Land sharing versus land sparing to protect water from pesticide pollution?

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Very preliminary version

Summary: In this paper, we investigate the concept of land sharing and land sparing strategies in the context of water pollution by pesticides. A land planner willing to reduce the risk of transfer of pesticides to neighbouring water bodies may either induce the adoption of integrated pest management practices by farmers through the use of incentives, the land sharing strategy, or take agricultural land out of production by purchasing it, the land sparing strategy. We propose an ex-ante assessment framework to help choosing between the sharing and sparing strategies at a water catchment level, to achieve water quality goals with respect to pesticide pollution. After proposing a theoretical model of parcel selection, we develop an empirical procedure on the Seine-Ource river catchment in Burgundy, France. We confirm that the targeting criterion based on the maximization of environmental gains under an economic cost constraint provides higher environmental gains than the other targeting criteria, where the land planner maximizes the surface selected under a budget constraint or the total environmental gains under a surface constraint, both for the land sharing strategy and for the land sparing strategy. We show that a combination of both strategies maximizes environmental gains, a conclusion that allows moving forward in the land sharing/sparing debate.

Keywords: water pollution, pesticides, integrated pest management, site selection

JEL classification codes: Q18, Q24, Q25, Q51

Introduction

The world agricultural production has increased considerably over the last decades thanks to technological innovations and to the increasing use of inputs, in particular of pesticides. However, the massive use of pesticides has many negative effects on the environment (see Pimentel *et al.,* 1992 for more details), a major one being the pollution of water bodies (see Ongley, 1996, for more details). This assessment is particularly true in Europe where public policies, such as the European Water Framework Directive or the Directive 2009/128/EC on sustainable use of pesticides, aim at reducing water pollution by pesticides. To achieve the water quality goals defined in the European legislation, European local decision makers can implement two main strategies: a land sharing one or a land sparing one.

These strategies were originally defined in the case of biodiversity conservation (Green et al, 2005), opposing wildlife-friendly farming that would improve wild population on farmland at the expense of decreasing agricultural yields, and land sparing that would reduce demand for farmland through an increase in yields. However these concepts also prove relevant to analyse water pollution, since for instance Hascic and Wu (2006) show that land uses significantly affect the level of water pollution in a water catchment. Applied to the case of water pollution by pesticides, the land sharing strategy would consist in implementing economic instruments such as taxes or subsidies to guide farmers toward sustainable pest management strategies (see for instance Sexton *et al.*, 2007 for more details), while the land sparing strategy would consist in purchasing and excluding from agricultural production the lands with the highest risk of pesticide contamination. One question of interest is then to assess the best strategy to implement. The answer is not straightforward and depends on the case considered. In the water pollution case, the most relevant scale of analysis is the water catchment level (see Coiner *et al.*, 2001). Langpap *et al.* (2008) provide an *ex post* analysis of the best land use policies with respect to the protection of water catchment ecosystems. We propose in this work to develop an *ex ante* method that helps in choosing between a land sharing and a land sparing strategy, at a water catchment level, to achieve water quality goals with respect to pesticide pollution.

The literature on reserve site selection, mainly based on conservation biology, is very helpful in defining an *ex ante* land sparing strategy. For instance, Margules *et al.* (1988) produce a method to select land to preserve that consists in maximizing biological biodiversity. Extensions of this work propose to switch from a maximization of the number of species preserved only to a strategy that also considers the cost of land purchase. For instance, Ando *et al.* (1998) compare both methods and show that the hierarchy of lands to preserve can be very different between methods. The first contribution of our work consists in adapting this literature to the problem of water pollution by pesticides. To do so, we need to measure the economic costs and the environmental gains linked to the purchase of land for conservation purpose. Concerning the economic cost of land purchase, we follow Newburn *et al.* (2006) by implementing the first stage of the hedonic method (see Palmquist, 2005, for more details on the method and Bastian *et al.* 2002 for an application next to ours because of being based on geographic information system). Indeed, this measurement is a good approximation of the opportunity cost of putting land into reserve. The environmental gains from land sparing are measured by the risk of pesticide contamination before purchase, since the after-purchase land use, the reserve, is assumed to bear a zero risk of pesticides contamination. Babcock *et al.* (1996) measure the environmental gains linked to surface water quality in a land sharing case with the distance of land from water bodies. Babcock *et al.* (1997) measure environmental gains linked to groundwater vulnerability to pesticide leaching with an index provided by Kellogg *et al.* (1992) that is a function of soil leaching potential, pesticide leaching potential, precipitation and chemical use. We implement a cumulated I-Pest indicator that measures the risk associated with pesticide application (see van der Werf and Zimmer, 1998, for more details on the method) at the plot level.

In the land sharing strategy, both environmental gains and economic costs are more difficult to compute at a water catchment level. There is a wide literature about the land sharing strategy applied to the biodiversity conservation problem, particularly within the framework of the American Conservation Reserve Program (see for instance Wu and Boggess, 1999). Indeed, this framework provides bids made by farmers as a measurement of economic costs. Such datasets do not exist in the European case. Following Coiner *et al.* (2001), we focus on a specific French water catchment. The costs of the land sharing strategy are valued with field surveys related to farms accounting data. The surveys also allow us to investigate an original land sharing strategy: Integrated Pest Management (IPM). This is our second main contribution. Stern *et al.* (1959) first developed the IPM concept. It is a multidisciplinary concept that promotes physical and biological regulation strategies to control pests while reducing the reliance on pesticides. Lechenet *et al.* (2014) show that it can theoretically be an efficient tool for reducing pesticide use at the least cost in French arable farming. Boussemart et al. (2011) show that less pesticide use per ha may be preferable for producers to reduce their costs. Wilson and Tisdell (2001) examine why farmers continue to use pesticides despite the increasing costs; in particular, they emphasize a 'lock-in' phenomenon in pesticides use. To solve this difficulty, Jacquet *et al.* (2011) shows that fiscal schemes can be helpful in the French case. It is why we decided to focus on farm accounting data to value the economic cost of the land sharing strategy.

Once we have computed the environmental gains and economic costs of land sharing and land sparing strategies, we follow Babcock *et al.* (1996) and implement three alternative targeting criteria for both: the maximization of the size under an economic cost constraint, the maximization of environmental gains under a size constraint and the maximization of environmental gains under an economic cost constraint. We confirm that, for a given budget, the targeting criterion based on the maximization of environmental gains under an economic cost constraint provides higher environmental gains than the other targeting criteria, both for the land sparing strategy and for the land sparing strategy.

Finally, following the literature on land sharing and land sparing relative to biodiversity conservation (see Fisher *et al.*, 2014, for more details), we propose to compare both strategies. We show that a combination of both strategies maximizes environmental gains, a conclusion that allows moving forward in the land sparing/sharing debate. This is our third contribution.

Section 1 presents our theoretical framework. Our empirical strategy is detailed in section 2. Finally, the results are presented and discussed in section 3. Section 4 provides some concluding remarks.

1. Theoretical framework

We analyse the situation where a planner responsible for the water policy intervenes on the agricultural land market, which consists of I fields. Let $1 \leq i \leq I$ be an indicator for each individual field of size s_i. In the land sharing case, we assume that each unit of land can generate either net returns $c_{h,i}$ or environmental gains $b_{h,i}$. In the land sparing case, the net returns are denoted $c_{p,i}$ and the environmental gains $b_{p,i}$. $c_{p,i}$ can be interpreted as the opportunity cost of agricultural production which we take to be the minimum amount that the planner has to spend in order to take this land out of production. $c_{h,i}$ is the minimum amount the planner has to bid in order to make farmers move toward IPM. The environmental gain is in terms of pesticide pollution avoided in water bodies.

We are going to assume three types of land planning behaviours usable for the land sharing strategy, for the land sparing one and for the strategy consisting in mixing both:

- The first assumption A1 is one of a land planner who only has an economic objective in mind: the planner only considers the cost of the strategy and aims at maximizing the size of land on which to intervene under an economic cost constraint. In this case, the amount of money spent cannot be higher than the budget B.
- The second assumption A2 is one of a land planner who only has an environmental objective in mind. The planner only considers the environmental gains of the strategy that he aims at maximizing. Without a constraint, such a strategy would result in intervening on the whole land under the jurisdiction of the planner. This would induce a problem of social acceptability that can be considered by adding a size constraint to the optimization of environmental gains. In this case, the size of land on which the land planner intervenes cannot be higher than the area A that is assumed lower than the total area under the jurisdiction of the land planner.
- The third assumption A3 is one of a land planner who has both environmental and economic objectives in mind: the planner maximizes the environmental gains under an economic cost constraint.

1.1 Land sharing and land sparing strategies separately

Let $x_{h,i}$ denote the amount of unit i subsidized by the land planner for the agricultural conversion to IPM and $x_{p,i}$ the amount of unit i purchased by the land planner for its water quality amenities. Obviously $x_{h,i}$ and $x_{p,i} \leq l_i$. We propose to detail the three types of behaviours (A1 to A3) in the land sharing case (A1h to A3h) but one can simply change notations to obtain the land sparing case –h becomes p.

In A1h case, the optimization problem is:

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \mathrm{B} \text{ and } x_{h,i} \leq s_i$$

Let λ_1 be the shadow price of the budget constraint and $\mu_{1,i}$ be the shadow price of the ith unit's production capacity. The Lagrangian function for this problem is:

$$L = \sum_{i=1}^{I} x_{h,i} + \lambda_1 . \left(B - \sum_{i=1}^{I} x_{h,i}.c_{h,i} \right) + \sum_{i=1}^{I} \mu_{1,i}.\left(s_i - x_{h,i} \right)$$

Let the values of the optimal solution be given by $x_{h,i}^{*}$, the Kuhn-Tucker conditions of the problem are:

$$\begin{cases} B-\sum_{i=1}^{I} x_{h,i}^{*}.c_{h,i} \geq 0, \lambda_1 \geq 0, \lambda_1.\left(B-\sum_{i=1}^{I} x_{h,i}^{*}.c_{h,i}\right)=0 \\ s_i - x_{h,i}^{*} \geq 0, \mu_{1,i} \geq 0, \mu_{1,i}.\left(s_i - x_{h,i}^{*}\right)=0, i=1,...,I \\ 1-\lambda_1.c_{h,i}-\mu_{1,i} \leq 0, x_{h,i}^{*} \geq 0, x_{h,i}^{*}.\left(1-\lambda_1.c_{h,i}-\mu_{1,i}\right)=0, i=1,...,I \end{cases} \quad \text{A1h}$$

This system of equations implies that:

$x_{h,i}^{*}=\left\{\begin{matrix} s_i \text{ if } 1/c_{h,i} > \lambda_1^{*} \\ 0 \text{ if } 1/c_{h,i} < \lambda_1^{*} \\ x_{h,i}^{\lambda_1} \text{ if } 1/c_{h,i} = \lambda_1^{*} \end{matrix}\right\}$ where λ_1^{*} denotes the optimal shadow value of the increase in the area converted to IPM associated with an increase in the budget constraint. Units of land with the inverse of conversion cost greater than λ_1^{*} will be converted, while units with strictly lower ratios will stay in production.

In A2h case, the optimization problem is:

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i} \leq \text{A and } x_{h,i} \leq s_i$$

Let the values of the optimal solution be given by $x_{h,i}^{**}$ and ϕ_2^{**} for the optimal shadow price of the size constraint. We deduce from the new Lagrangian function and from the Kuhn-Tucker conditions applied to this function that:

$x_{h,i}^{**}=\left\{\begin{matrix} s_i \text{ if } b_{h,i} > \phi_2^{**} \\ 0 \text{ if } b_{h,i} < \phi_2^{**} \\ x_{h,i}^{\phi_2} \text{ if } b_{h,i} = \phi_2^{**} \end{matrix}\right\}$ where ϕ_2^{**} denotes the optimal shadow value of the increase in environmental amenity associated with an increase in the size constraint. Units of land with environmental gains greater than ϕ_2^{**} will be converted, while units with strictly lower environmental gains will stay in production.

In A3h case, the optimization problem is:

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \text{B and } x_{h,i} \leq s_i$$

Let the values of the optimal solution be given by $x_{h,i}^{***}$ and λ_3^{***} for the optimal shadow price of the budget constraint. We deduce from the new Lagrangian function and from the Kuhn-Tucker conditions applied to this function that:

$$x_{h,i}^{***} = \begin{cases} s_i \text{ if } b_{h,i}/c_{h,i} > \lambda_3^{***} \\ 0 \text{ if } b_{h,i}/c_{h,i} < \lambda_3^{***} \\ x_{h,i}^{\lambda_3} \text{ if } b_{h,i}/c_{h,i} = \lambda_3^{***} \end{cases}$$

where λ_3^{***} denotes the optimal shadow value of the increase in the environmental amenity associated with an increase in the budget constraint. Units of land with ratios of environmental gains to costs of conversion greater than λ_3^{***} will be converted, while units with strictly lower ratios will stay in production.

1.2 Combination of land sharing and land sparing strategies

We now turn to the case in which the land planner can implement either a land sharing strategy or a land sparing one on each unit of land. We make the same assumption as before on the planner behaviour except that now he combines strategies (A1hp to A3hp).

In A1hp case, the optimization problem with a combination of strategies becomes:

$$\max_{x_{h,i},\, x_{\mathrm{p},i}} \sum_{i=1}^{I} x_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.c_{\mathrm{p},i} \leq \mathrm{B} \text{ and } x_{h,i} + x_{\mathrm{p},i} \leq s_i$$

Let π_1 be the shadow price of the budget constraint and $\rho_{1,i}$ be the shadow price of the ith unit's production capacity. The Lagrangian function for this problem is:

$$L = \sum_{i=1}^{I} x_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i} + \pi_1.\left(B - \sum_{i=1}^{I} x_{h,i}.c_{h,i} - \sum_{i=1}^{I} x_{\mathrm{p},i}.c_{\mathrm{p},i} \right) + \sum_{i=1}^{I} \rho_{1,i}.\left(s_i - x_{h,i} - x_{\mathrm{p},i} \right)$$

Let the values of the optimal solution be given by $x_{h,i}^{'}$ and $x_{\mathrm{p},i}^{'}$, the Kuhn-Tucker conditions of the problem are:

$$\begin{cases} B - \sum_{i=1}^{I} x_{h,i}^{'}.c_{h,i} - \sum_{i=1}^{I} x_{\mathrm{p},i}^{'}.c_{\mathrm{p},i} \geq 0,\ \pi_1 \geq 0,\ \pi_1.\left(B - \sum_{i=1}^{I} x_{h,i}^{'}.c_{h,i} - \sum_{i=1}^{I} x_{\mathrm{p},i}^{'}.c_{\mathrm{p},i} \right) = 0 \\ s_i - x_{h,i}^{'} - x_{\mathrm{p},i}^{'} \geq 0,\ \rho_{1,i} \geq 0,\ \rho_{1,i}.\left(s_i - x_{h,i}^{'} - x_{\mathrm{p},i}^{'} \right) = 0,\ i = 1,\ldots,I \\ 1 - \pi_1.c_{h,i} - \rho_{1,i} \leq 0,\ x_{h,i}^{'} \geq 0,\ x_{h,i}^{'}.\left(1 - \pi_1.c_{h,i} - \rho_{1,i} \right) = 0,\ i = 1,\ldots,I \\ 1 - \pi_1.c_{\mathrm{p},i} - \rho_{1,i} \leq 0,\ x_{\mathrm{p},i}^{'} \geq 0,\ x_{\mathrm{p},i}^{'}.\left(1 - \pi_1.c_{\mathrm{p},i} - \rho_{1,i} \right) = 0,\ i = 1,\ldots,I \end{cases} \tag{A1hp}$$

This system of equations helps in choosing between a land sharing strategy and a land sparing one. When the budget constraint is binding, units of land with costs of conversion higher than purchase costs are purchased and units of lands with costs of conversion higher than purchase costs are converted. In this case, system of equations (A1hp) implies that:

$$\begin{cases} x'_{h,i} \leq s_i \text{ and } x'_{\mathrm{p},i} = 0 \text{ if } c_{\mathrm{h},i} - c_{\mathrm{p},i} < 0 \\ x'_{h,i} = 0 \text{ and } x'_{\mathrm{p},i} \leq s_i \text{ if } c_{\mathrm{h},i} - c_{\mathrm{p},i} > 0 \\ x'_{h,i} = x^{\pi_1}_{h,i},\, x'_{\mathrm{p},i} = x^{\pi_1}_{\mathrm{p},i} \text{ and } x'_{h,i} + x^{\pi_1}_{h,i} < s_i \text{ if } c_{\mathrm{h},i} - c_{\mathrm{p},i} = 0 \end{cases}$$

When the budget constraint is not binding, the logic is different, especially if both costs are equal, since (A1hp) then implies that π_1=0 and:

$$x'_{h,i} = x^{\pi_1}_{h,i},\, x'_{\mathrm{p},i} = x^{\pi_1}_{\mathrm{p},i} \text{ and } x'_{h,i} + x^{\pi_1}_{h,i} = s_i \text{ if } \rho'_{1,i} = 1$$

Hence, the value of the shadow price of the ith unit's production capacity plays a crucial role in the choice between a land sharing or a land sparing strategy.

In A2hp case, the optimization problem with a combination of strategies becomes:

$$\max_{x_{h,i},x_{\mathrm{p},i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.b_{\mathrm{p},i},\ \text{s.t.} \sum_{i=1}^{I} x_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i} \leq \mathrm{A} \text{ and } x_{h,i} + x_{\mathrm{p},i} \leq s_i$$

Let the values of the optimal solution be given by $x''_{h,i}$ and $x''_{\mathrm{p},i}$. We deduce from the new Lagrangian function and from the Kuhn-Tucker conditions applied to this function that:

$$\begin{cases} x''_{h,i} \leq s_i \text{ and } x''_{\mathrm{p},i} = 0 \text{ if } b_{h,i} - b_{\mathrm{p},i} > 0 \\ x''_{h,i} = 0 \text{ and } x''_{\mathrm{p},i} \leq s_i \text{ if } b_{h,i} - b_{\mathrm{p},i} < 0 \\ x''_{h,i} = x^{\psi_2}_{h,i},\, x''_{\mathrm{p},i} = x^{\psi_2}_{\mathrm{p},i} \text{ and } x''_{h,i} + x''_{\mathrm{p},i} \leq s_i \text{ if } b_{h,i} - b_{\mathrm{p},i} = 0 \end{cases}$$

Here, the environmental gains are decisive in the choice between a land sharing or a land sparing strategy: the strategy inducing the highest environmental gains will be chosen.

In A3hp case, the optimization problem with a combination of strategies becomes:

$$\max_{x_{h,i},x_{\mathrm{p},i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.b_{\mathrm{p},i},\ \text{s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.c_{\mathrm{p},i} \leq \mathrm{B} \text{ and } x_{h,i} + x_{\mathrm{p},i} \leq s_i$$

Let the values of the optimal solution be given by $x'''_{h,i}$, $x'''_{\mathrm{p},i}$ and π'''_3 the optimal shadow price of the budget constraint. We deduce from the new Lagrangian function and from the Kuhn-Tucker conditions applied to this function that, when the budget constraint is binding:

$$\begin{cases} x_{h,i}^{'''} = s_i \text{ and } x_{\mathrm{p},i}^{'''} = 0 \text{ if } \left(b_{h,i} - b_{\mathrm{p},i}\right) \big/ \left(c_{h,i} - c_{\mathrm{p},i}\right) > \pi_3^{'''} \\ x_{h,i}^{'''} < s_i \text{ and } x_{\mathrm{p},i}^{'''} = 0 \text{ if } b_{h,i}/c_{h,i} - b_{\mathrm{p},i}/c_{\mathrm{p},i} > 0 \\ x_{h,i}^{'''} = 0 \text{ and } x_{\mathrm{p},i}^{'''} = s_i \text{ if } \left(b_{h,i} - b_{\mathrm{p},i}\right) \big/ \left(c_{h,i} - c_{\mathrm{p},i}\right) < \pi_3^{'''} \\ x_{h,i}^{'''} = 0 \text{ and } x_{\mathrm{p},i}^{'''} < s_i \text{ if } b_{h,i}/c_{h,i} - b_{\mathrm{p},i}/c_{\mathrm{p},i} < 0 \\ x_{h,i}^{'''} = x_{h,i}^{\pi_3},\ x_{\mathrm{p},i}^{'''} = x_{\mathrm{p},i}^{\pi_3} \text{ and } x_{h,i}^{'''} + x_{\mathrm{p},i}^{'''} = s_i \text{ if } \left(b_{h,i} - b_{\mathrm{p},i}\right) \big/ \left(c_{h,i} - c_{\mathrm{p},i}\right) = \pi_3^{'''} \\ x_{h,i}^{'''} = x_{h,i}^{\pi_3},\ x_{\mathrm{p},i}^{'''} = x_{\mathrm{p},i}^{\pi_3} \text{ and } x_{h,i}^{'''} + x_{\mathrm{p},i}^{'''} < s_i \text{ if } b_{h,i}/c_{h,i} - b_{\mathrm{p},i}/c_{\mathrm{p},i} = 0 \end{cases}$$

The choice between a land sharing and a land sparing strategy is even more complex than for A1hp case since it depends (i) on the difference of the benefit to cost ratio between each strategy, (ii) on the ratio of benefit difference to cost difference and (iii) on $\pi_3^{'''}$, the optimal shadow value of the increase in the environmental amenity associated with an increase in the budget constraint.

Consequently, depending on the budget and the distribution of costs and benefits over land units and strategies, a land planner may select only units for purchase, or only units for conversion, or a mix of both, whatever his strategy is (A1 or A2 or A3).

2. Empirical procedure

Data from the Seine-Ource catchment are used to analyse the implications and discuss the efficiency of strategies A1-A3 described above. Located in the heart of Burgundy, France, it is a mostly agricultural area spanning over 71 municipalities and 80 000 hectares. Area under agriculture represents 59 300 hectares, of which 21% are permanent pastures, 63 % are dedicated to cereal crops and 16 % to fodder production. Levels of pesticides above the regulatory thresholds are regularly measured in the area's waterbodies (ARS Bourgogne, 2009). The empirical procedure consists in three steps: (i) the computation of environmental gains in the catchment under study and for both strategies, (ii) the computation of the economic costs and (iii) the simulation of land planner decision for the three strategies under study.

2.1. Computation of the environmental gains

To estimate the environmental gains attached to each strategy, we rely on I-Phy (van der Werf and Zimmer, 1998; Bockstaller et al., 2008), a predictive indicator that assesses the environmental impacts of pesticide use as the risk of contamination of the air, and surface and ground waters. It is calculated at the parcel scale, based on different inputs : environmental variables (leaching potential, runoff potential, distance to river), farming practices variables (crop type, active ingredient, sowing date, spraying date, banded spraying, equipment characteristics, presence of crop residues), pesticides characteristics (active ingredient mobility, half-life, toxicity, exposure, transfer rate). The application rate intervenes at the last step of the calculation, once the risks of contaminations of air, surface and groundwater have been assessed[1].

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[1] The « air » component is not accounted for in the analysis, due to our focus on water pollution.

The French database systems from IGN (Institut Géographique National, the French National Geographic Institute) and from GIS Sol (Groupement d'Intérêt Scientifique Sol, Soil Scientific Interest Group) are used to gather topographical and pedological data at the parcel scale: soil texture, organic matter content, slope, etc. This allows us to compute the runoff and leaching potentials and distance to the river for each parcel.

To characterize current farming practices at the catchment scale, we adopt a two-step procedure. From field farm surveys we identified six typical current field crop production systems depending on the type of crop rotation (rapeseed-wheat-barley or rapeseed-wheat-silage maize-wheat) and tillage practices (no tillage, systematic tillage, tillage on rapeseed and maize and no tillage on wheat and barley). Each typical production system is precisely characterized with respect to tillage, sewing, fertilization, harvesting and crop protection practices (like in Lechenet *et al.*, 2014). Then to identify the parcels concerned by these typical production systems in the Seine-Ource catchment, we use the RPG (Registre Parcellaire Graphique, Land parcel identification system), a cartographic field pattern registry containing at parcel level all productive land uses receiving payments from the EU CAP and with a typology of agricultural production in 26 classes that is sufficiently fine for selecting plots under typical production systems. We select the plots that have been registered as growing our typical crops of interest over the 2006-2009 period to specify the sample of plots to which the land sharing or sparing strategies can be applied.

The "pesticides inputs" component of the I-Phy calculation is informed by the depiction of the typical production systems.

Consequently, we obtain an I-Phy score for each parcel for years 2006 to 2009 based on actual land uses and typical production systems; we average these scores to produce an I-Phy score for each parcel under study before land planning. Then, the environmental gain scores used in the optimization are the differences between I-Phy scores after and before land planning implementation, an assessment of the reduction in the risk of contamination of waterbodies by pesticides. In the land sparing strategy, the I-Phy score after land planning implementation is set equal to its maximum (10) since we assume no agricultural production once the plots have been acquired by the land planner; in the land sharing strategy, it is computed with the assumption that IPM production systems are implemented.

The IPM production systems are characterized based on the main objective of reducing the dependency of farmers on pesticides and more precisely herbicides, hence the environmental impact of neighboring waterbodies. Two typical IPM production systems are conceived (with and without fodder crops). They span over 6 years, include a diversity of crops such as pea-barley mixes and are more reliant on soil labour than conventional production systems. However, pesticides are not completely banned, but greatly reduced (see Appendix 1). According to the crop or mixed crop/livestock orientation of the farms, they are allocated an IPM production system; the I-Phy score after land planning decision is averaged over the six years of the IPM rotation.

2.2. Computation of the economic costs

The computation of the economic costs differs depending on which strategy is analysed. The main originality of our work is that they are estimated before the implementation of a strategy, *ex ante*.

The land sharing strategy consists in providing incentives to farmers to adopt IPM production systems to reduce their dependency to pesticides in order to improve water quality. Consistent with the current European policy framework, we concentrate on the case of a subsidy to convert from conventional to IPM crop production. Ideally, an optimal subsidy scheme would be individualized to account for differences in marginal costs and benefits associated with the conversion for each plot under scrutiny. However, actual programs rely on fixed per hectare payments.

The semi-net margins of each production system analysed above (conventional and IPM) are used to compute the per-hectare subsidy level in the Seine-Ource catchment. Within each production system, for each crop, the production costs are computed for a typical set of farming practices informed by the field surveys and expert knowledge. To compute the mechanization and fuel costs, we use data from the Bureau de Coordination du Machinisme Agricole (French agricultural mechanization coordination office) about purchase and maintenance costs, working output and fuel consumption of the agricultural machines used in the production systems (which are more numerous in the IPM cases). Seed prices are taken from a national synthesis from the Groupement National Interprofession des Semences (French national union of seed producers) for the 2010/2011 campaign, pesticides prices from the Criter database from INRA (French national institute for agronomic research – see Fortino and Reau, 2010) and fertilizers' prices from the Agreste statistics (French national agricultural statistics). Refer to Appendix 1 for a description of the production costs in the different production systems. Finally, the semi-net margin is calculated under the assumption that yield objectives, hence gross products, are the same for conventional and IPM production systems.

A global semi-net margin before land planning implementation is calculated, averaged over the four years of land occupation for which we have extracted data from the RPG. The global semi-net margin after land planning decision is based on the assumption of a generalized adoption of the IPM production systems assuming that permanent pastures are not affected, and that parcels that were under a cereal or cereal/fodder crop orientation remain as such under IPM. The opportunity cost of the land sharing strategy is then established at 50 euros per hectare per year for a cereal-only farm orientation, and 15 euros per hectare per year for a cereal and fodder crop farm, the amounts necessary to ensure no loss in semi-net margin at the catchment scale for each orientation. These levels of subsidy are of the same order of magnitude as agricultural payments currently in place in France, such as the Agro-Environmental Measures for the "diversification of cultures" set at 32 euros per hectare per year.

In the land sparing strategy, we assume that the cost of the land planning decision is equal to the cost of the purchase of land. To estimate this cost, the first step is to use the hedonic price method that consists in breaking up the price of a land into its characteristics. This estimation is based on sales that really occurred. The water catchment of Seine and Ource is too small to conduct such an estimation. In France, analysts of agricultural land markets (SAFER – Société d'Aménagement Foncier et d'Etablissement Rural – French companies for agricultural real estate management and rural development) work at the "Département" level. Thus, we work at the level of Côte-d'Or that is the French "department" of 8 763 km² located in Burgundy in which the Seine and Ource water catchment is located. We implement the following semi-logarithmic model of hedonic price on 6 477 sales, recorded between 1992 and 2008 by the SAFER:

$$\ln c_i = \alpha + \beta l_i + \gamma t_i + \theta p_i + \varphi v_i + \varepsilon_i$$

where c_i indicates the price of the parcel in constant Euros, l_i the vector of the characteristics of the location of the parcel i, t_i that of its topographic characteristics, p_i of its pedologic characteristics and v_i a vector of control variables; α represents the constant and β, γ, θ and φ the marginal effects of each of the explanatory variables; ε_i is a random error term. Most of these variables are not included in the SAFER database. Consequently, we use exogenous geographical information. More precisely, the characteristics of location of the parcel are the following continuous variables that we computed from ODOMATRIX (see Hilal, 2010, for details): Euclidian distance to the town hall of the municipality, travel distances to shopping and services (closest centre of retail and services place), to employment (closest urban centre) or to Dijon, the regional capital, which makes it possible to tap the expectations of urbanization in connection with access to some higher functions. The topographic characteristics also gather continuous variables such as the surface area of the parcel, its altitude and its slope that we computed from the data provided by IGN (Institut Géographique National, the French national geographic institute). These variables give us information on the capacity in terms of agricultural production of the parcel studied. Most of the variables described above do not make it possible to take into account the soil characteristics of the parcels, which constitute, however, one of their essential productive attributes. In order to measure this attribute, we have chosen to concentrate on the texture of the soils, which is defined by the size of its component particles and provided by Donesol database (GIS Sol, Soil Scientific Interest Group). Apart from these variables, we have used other more general variables that we have called control variables and that are available in the SAFER database: variables linked to the year of the transaction, to the fact that there is a farmer who is the purchaser of the parcel of interest[2], or to the fact that the parcel is cropland, as opposed to being a meadowland. The conversion of the prices into constant Euros enables us to take into account the effects of inflation, but not the evolution between years of the real estate market for the period under consideration (1992 - 2008). We introduce annual dichotomous variables to control these effects.

The second step of the estimation of the purchase cost of agricultural lands in the water catchment under consideration consists in using the model estimated to predict the price of agricultural parcels that were or were not the object of sales. For this purpose, we needed to compute the values of our explanatory variables for all the agricultural lands of the water catchment. Furthermore, we found that the predictor of Meulenberg (1965) suits the best for our dataset. Indeed, our assumption of a semi-logarithmic model calls for the addition of a corrective term to a naive prediction that would consist in simply implementing the following computation

$$c_i = \exp\left(\hat{\alpha} + \hat{\beta} l_i^* + \hat{\gamma} t_i^* + \hat{\theta} p_i^* + \widehat{\varphi} v_i^*\right)$$

---

[2] In France, the farmer of a parcel has a pre-emptive right on the sale of that parcel (see Boinon, 2003, for more details on French real estate policy).

where the hats represent the value of the estimated parameters, and the stars the values of the explanatory variables for parcels for which the price is to be predicted. Meulenberg (1965) proposes introducing the corrective term $\upsilon_i = x_i \left(X'X \right)^{-1} x_i'$ such that: $E[\exp(\hat{\varepsilon}_i)] = \exp\left(0.5*\left(1-\upsilon_i\right)\hat{\sigma}^2\right)$ and using $c_i * E[\exp(\hat{\varepsilon}_i)]$ as the predicted price of the agricultural parcel.

Finally, we proceed under the following assumptions: if the land sharing strategy is adopted, farmers are subsidized at 50 euros per hectare per year for a cereal-only farm orientation, and 15 euros per hectare per year for a cereal and fodder crop farm, for a contract length of 15 years, accounting for an actualisation rate of 4%; when the land sparing strategy is chosen, land is purchased for once over an infinite time horizon.

In the Seine-Ource water catchment, we identify 2 273 lands that are relevant to implement the optimization strategies described in section 1. Table 1 presents some descriptive statistics of our main variables of interest.

Table 1: Descriptive statistics of land surface, costs and gains

	Mean	**Standard Deviation**	**Minimum**	**Maximum**
Surface (ha)	3.76	5.33	0.005	73.65
Land sparing cost (€)	11,410	14,570	115	112,359
Land sharing cost (€)	1,809	2,750	0.95	38,896
Land sparing gain	8.98	0.79	4.98	9.99
Land sharing gain	2.89	0.62	0.065	3.83
Land sparing gain/cost	0.005	0.008	0.00007	0.083
Land sharing gain/cost	0.029	0.103	0.00003	1.773

2.3. Simulation of land planner decisions

We simulate the decisions of three types of land planners, according to assumptions A1 to A3, in our catchment. To do so, we follow a ranking based on both Babcock *et al.* (1996) and our theoretical framework. This ranking, detailed below, is a one shot ranking, without time delay. If the ranking criterion is equal for two or more parcels when the budget constraint binds, the solution is not unique. Then, to avoid adding another *ad hoc* criteria, those parcels are ranked randomly to determine the full set of parcel selected.

When land sharing and land sparing strategies are considered separately, rankings are quite simple and are the same as in Babcock *et al.* (1996). In A1h and A1p cases, the land planner selects land according to a ranking based on costs: land with the lowest costs are selected first. In A2h and A2p cases, the planner selects land according to a ranking based on environmental gains: land with the highest environmental gains are selected first. In A3h and A3p cases, the planner selects land according to a ranking based on the benefit to cost ratio: land with the highest ratio are selected first.

When land sharing and land sparing strategies are considered jointly, rankings are more complex. They directly result from our theoretical framework. In A1hp case, lands are ranked (in decreasing order) according to the minimum cost between a land sharing or a land sparing strategy: land with the lowest minimum cost will be selected first and assigned to the best strategy with the lowest cost. In A2hp case, the planner selects land according to a ranking based on the maximum environmental gain between a land sharing and a land sparing strategy: land with the highest maximum environmental gain will be selected first and assigned to the strategy with the highest benefit.

To sum up, in A1hp case, a change in the strategy given by the ranking according to the minimum cost would not bring additional units of surface (the criterion which is maximized) whereas such a change would spend units of budget. In A2hp case, a change in the strategy given by the ranking according to the maximum environmental gain would not bring additional environmental gain (the criterion which is maximized) whereas such a change would consume units of surface.

This is quite different in A3hp case where a change in the strategy given by the ranking according to the maximum benefit to cost ratio would bring an additional benefit (the criterion which is maximized) at the expense of units of budget. In other words, such a change would not bring additional benefit to cost whereas it could generate additional benefit with respect to additional costs.

Therefore, in A3hp case, lands are first ranked (in increasing order) according to the maximum benefit to cost ratio between a land sharing or a land sparing strategy. To be selected, each land i must generate a maximum benefit to cost higher than the maximum difference of benefit to cost induced by a change of the selection strategy chosen for the previous land selected j ≠ i: $\max(b_{h,i}/c_{h,i}, b_{\mathrm{p},i}/c_{\mathrm{p},i}) > \max((b_{\mathrm{s2,j}} - b_{\mathrm{s1,j}})/(c_{\mathrm{s2,j}} - c_{\mathrm{s1,j}}))_{\mathrm{j<i}}$. If it is not the case, the previous land j selection strategy incriminated will switch from s1 to s2. This procedure is implemented until the budget constraint binds.

3. Results and discussion

We can first deduce from Table 1 that, on average, a land sharing strategy is preferred in A1 case (the mean cost is lower) and in A3 case (the mean gain/cost is higher). A land sparing strategy is preferred in A2 case (the mean gain is higher).

When land sharing and land sparing strategies are considered separately, this result is partly confirmed outside the average. Indeed, Table 2 shows that, for a given budget, the number of parcels, the surface and the environmental gain (percentage of the total possible gains if all lands were selected with the strategy) of lands selected are higher with the sharing strategy than with the sparing one. For a given surface, the environmental gain and the number of parcels converted are higher with the sharing strategy than with the sparing one; the cost is then lower with the sharing strategy than with the sparing one. Thus, outside average, it is better to choose a land sharing strategy than a land sparing one.

More particularly, we know from Table 2 that, for a given budget equal to 200 000 €, the environmental gain and the number of parcels is higher in A3h and A3p cases than in A1h and A1p cases. The global surface selected is higher in A1h and A1p cases than in A3h and A3p cases. This means that, for a given budget, the environmental economic land-planner (A3 maximisation) increases environmental gains with respect to a pure economic land-planner (A1 maximisation). Furthermore, an environmental economic land-planner favours small parcels (mean size of 0.45 ha with a land sharing strategy and of 0.12 ha with a land sparing strategy), especially with respect to a pure economic land-planner (mean size of 3.23 ha with a land sharing strategy and of 10.47 ha with a land sparing strategy). For a given surface (equal either to A1 surface or to A3 surface), the environmental gain, the cost and the number of parcels are higher in A2h and A2p cases than in A1h, A1p, A3h and A3p. This means that a pure environmental land-planner (A2 maximisation) increases the environmental gain but also the cost of the intervention. If we look into more details at the results, we can conclude that, for a given surface, a pure environmental land-planner favours small parcels (mean size of 0.84 ha for A1 surface constraint and of 0.45 ha for A3 surface constraint in the land sharing strategy, and mean size of 0.22 ha for A1 surface constraint and of 0.11 ha for A3 surface constraint in the land sparing strategy) with respect to both the other types of planners. Finally, environmental objectives favour small parcels while economic objectives favour large one. This is consistent with economic intuition since large parcels are the cheapest. Concerning the environmental gain, the indicator of pest contamination that we use is independent of the parcel size. This explains that small parcels are selected first to maximize environmental gain.

Table 2: Total cost, environmental gain, surface and number of parcels for separated strategies

	Cost (€)		**Env. Gain (and %)**		**Surface (ha)**		**Nb. of parcels**	
	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing
A1 case	200,000	200,000	138 (0.7)	631 (9.6)	157	1,140	15	353
A2 case (A1 surface)	651,346	569,917	6,481 (31.8)	4,020 (61.1)	157	1,140	714	1,364
A2 case (A3 surface)	277,261	234,231	3,657 (17.9)	3,116 (47.4)	43.5	472	404	1,057
A3 case	200,000	200,000	3,198 (15.7)	3,012 (45.8)	43.5	472	350	1,047

Table 4 of Appendix 2 shows how results of Table 2 evolve with the budget constraint. Every variables (environmental gain, number of parcels, surface and mean size of parcel selected) increase with the budget except the mean size of parcel selected in A1 case. Indeed, within a land sparing strategy, a pure economic land-planner selects parcels of smaller mean size when the budget increases. This is due to the fact that this land-planner purchases first the larger parcels that become less abundant when the budget increases. Within a land sharing strategy, there is no clear trend concerning the size of parcels. One can explain this by the fact that the heterogeneity of costs of conversion linked to the differentiation between cereal-only farm and fodder crop farm is more important than the fact that these costs increase with the size of the parcel (they are proportional to the surface).

At this step, when considered separately, it is better to choose a land sharing strategy than a land sparing one in the Seine-Ource catchment. However, our theoretical framework brings to the fore that it is not that simple. Let's now turn to the case where the land planner has the possibility to combine strategies by acquiring some parcels and subsidizing the adoption of IPM on others. Table 3 shows that, with a total budget of 200,000 €, it is optimal to enforce a combined strategy under assumption A3: 253 parcels of total surface 2.86 hectares are purchased, at a cost of 126,444 € and for an environmental gain of 2,319, while 520 parcels of total surface 174 hectares are converted to IPM, at a cost of 73,556 € and for an environmental gain of 1,508. Two-third of the total budget is allocated for the purchase of 14% of the total surface concerned by land planning that provide 60% of the resulting environmental gains.

With the same budget of 200,000 €, under assumption A1, only the sharing strategy is enforced: 356 parcels are converted to IPM over a total surface of 1,140 hectares for an environmental gain of 640. The land planning decision covers a wider area than under assumption A3, with a lower environmental gain. The per-hectare cost differential between the land sharing and land sparing strategies explains in part the lack of combined strategies implemented by the land planner. An immediate extension of this paper will be to alter contract length or the discount rate (set at 4%).

Under assumption A2, only the sparing strategy is enforced. With a surface constraint set at the total area of land under land planning (sharing or sparing) under assumption A3 (202.6 hectares), 793 parcels are purchased, for a total cost of 808,779 euros, and for an environmental gain of 7,182. Implement land planning over the same surface comes at a higher price (4 times higher), with increased environmental gains (below twice the benefits). With a laxer surface constraint set at the area converted under assumption A1, 1,376 parcels are purchased for a total cost of 3,644,718 euros and environmental gains of 12,398 : this represents a 5.6 times increase in benefits for a price increase by 4.5 times. The fact that a combined strategy is not enforced is due to a characteristic of our context, since the adoption of IPM production system will always produce a risk of pesticides contamination, even if very low, higher than if the same parcel is purchased and put out of production. Then for the same parcel, the environmental gains of the land sparing option are always greater than that of the land sharing option (see Table 1). Consequently, a land planner looking at maximising an environmental objective will not have recourse to the sharing strategy even if given the possibility to do so.

Table 3: Total cost, environmental gain, surface and number of parcels for combined strategy

	Cost (€)		**Env. Gain**		**Surface (ha)**		**Nb. of parcels**	
	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing
A1hp case	-	200,000	-	640	-	1,140	-	356
A2hp case (A1	3,644,718	-	12,398	-	1,140	-	1,376	-

surface)								
A2hp case (A3 surface)	808,779	-	7,182	-	202.6	-	793	-
A3hp case	126,444	73,556	2,319	1,508	28.7	174	253	520

Table 5 of Appendix 2 shows how the contribution of each strategy to total benefits, costs and surface under protection evolves with the budget constraint under assumption A3. A tighter budget constraint decreases the share of funds allocated to the land sparing strategy, which concerns a lower portion of total acreage under protection (2% for a total budget of 50,000 € for instance) and provides a lower share of the total environmental gains. Note that if the cost and benefit shares of both strategies are of the same order of magnitude over the budget range, the surfaces involved in the land sparing strategy always lay below those concerned by the adoption of IPM production systems.

Finally, a comparison of Table 2 and Table 3 shows that a pure environmental land-planner spends more or the same amount of money when he combines land sharing and land sparing strategies than when he implements them separately. The surface and the number of parcels selected when strategies are combined are always higher or equal than the one obtained when strategies are separated except for environmental economic land-planner who selects less and smaller parcel when combining strategies. However, the environmental gain is always higher when strategies are combined than when they are considered separately. For instance, for a given budget of 200,000 euros, the total environmental gain is equal to 3,827 for an environmental economic land-planner who combines strategies while it is equal to 3,198 if he only implements a land sharing strategy. Thus, the combination of strategies increases the environmental gain of planning without altering the cost of this planning.

Conclusion

Selection of a land planning strategy to reduce the risk of pesticides transfer from agriculture to surface and underground waterbodies has important implications for the total environmental gain and area of land covered that can be obtained with a given budget. In this paper two strategies are analyzed: a land sharing strategy, subsidizing the adoption of IPM practices, or a land sparing strategy, purchasing land to put out of production; these strategies can be used in isolation or combined in a policy mix. A theoretical approach brings to the fore how different types of land planning objectives – maximizing surface under a budget constraint, maximizing benefits under a surface constraint, or maximizing benefits under a budget constraint – imply different selection criteria. For instance, when the objective is the maximization of benefits under a budget constraint, with only one strategy available, it is the ratio of benefit to costs of each parcel that determined whether a parcel is selected; when land sparing and sharing can be combined, it is also the ratio of the differences between benefits over the differences between costs that guides the selection of a parcel.

Our empirical analysis applies the above framework to the Seine-Ource river catchment, in Burgundy (France) to analyze both the type of land planning objectives and the possibility to mix strategies. First we show that when only one strategy can be implemented the best option for the Seine-Ource river catchment is the land sharing one. Then we proceed to the case where strategies can be combined: for our set of parameters, the two strategies are mixed only when the land planner seeks to maximize benefits under a cost constraint. For the same parcel, the environmental gains of the land sparing option are always greater than that of the land sharing option: a land planner looking only at the benefits side will never chose to combine strategies even if given the possibility to do so. The costs of the land sparing option are also greater than that of the land sharing option, given our calculation of annual subsidies and our assumptions on contract length and discount rate, which explains the lack of combination of strategies when the land planner seeks to maximize the area of land protected under a given budget constraint. An immediate extension of this work would assess the sensitivity of this result to some parameters of the model.

These preliminary results put in perspective the importance of considering the possibility to implement a mix of strategies when comparing targeting options for the preservation of water from pesticides pollution. They also provide a ranking procedure for each land planning program, which would prove useful to implement.

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Appendix 1: mean production costs for each typical conventional and IPM production systems analysed.

The production systems are defined as follows :

- PS1 : rapeseed-wheat-barley
- PS2 : rapeseed-wheat-silage maize-wheat
    - with no tillage (a), systematic tillage (b) or tillage on rapeseed and maize and no tillage on wheat and barley (c)
- IPM1 : rapeseed-wheat- intermediary crop (white mustard)-pea/barley mix – winter barley – intermediary crop (oat)- sunflower – wheat.
- IPM2 : rapeseed-wheat- intermediary crop (white mustard)-pea/barley mix – winter barley – intermediary crop (oat)- silage maize – wheat.

Figure 1 presents the mean production costs, detailed by expenditure item, for the 6 conventional and 2 IPM production systems analysed in the paper.

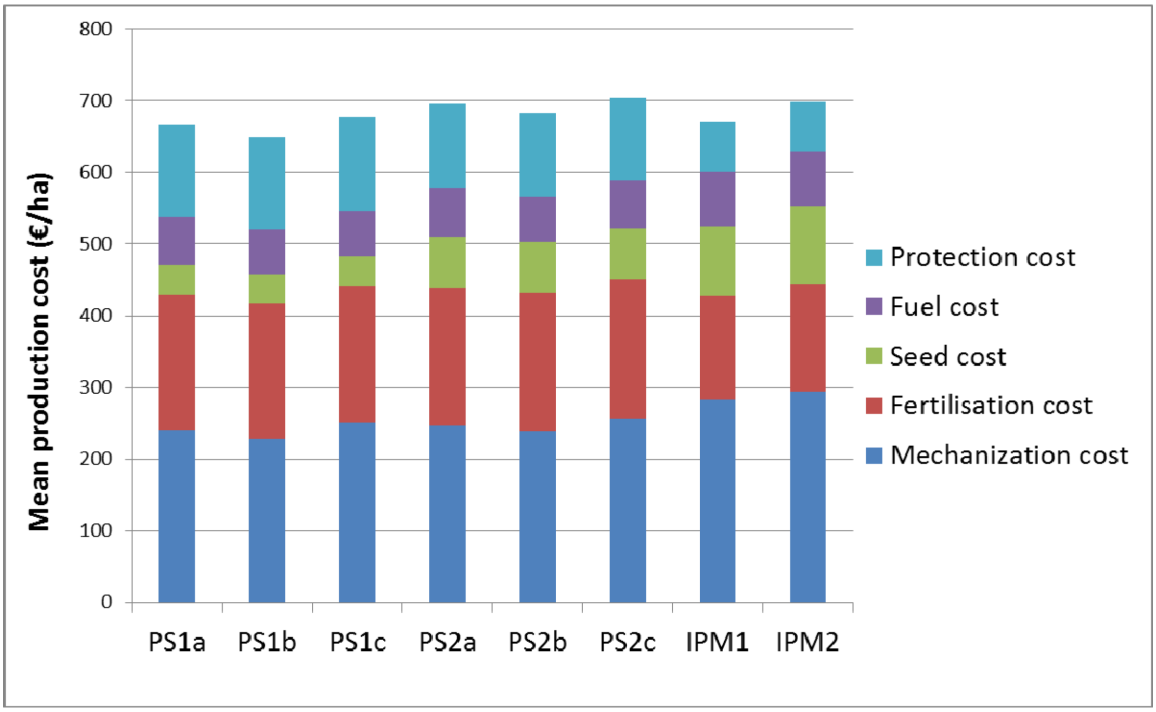

Figure 1: mean production costs for conventional and IPM production systems

Appendix 2: sensitivity analysis of results.

Table 4: Sensitivity analysis of results without the possibility of combining sparing and sharing strategies.

Cost		**Environmental gains**		**Number of parcels**		**Surface**		**Mean size of parcels**	
Sparing	Sharing	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing	Sparing	Sharing
€	€					ha	ha		
A1 maximisation									
50,000	50,000	5	176	1	99	42	316	42.08	3.19
100,000	100,000	30	326	4	185	83	631	20.87	3.41
150,000	150,000	76	536	9	306	121	947	13.43	3.09
200,000	200,000	138	631	15	353	157	1,140	10.47	3.23
250,000	250,000	246	717	27	382	191	1,235	7.07	3.23
300,000	300,000	276	792	31	407	223	1,329	7.18	3.27
350,000	350,000	334	920	37	447	254	1,424	6.86	3.19
400,000	400,000	391	967	43	462	284	1,519	6.60	3.29
450,000	450,000	424	1,064	47	493	313	1,613	6.66	3.27
500,000	500,000	491	1,139	54	518	341	1,708	6.32	3.30
A2 maximisation (A1 surface)									
270,628	156,729	3,599	2,732	398	923	42	316	0.11	0.34
421,890	312,881	4,934	3,393	543	1,151	83	631	0.15	0.55
540,115	473,336	5,809	3,811	640	1,293	121	947	0.19	0.73
651,346	569,917	6,481	4,020	714	1,364	157	1,140	0.22	0.84
769,766	615,585	7,017	4,113	774	1,396	191	1,235	0.25	0.88
876,444	660,551	7,452	4,200	822	1,428	223	1,329	0.27	0.93
980,152	708,765	7,829	4,282	865	1,454	254	1,424	0.29	0.98
1,068,448	755,035	8,143	4,359	900	1,481	284	1,519	0.32	1.03
1,152,778	802,665	8,425	4,434	931	1,506	313	1,613	0.34	1.07
1,234,886	845,553	8,675	4,505	958	1,532	341	1,708	0.36	1.11
A2 maximisation (A3 surface)									
88,686	57,983	1,680	1,855	186	619	9	116	0.05	0.19
157,742	114,415	2,476	2,441	274	823	19	231	0.07	0.28
218,138	173,100	3,105	2,827	343	956	31	348	0.09	0.36
277,261	234,231	3,657	3,116	404	1,057	44	472	0.11	0.45
332,700	305,612	4,181	3,371	462	1,144	58	617	0.13	0.54
377,744	368,665	4,579	3,553	505	1,204	71	740	0.14	0.61
426,266	430,105	4,956	3,713	546	1,259	84	864	0.15	0.69
470,016	489,863	5,308	3,850	584	1,306	98	981	0.17	0.75
509,062	550,882	5,589	3,982	615	1,351	111	1,102	0.18	0.82
559,127	609,373	5,940	4,099	655	1,390	127	1,219	0.19	0.88
A3 maximisation									
50,000	50,000	1,236	1,782	136	618	9	116	0.06	0.19
100,000	100,000	1,989	2,359	218	814	19	231	0.09	0.28
150,000	150,000	2,632	2,734	289	950	31	348	0.11	0.37
200,000	200,000	3,198	3,012	350	1,047	44	472	0.12	0.45
250,000	250,000	3,708	3,232	406	1,128	58	617	0.14	0.55
300,000	300,000	4,175	3,411	457	1,188	71	740	0.15	0.62
350,000	350,000	4,607	3,567	506	1,243	84	864	0.17	0.69
400,000	400,000	5,007	3,708	550	1,293	98	981	0.18	0.76
450,000	450,000	5,372	3,836	590	1,337	111	1,102	0.19	0.82
500,000	500,000	5,711	3,952	627	1,377	127	1,219	0.20	0.89

Table 5: Sensitivity analysis of results with the possibility of combining sparing and sharing strategies.

Cost			**Surface**			**Environmental gains**		
Total	Sparing	Sharing	Total	Sparing	Sharing	Total	Sparing	Sharing
€	*%*	*%*	ha	*%*	*%*		*%*	*%*
A1 maximisation								
50,000	*0.0*	*100.0*	316	*0.0*	*100.0*	171	*0.0*	*100.0*
100,000	*0.0*	*100.0*	631	*0.0*	*100.0*	341	*0.0*	*100.0*
150,000	*0.0*	*100.0*	947	*0.0*	*100.0*	543	*0.0*	*100.0*
200,000	*0.0*	*100.0*	1,140	*0.0*	*100.0*	640	*0.0*	*100.0*
250,000	*0.0*	*100.0*	1,235	*0.0*	*100.0*	737	*0.0*	*100.0*
300,000	*0.0*	*100.0*	1,329	*0.0*	*100.0*	832	*0.0*	*100.0*
350,000	*0.0*	*100.0*	1,424	*0.0*	*100.0*	885	*0.0*	*100.0*
400,000	*0.0*	*100.0*	1,519	*0.0*	*100.0*	935	*0.0*	*100.0*
450,000	*0.0*	*100.0*	1,613	*0.0*	*100.0*	998	*0.0*	*100.0*
500,000	*0.0*	*100.0*	1,708	*0.0*	*100.0*	1,079	*0.0*	*100.0*
A2 maximisation – surface constraint from A1 maximisation								
1,159,671	*100.0*	*0.0*	316	*100.0*	*0.0*	8,449	*100.0*	*0.0*
2,114,969	*100.0*	*0.0*	631	*100.0*	*0.0*	10,479	*100.0*	*0.0*
3,064,085	*100.0*	*0.0*	947	*100.0*	*0.0*	11,762	*100.0*	*0.0*
3,644,718	*100.0*	*0.0*	1,140	*100.0*	*0.0*	12,398	*100.0*	*0.0*
3,970,595	*100.0*	*0.0*	1,235	*100.0*	*0.0*	12,683	*100.0*	*0.0*
4,303,896	*100.0*	*0.0*	1,329	*100.0*	*0.0*	12,952	*100.0*	*0.0*
4,644,385	*100.0*	*0.0*	1,424	*100.0*	*0.0*	13,206	*100.0*	*0.0*
4,954,679	*100.0*	*0.0*	1,519	*100.0*	*0.0*	13,444	*100.0*	*0.0*
5,279,368	*100.0*	*0.0*	1,613	*100.0*	*0.0*	13,671	*100.0*	*0.0*
5,589,308	*100.0*	*0.0*	1,708	*100.0*	*0.0*	13,889	*100.0*	*0.0*
A2 maximisation – surface constraint from A3 maximisation								
435,464	*100.0*	*0.0*	87	*100.0*	*0.0*	5,026	*100.0*	*0.0*
589,420	*100.0*	*0.0*	138	*100.0*	*0.0*	6,139	*100.0*	*0.0*
729,351	*100.0*	*0.0*	178	*100.0*	*0.0*	6,828	*100.0*	*0.0*
808,779	*100.0*	*0.0*	203	*100.0*	*0.0*	7,182	*100.0*	*0.0*
912,512	*100.0*	*0.0*	234	*100.0*	*0.0*	7,592	*100.0*	*0.0*
1,002,810	*100.0*	*0.0*	261	*100.0*	*0.0*	7,907	*100.0*	*0.0*
1,064,494	*100.0*	*0.0*	282	*100.0*	*0.0*	8,129	*100.0*	*0.0*
1,138,376	*100.0*	*0.0*	308	*100.0*	*0.0*	8,374	*100.0*	*0.0*
1,214,252	*100.0*	*0.0*	335	*100.0*	*0.0*	8,619	*100.0*	*0.0*
1,299,967	*100.0*	*0.0*	363	*100.0*	*0.0*	8,856	*100.0*	*0.0*
A3 maximisation								
50,000	*29.7*	*70.3*	87	*2.2*	*97.8*	1,907	*28.1*	*71.9*
100,000	*45.3*	*54.7*	138	*6.7*	*93.3*	2,696	*42.2*	*57.8*
150,000	*54.9*	*45.1*	178	*9.8*	*90.2*	3,303	*52.1*	*47.9*
200,000	*63.2*	*36.8*	203	*14.1*	*85.9*	3,828	*60.6*	*39.4*
250,000	*66.7*	*33.3*	234	*16.8*	*83.2*	4,295	*65.3*	*34.7*
300,000	*69.8*	*30.2*	261	*19.3*	*80.7*	4,722	*69.4*	*30.6*
350,000	*73.4*	*26.6*	282	*22.2*	*77.8*	5,114	*73.4*	*26.6*
400,000	*75.7*	*24.3*	308	*24.9*	*75.1*	5,474	*76.2*	*23.8*
450,000	*77.3*	*22.7*	335	*26.5*	*73.5*	5,810	*78.6*	*21.4*
500,000	*78.1*	*21.9*	363	*27.4*	*72.6*	6,121	*80.1*	*19.9*