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Impacts of agricultural land use changes on pesticide use in French agriculture

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ABSTRACT

Public policies seeking to regulate pesticide use must be based on a clear identification of the factors influencing such use. Since the agricultural use of pesticides is primarily crop-dependent, agricultural land use change is potentially an important driver of the overall level of pesticide use in a given country. In this paper, we investigate the influence of agricultural land use changes on pesticide use in French agriculture over the period 1989–2013, during which important changes in the Common Agricultural Policy took place. Toward that end, we developed a method allowing the direct effects of agricultural land use changes to be disentangled from other factors affecting the intensity of pesticide use. On the basis of standard protection programs defined by crop protection experts, a fixed pesticide use intensity is estimated for 19 annual and perennial crops representing 90% of French arable land area and the bulk of pesticide use in French agriculture. These coefficients, combined with national agricultural land use statistics, are used to construct an artificial index of pesticide use in France whose variations depend solely on changes in agricultural land use. This index is calculated over the period 1989–2013. Our results indicate that the direct impacts of agricultural land use changes on pesticide use in France have varied depending on the time period considered, reflecting the influence of public regulations, notably the compulsory set-aside policy in force during the 1990s, and market conditions, particularly the context of high prices for cereal grains at the end of the 2000s. Over the six years from 2008 to 2013, this index is roughly constant, indicating that the 17% increase in French pesticide use in 2013 compared to 2008 (as assessed from annual pesticide sales) cannot be even partially attributed to agricultural land use changes. Since 2000, land use changes mainly corresponded to substitutions between crops with similar per-hectare pesticide use intensities, and/or to substitutions with counterbalancing impacts on these intensities. A prospective approach shows that other types of land use changes (*e.g.* a massive conversion of grassland to arable land or, conversely, a strong diversification of arable crop rotations), could have much higher impacts on pesticide use, with the effect of either offsetting or reinforcing efforts to reduce pesticide use intensity in arable crops. Thus, better coordination is needed between public policies aimed at regulating pesticide use and public policies influencing land use.

1. Introduction

Sustainable use of plant protection products in agriculture requires public regulation to balance the multiple and ambivalent effects of pesticides on crop productivity, the environment, and human health (Colborn and Short, 1999; Popp et al., 2013). For many decades, such regulations have gradually expanded in countries such as those of Western Europe, where agricultural systems rely on an intensive use of chemical inputs. The European Union (EU) has developed a regulatory framework based on common procedures for the assessment of plant protection products and their active ingredients prior to market authorization (Official journal of the EU, 2009; Jess et al., 2014). A second important objective is the promotion of a sustainable use of authorized products,

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combining a wide range of actions: farmers' education and training, support for research and innovation, economic incentives such as support to organic farming, crop insurance, agricultural product labelling, *etc.* (Praneetvatakul et al., 2013; Lefebvre et al., 2015). To fulfil these aims, European countries adopted a wide variety of official programs that have been revised over the years (Barzman and Dachbrodt-Saaydeh, 2011; Pedersen et al., 2012). In order to coordinate these national strategies, European Directive 2009/128 (Official journal of the EU, 2009) specifies a common framework based on the concept of Integrated Pest Management (IPM) and according to which all EU Member States have to define national action plans (Baur et al., 2011; Barzman et al., 2015). In France, one of the largest users of pesticides worldwide (Zhang et al., 2011) and the second most pesticide-consuming country in Europe after Spain (Eurostat, 2015), an ambitious plan was launched in 2008 that aimed to reduce pesticide use by 50% within 10 years (Ecophyto Plan, 2008). Recently, this plan has been revised, with the deadline for a 50% reduction postponed to 2025, because observed pesticide use was not decreasing as expected (Ecophyto Plan 2, 2016).

National strategies for promoting a sustainable use of pesticides will be effective only if they are based on a clear understanding of the main factors driving agricultural pesticide use and how those factors change over time. Elementary decisions concerning pesticide applications are made by farmers according to the plant health status of a given field. At the field or farm scale, the nature and amount of pesticides used are primarily crop-dependent, since each crop or vegetative cover faces a specific complex of associated pests: some crops do not require any pesticide application, while others receive dozens of applications per year (Ewald and Aebischer, 1999; Sattler et al., 2007; Andert et al., 2015). For a given crop, pesticide use intensity also fluctuates according to spatial and temporal changes in pest populations, which in turn depend on climatic or other environmental factors, and on the cropping systems and in particular the crop rotations within which the crop is included (Karlen et al., 1994; Meynard et al., 2003; Deike et al., 2008; Nemecek et al., 2008; Bürger et al., 2012). When the frequency of a given crop increases in time and in space, this favours the development of associated pests and will tend to increase the intensity of pesticide use for that crop (Rusch et al., 2010; Ratnadass et al., 2012). Lastly, pesticide use intensity also fluctuates because of the great diversity of farmers' behaviour when faced with a given epidemiological context (Feinerman et al., 1992; Wilson and Tisdell, 2001; Aubertot et al., 2006; Lagerkvist et al., 2012; Nave et al., 2013). When upscaling this analysis to the regional or national level, two main groups of factors can be distinguished to explain total pesticide use and changes in total pesticide use over time: i) the spatial extent of the different types of land use, and ii) the local intensity of pesticide use on the corresponding land covers. Subsequently, changes in pesticide use over time can result both from the direct impact of land use changes (*i.e.* from the substitution of crops receiving contrasting levels of pesticides per hectare) and from changes in pesticide use intensity (*i.e.* from an increase or reduction in application rates per hectare for a given crop), again resulting from both land use changes and the epidemiological effects of crop frequencies. When considering pesticide use regulation, disentangling these two groups of factors is a useful exercise, since the economic drivers and regulatory measures influencing land use and crop management are not the same. Depending on the circumstances, the impacts of land use and crop management changes on pesticide use may either converge or diverge, making changes in pesticide use over time difficult to interpret at a national scale. Analysing agricultural land use changes over time and assessing the direct impact of these changes on pesticide use is thus an initial and essential step in identifying the actual drivers of pesticide use at the national level.

The aim of this paper is to develop such an analysis for agriculture in France, which offers a useful case study since the crops grown in France are highly diverse and correspond to a wide range of pesticide use intensities. The approach consists in building an artificial index of pesticide use at the national level, one in which variations over time depend solely on land use changes. The purpose of this index is not to provide an accurate description of overall pesticide use variations over time, but to reveal the underlying portion of these variations which results directly from changes in land use. This index of artificial pesticide use is calculated each year for the period 1989–2013, during which different types of land use changes occurred in connection with changes in the political and socio-economic context. In particular, the European Common Agricultural Policy (CAP) was substantially revised in 1992, and again in 1999, 2003 and 2009. In addition to this historical analysis, a prospective approach is outlined by comparing the values of the index associated with three contrasting land use scenarios corresponding to different options of agri-environmental policy. Lastly, a focussed analysis is made of the 2009–2013 period, corresponding to the five first years of implementation of the Ecophyto Plan. For this period, an official indicator of pesticide consumption, defined on the basis of annual pesticide sales, is available. Comparing variations over time of this indicator and our index allows us to evaluate to what extent land use changes worked against, or on the contrary reinforced, the general objective of the Ecophyto Plan. This opportunity to compare simulated and observed data is another reason France makes an interesting case study.

2. Material and methods

2.1. Analytical framework

2.1.1. Total pesticide use in French agriculture: the NODU indicator

A new official framework for monitoring overall pesticide use in France was established in 2008 in connection with the Ecophyto Plan. A public database of pesticide sales was created and a new official indicator was adopted, the *NODU*, or number of unit doses (Ministry of Agriculture, 2015). The *NODU* indicator (or $NODU_t$ where t represents the year) was developed to complement the *QSA*, or quantities of active substances indicator (QSA_t), representing the total gross weight of all active substances sold during year t. Within the DPSIR classification (Drivers—Pressures—State—Impact—Responses) (Smeets and Weterings, 1999), pesticide use indicators correspond to the "Drivers" class of indicators, and as such are not intended to provide a direct assessment of the pollution caused by pesticide use (represented by the "Pressures" class of indicators). The relevance of pesticide use indicators nevertheless depends on the possibility of relating them to the impacts of pesticide use.

The *QSA* indicator is easy to understand and calculate. It does not distinguish between active substances with different effective doses, however, and as a result tends to overestimate the reduction in pesticide use resulting from the replacement of ponderous active substances by more effective ones, *i.e.*, those that are effective at lower use rates. The *NODU* indicator was constructed to overcome this limitation by expressing the quantity of pesticides sold annually in France in terms of the number of standardized unit doses applied (Ministry of Agriculture, 2015). To arrive at this value, the total quantity of each active substance i sold during year t ($QSA_{i,t}$) is divided by a reference unit dose ($DUSA_i$) that is specific to each active substance and does not vary with time. $NODU_t$ is then calculated by adding up these ratios for all active substances:

$$NODUt = \sum i(QSA_{i,t}/\mathrm{DUSA_i}) \quad (1)$$