is questionable because irrigation water is a common-pool resource (rivalry and non-excludability) with environmental externalities. Pure economic instruments could not work with this type of resource (Ostrom, 2002). This policy measure reduces the net return of all crops, and this effect is more severe for field crops than for fruits. When the price increases to 0.07 €/m^3 (an increase of 50%), water and nitrogen fertilizer use are slightly reduced and environmental damage is constant. The major impact of the price increase is the loss of 20 percent in quasi-rent and 1 percent in social welfare (226 and 225 million €, respectively). Irrigation acreage is slightly reduced.

When water price increases to 0.095 €/m^3 (double of current price), the use of water falls to 1,544 hm^3. The use of nitrogen fertilizer decreases by 25 percent and pollution emissions are reduced by 26 percent both for N_2O and for nitrogen emission loads. This policy measure has a high cost for farmers, with a fall of 35 percent in their quasi-rent down to 180 million €. Social welfare is reduced by 5 percent to 217 million €. Irrigated acreage is strongly reduced by 31 percent compared to baseline.

Another possible alternative to improve water management and reduce irrigation environmental impacts is the investments in irrigation modernization. This scenario corresponds with a technological change in the agricultural production process. The introduction of new irrigation technologies gives rise to considerable changes in the production function and in the cost and benefit functions. There are also changes in the productivity of inputs and in their use level. New irrigation technologies improve crop yield and conversion to more profitable crops, as well as the possibility of producing more than one harvest in areas with favourable weather (Lecina et al., 2009). Investments in irrigation modernization projects are costly. Costs are composed by costs of primary and secondary distribution networks, and costs of plot irrigation systems. Mema and Albiac (2004) calculate a net annual cost of irrigation modernization equal to 190 €/ha/year. However, the current increase in energy costs causes an increase in investment costs. Lecina et al. (2009) consider an investment value of 9,000 €/ha equivalent to 300 €/ha/year as a net annual amortisation. Guardia (2010) estimates an investment of

10,000 €/ha, with 6,500 €/ha in network modernization and 3,500 €/ha in plot irrigation systems, with a net annual amortisation of 385 €/ha/year. This forces farmers to change the crop mix in order to increase income. In this study, we consider an investment cost of 300 €/ha/year. Results of the scenario show a slight reduction in water use of about 8 percent to 2,010 hm^3. Nitrogen fertilizer use falls 15 percent to 93,000 t N. Environmental effects of the irrigation modernization policy are important, with a decrease of 15 percent in N_2O emissions and 9 percent in nitrogen emission loads. Environmental damages decrease to 44 million €. This policy measure increases farmer's quasi-rent by 1 percent to 281 million €, and social welfare by 5 percent to 238 million €.

Forest area in Aragon exceeds one million and a half hectares. The largest areas are located in counties with low agricultural income and extensive agricultural production activities such as Gudar-Javalambre, Ribagorza and Sobrarbe. Forests in Aragon are already an important reserve of carbon, removing 3.4 million t CO_2eq/year from the atmosphere. Environmental benefits from carbon sequestration are evaluated at 75 million €/year (using a price of 22 €/t CO_2), these environmental services are important and surpass the market value of forest production activities.

The study by the Government of Aragon (2008) about the functionality of woody vegetation of Aragon as a carbon sink, presents simulations of carbon sequestration under several forest management options for the most important forest species in Aragon: *Pinus halepensis, Pinus sylvestris*, *Pinus nigra* and oaks of *Quercus pyrenaica* (Table 2). Results underline the importance and potential of forests in Aragon to mitigate climate change and show that carbon sinks could be further enhanced up to 700,000 t CO_2eq (+20). The value of these additional environmental benefits is 14 million €, and imply 75 hm^3 of additional water use. This is a feasible mitigation option since the watersheds where the forests are located do not present problem of water scarcity.

A ranking of these policy measures can be obtained by comparing farmers' quasi-rent and social welfare effects, emissions mitigation potential, and water use saving of each measure. The first best measure of taxing emissions increases welfare in the region up to 281 million € (+24%). Nevertheless, this measure is not reachable because it requires detailed information about individual emission loads of each plot, which has a prohibitive cost. Among the second best measures, standards limiting nitrogen fertilization improve farmers' quasi-rent (+8%) and social welfare (+15%). The main obstacle to implement quantitative limits on nitrogen fertilization is the difficulty to verify farmer compliance. The solution in order to implement standards is to give control responsibility to irrigation user associations, through the measurements of water quality in the returns of the modernized irrigation districts. At the present, there is already a network of pollution measurement stations in the main irrigation districts. Also the control can be done in vulnerable zones of polluted aquifers using the register fertilization book, which is a mechanism already implemented by the Government of Aragon following Nitrates Directive norms. But the usefulness of this fertilization book mechanism remains to be seen, because it is based on penalties on individual farmers drawn by chance, and not on measured total pollution loads coming from the whole irrigation districts. Another possible option to implement the standards is the introduction of subsidies and fees system.

A very interesting policy measure is the investments in irrigation modernization that improve social welfare by 5 percent and increase farmers' quasi-rent by 1 percent. This measure has beneficial environmental effects such as reducing pollution and environmental damages, but its financial feasibility is conditioned by the existence of public subsidies. Uku (2003) notes that the necessary investments can not be financially sustained by the additional income from higher yields of field crops, even when public subsidies from the National Irrigation Plan are accounted for. The only crops that can sustain the investments, with or without subsidies, are vegetables such as tomatoes, peppers and others. In the present study, results from the irrigation modernization scenario coincide with previous findings by Uku (2003), with the only difference that the effects of modernization on fruits are included. Results highlight that fruits can support high investments while field crops require public subsidies. Consequently, irrigation modernization may at long term induce the expansion of high-profit crops (vegetables, fruits). These crops are highly input and pollution intensive, which would further increase GHG and nitrogen emission loads and water demand.

Table 2. Carbon sequestration per specie and forest management option.

Species	Acreage (ha)	Carbon sequestration (t CO_2/ha) by scenario*				Increase
Pinus halepensis	269,848	Passive 120	Passive 60	Forest treatment 1	Forest treatment 2	70%
		74.9	45.9	77.8	74.1	
Pinus sylvestris	253,696	Very long turn 120 year		Long turn 80 year		40%
		215.4		302.4		
Pinus nigra	123,956	Observed forestry		Reference forestry		6%
		295.8		312.8		
Quercus pyrenaica	4,040	Cleaning		Conversion to high forest		60%
		67.5		107.4		

Source: Gobierno de Aragón (2008). * Detailed description of the different forest management options can be seen in the work by Kahil (2011).

Economic instruments such as taxing irrigation water are quite inefficient to abate pollution and reduce the use of water, both in terms of farmers' quasi-rent and social welfare. To achieve savings of water and abate pollution, a sharp increase in water price is needed because of the rigidity of irrigation water demand, which exacerbates farmer's losses. Albiac (2009) affirm that the price mechanism is a good instrument to curb industrial and urban water demand, but it is clearly unable to allocate water in agriculture and it is quite inefficient to abate agricultural nonpoint pollution.

From a pollution mitigation perspective, measures such as standards limiting nitrogen fertilization and very high irrigation water prices reduce pollution loads. Forest management to increase carbon sequestration is a good alternative for mitigation, but uses relatively important quantities of water, which are equivalent to the urban and industrial water use of the city of Zaragoza (about 75 hm^3).

From a water use saving perspective, an irrigation water tax could save water with large increase in prices, with heavy losses for farmers. Otherwise, updating irrigation technologies does not necessarily save water, due to the increase of water-intensive crops such as alfalfa, apple, pear and peach. In this respect, one solution is to control water allocation and illegal water withdrawals to limit the expansion of input-intensive crops or double crops. Another solution is to reduce water allowance to the modernized district.

5. CONCLUSIONS AND RECOMMENDATIONS

Climate change is an important environmental threat to human society. The scientific studies indicate that the impacts on humans and ecosystems would be especially severe in some regions. Projections in the Mediterranean basin over the next 100 years point to a large fall in water resources close to 40 percent, a reduction of water availability per person of 70 percent, and a degradation of water quality (IPCC, 1996b). Agriculture would be the most affected sector from this environmental threat, because of its dependency from climate. Also, agriculture is a key sector in the design of climate change policies, because it has a twofold influence on climate change as a source of GHG emissions and as a carbon sink.

In Aragon, agricultural and forest activities cover 90 percent of the territory. These activities are generating a large amount of GHG emissions, and one contribution of this study is the evaluation of the GHG emissions from the agricultural sector in Aragon. The GHG emissions exceed three million t CO_2eq, which is above 15 percent of the total emissions in the region. Crop cultivation emits around 1 million t CO_2eq of N_2O and 23,000 t N-NO_3^- of nitrogen emission loads, from the use of fertilizers.

The results of the study indicate that standards limiting nitrogen fertilization and investments in irrigation modernization are the preferred second best policy measures. These measures guarantee pollution abatement and improve both farmers' quasi-rent and social welfare. However, these measures have certain technical and financial obstacles such as difficulties in the implementation of quantitative limits, problem to finance the irrigation modernization projects, and high transaction cost of measures. These shortcomings can be overcome through public and stakeholders intervention that will be a key driver of future farmers' decisions to address climate change.

An important issue for water policy is the efficiency of economic instruments to reduce water scarcity and abate pollution. In this respect, results show that water pricing is an inefficient solution that generates substantial losses both in terms of social welfare and farmers' quasi rent. Water pricing also creates incentives for illegal activities such as groundwater extraction through individual wells, caused by the adoption of new pumping technologies with costs below the water price. An adequate management of water resources in the agricultural sector can only be brought about by cooperation of stakeholders through the right institutional setting.

Aragon forests play an important role in the mitigation of GHG emissions in the region. Nevertheless, further analyses are needed to determine the effects of forest management to increase carbon sequestration over the water balances in watersheds. However, carbon sequestration by forest management could not be a good measure in watersheds with acute water scarcity.

The design and ranking of climate change mitigation and adaptation measures in the agricultural and water resources sectors is a complex task. It requires generating reliable biophysical and economic information about structural and physical characteristics of farms, agronomic practices, and production technologies. Also, it is essential to have detailed information about pollution processes, environmental damages of pollutant loads, and costs of environmental damages, as well as on the dynamics of nutrients in soil. Another important aspect to consider for the choice of the correct climate change policies is the implementation costs of instruments. Policies that seem suitable may be linked to implementation difficulties related to their political acceptability or transaction costs, and policy makers should evaluate the trade-off between cost efficiency and simplicity of implementation.

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