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The cost of emission mitigation by legume crops in French agriculture

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ABSTRACT

This paper considers the cost of greenhouse gas mitigation potential of legume crops in French arable systems. We construct marginal abatement cost curves to represent this mitigation or abatement potential for each department of France and provide a spatial representation of its extent. Despite some uncertainty, the measure appears to offer a significant low cost mitigation potential. We estimate that the measure could abate half of the emission reduction sought by a national plan for the reduction of chemical fertilizer emissions by 2020. This would be achieved at a loss of farmland profit of 1.2%. Considering the geographical heterogeneity of cost, we suggest that a policy implementing carbon pricing in agriculture would be more efficient than a uniform regulatory requirement for including the crop in arable systems.

1. Introduction

Agriculture accounts for a significant proportion of total greenhouse gas (GHG) emissions both in France and at the European level. In 2011, European Union agriculture accounted for 461 million tCO_2eq, while in France the amount was 92.5 million tCO_2eq (respectively 10.8 and 20.6% of European and French GHG emissions including land use, land use change and forestry according to UNFCCC National Inventory Report, 2013)[1]. A recent European Commission communication (European Commission, 2014) on the policy framework for climate and energy indicated that emissions from sectors outside the EU Emission Trading Scheme (EU-ETS) would need to be cut by 30% below the 2005 level by 2030. At the same time, within the framework of the 'energy-climate' package France has committed to reduce emissions of its sectors not covered by the EU-ETS by 14% by 2020 compared to 2005 emission levels (European Union, 2009).

Given these ambitions, there is increasing scrutiny of the mitigation measures and specifically their cost relative to other option available within agriculture and in other sectors. This paper considers the abatement of emissions from crop fertilization, which represents a major source of emissions from French agriculture (a fifth of French agricultural emissions[2]). This comprises emissions of nitrous oxide mainly emitted during the process of denitrification of nitrogenous fertilizers spread on arable land. The paper assesses the overall abatement potential of a key measure, the introduction of leguminous crops, and the associated costs and co-benefits in farm systems.

Legumes (fabaceae), commonly known in France as alfalfa, pea, or bean family, have the ability to naturally fix atmospheric nitrogen and can reduce N_2O emissions compared with conventional crops (maize, wheat, barley, oilseed, rape). This function is conferred by rhizobium bacteria that live in symbiosis at the level of their roots in little organs called nodules. As a consequence, they need far less fertilizer thanks to the fixing effect allowing nitrogen to stay in the ground for up to two years after planting. This contributes additional amounts of nitrogen to subsequent crop in rotations. Studying alternative crop emissions, Jeuffroy et al. (2013) demonstrated that legume crops emit around five to seven times less GHG per unit area compared with other crops. Measuring N_2O fluxes from different crops they show that peas emitted 69 kgN_2O/ha; far less than winter wheat (368 kgN_2O/ha) and rape emissions (534.3 kgN_2O/ha). Moreover, compared to the emissions from cattle meat production, human consumption of peas instead of meat leads to 85 to 210 times less N_2O emissions for the same content of protein ingested.[3] Despite this mitigation benefit, N-fixing crops have low agronomic performance (see Appendix A) and consequently their

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[1] United Nations Framework Convention on Climate Change.

[2] Calculated by dividing the 20.29 $MtCO_2eq$ emissions from crops (see Appendix A) by the 94.3 $MtCO_2eq$ French agricultural emissions (CITEPA, 2012).

[3] 20–37 gN_2O/kg protein for meat and 0.17–0.23 gN_2O/kg protein for peas. The amount of emissions for meat is obtained using the N_2O content from feed fertilization and manure management included in cattle meat from Dolle et al. (2011) of 3026 $kgCO_2eq$ and 1615 $kgCO_2eq$ per kg of meat. The amount of emissions for pea is obtained using the yield of 25–34 q/ha from Agreste data. The protein content of meat (27.6 g/100 g) and peas (8.8 g/100 g) required for the calculation is from Ciqual (2012).

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introduction in arable systems will, in most regions, incur a penalty in terms of farm revenue.

Recent research (Pellerin et al., 2013) has suggested the cost of GHG mitigation via grain legumes at around 19 euros/tCO_2eq. This paper scrutinizes this assessment by proposing three improvements: (1) determining the spatial variation of cost across French Departments; (2) studying how cost varies according to reduction targets; and (3) analyzing the sensitivity of the abatement cost with respect to agricultural seed prices and farmers' ability to exploit low abatement cost.

Here, abatement cost assessment is linked to the substitution of other arable crops by legume crops in farmlands simulating two consecutive years, so as to integrate the fixing effect of the preceding period. This methodology allows the derivation of a marginal abatement cost curve for each French metropolitan geographical area.[4] The results are then subject to a sensitivity analysis to examine growers' responses to low cost abatement, crop prices and agricultural input prices.

The paper is structured as follows. The next section presents the context of N-fixing crop cultivation in France and in Europe and Section 3 analyzes abatement cost assessment in the scientific literature. Section 4 describes the methodology. Section 5 analyzes the results and compares them with the previous INRA (National Institute of Agronomic Research) study (Pellerin et al., 2013). Finally, a discussion considers the policy relevance of carbon pricing to promote N-fixing crops.

2. Context

Despite their beneficial properties, the area planted to legumes in France has been on a steady downward trend. For fodder legumes the fall started in the 1960s from a high of 17% of the French arable land. The area then decreased steadily, reaching 2% in 2010 (Duc et al., 2010). For grain legumes, the fall began later at the end of the 1980s after years of political effort to develop them through the common agricultural policy (CAP) (Cavaillès, 2009).

This decline is due to several factors. First an increasingly meat-based diet incorporating less vegetable proteins led to lower consumption of legumes by humans. The General Commission for Sustainable Development reports that in France between 1920 and 1985 human seed legume consumption fell from 7.3 kg/person/year to 1.4 kg/person/year (Cavaillès, 2009). This trend coincided with a change in livestock feeding regimes, with legume-based rations being increasingly replaced by maize silage, grass plants and imported soybean meal. The loss of agricultural nitrogen due to this switch in farmlands was compensated by chemical fertilizers, which had become increasingly price-competitive since the 1960s. Simultaneously, trade agreements on the abolition of custom tariffs between Europe and the United States favored American soybean imports. Finally, a lack of agronomic research dedicated to legumes compared with common crops, led to a relative decrease of their agronomic performance (Cavaillès, 2009).

In France, as in the rest of the European Union (EU) these factors have led to a strong dependency on soya imported from America to feed livestock. In 2009, soya was the largest food commodity imported into the EU (12.5 million tons) ahead of palm oil and bananas (FAO[5]). These imports come mainly from South America (49% from Brazil and 31% from Argentina (European Commission, 2011)) and at a significant cost: the average annual trade balance, calculated over the period 2004–2008, represented a loss equivalent to 1 billion euros (Cavaillès, 2009) for France and up to 10.9 billion euros for the EU. It follows that increasing legume areas in French agriculture can both mitigate GHG emissions and limit dependency on feed imports. This is all the more so given the trend of increasing chemical fertilizer prices. In 2010, the price of fertilizers and soil conditioners spread on farmland in France was some 65% higher than 1990, this increase being largely related to higher global energy prices. Thus, the increasing scarcity of fossil fuels provides another reason to explore the potential development of legume crops.

3. Cost-effectiveness Analysis in the Literature

For cost-effectiveness analysis Vermont and De Cara (2010) identify three broad approaches for the derivation of marginal abatement cost curves (MACCs), the device typically used to evaluate pollution abatement costs and benefits. These are: i) a bottom-up or engineering approach; ii) an economic approach consisting of modeling the economic optimization of a set of (in this case) farm operations; and iii) a partial or general equilibrium approach that extends and relaxes some of the assumptions about wider price effects induced by mitigation activity.

The engineering approach focuses on the potential emission reduction of individual measures and observes their cumulated abatement and associated costs. The required data to appraise abatement costs are ideally collected from measures applied on test farms, thereby reducing some uncertainty the estimated cost and mitigation potential for each mitigation measure. It is normally the case that more measures are assessed using the engineering approach relative to the economic approach (MacLeod et al., 2010; Moran et al., 2010; Pellerin et al., 2013).

The economic approach consists of modeling the economic optimization of a set of farm operations located within a given geographical scale. The objective function is typically to maximize profit of these farms under given constraints such as available arable land or even lay fallow land as imposed by agricultural policies. The introduction of a carbon tax as a new constraint allows the model to reconfigure farm activities to accommodate the necessary GHG emission reductions. The resulting loss in profit (opportunity cost) and GHG reduction provide the relevant abatement cost information.

Equilibrium models relax some of the cost assumptions made in the economic approach and include a description of the demand for agricultural products thereby allowing a price feedback into the cost of mitigation (Vermont and De Cara, 2014). Their level of spatial disaggregation is generally lower than that of bottom-up models and their geographic scope and coverage are generally wider. This approach has been used to assess abatement cost at the level of the USA (Schneider and McCarl, 2006; Schneider et al., 2007; MacCarl and Schneider, 2001).

A noteworthy difference between the approaches is the frequent observation of negative cost options in the engineer approach for some options (Moran et al., 2010; MacKinsey and Company, 2009). These are obviated in any optimization approach and are in any case questioned by some authors. Kesicki and Ekins (2012) for example suggest that they more likely imply a failure to assess some hidden costs (diffusion of the information, administration barriers) than any real opportunity to reduce emissions while increasing farm gross margins. Another observation is that each mitigation measure in the engineering approach is associated with a constant marginal cost — creating a stepwise marginal abatement curve (each step corresponding to an option). This observation suggests that the economic potential per ton CO_2 equivalent mitigation is the same for each specific option irrespective of spatial scale or in terms of the overall volume of emission reduction, which would seem unlikely. Indeed, due to regional variability in soils, farm systems, climate and yields, abatement cost would also vary for any individual mitigation measure.

Results from studies employing the economic approach are depicted by continuously increasing abatement cost curves, with no negative cost. An advantage of these studies is optimization of fewer mitigation measures over a large number of farm types. For example De Cara and Jayet (2011) modeled around 1300 EU farms optimizing animal feed, a reduction in livestock numbers, a reduction of fertilization and the conversion of croplands to grasslands or forests.

Legumes have been specifically assessed in a UK study constructing a national MACC for agricultural GHG emissions (Moran et al., 2010). The marginal abatement cost obtained for legume crops appears constant

[4] Each geographical area corresponds to a department. In the administrative divisions of France, the department (French: département) is one of the three levels of government below the national level. It is situated between the region and the commune.

[5] http://faostat.fao.org/.