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Interaction between pollinators and pesticide use in agricultural crops: An ecological-economical modeling approach in South West France

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Abstract

Recent years have witnessed a substantial decline of pollinators in Europe. This phenomenon has been partly associated with changing farm practices and in particular with the increase of pesticides use. These practices have particularly affected the insect pollinators and more specifically the bee populations. The bee's pollination plays a crucial role in the oilseed crop production and especially in the hybrid sunflower (Helianthus Annuus) seed production, which is an important economic industry that supports other agricultural sectors. In this paper, we developed an ecological-economic model of a single farm output, assuming that both pest control and pollination are essential inputs, for two farm-types in South-Western France. According to different agronomic contexts, different levels of subsidies or penalties can be efficiently targeted to the implementation of new farming practices. The results

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depend on farm characteristics, agri-environmental indicators, labor allocation capacities and also farmers' perceptions of yield risks.

Introduction

Pollination service is offered by commercial bees and wild bees. The pollination service provided by commercial bees is commercialized by beekeepers to farmers while the pollination service provided by wild bees is offered by nature i.e. it is an ecosystem service. Recent years have witnessed a substantial decline in both kinds of pollinators, wild and commercial bees, in Europe (but also of other insect not studied here). This phenomenon has been partly associated with existing farm practices and in particular with the increase of pesticides use (Benton et al. 2002; Goulson, 2013; Henry et al., 2012; Mommaerts et al., 2010; Whitehorn et al., 2012). The production decisions have a serious effect on the insect population, although the precise links are subject to much debate. The bee's pollination plays a very important role in the crop production (Gallai et al. 2009; Klein et al. 2007) and especially in the hybrid sunflower (Helianthus Annuus) seed production, which is an important economic industry that supports other agricultural sectors (confection markets that use hybrid seeds and sunflower oil) (Greenleaf et al., 2006).

The interaction between wild and commercial bees contributes more than the direct contribution of the commercial bees to the sunflower pollination (Greenleaf et al., 2006). These findings also demonstrate the economic importance of interspecific interactions for ecosystem services and suggest that the protection of wild bee pollinators can help a lot the food production supply by compensating the commercial bees scarcity (Greenleaf et al., 2006). Many Agri-Environmental Measures (AEM)/Schemes have taken place around Europe for the protection of pollinators. Unfortunately, the majority of studies were inadequate to assess reliably the effectiveness of the AEM on the insect pollinators because there is no baseline data in order to examine the trends of biodiversity over time (Kleijn and Sutherland, 2003; Knop, 2006). A number of studies that compared the change of species richness in AEM fields and control plots included only few species groups (mainly plants and birds) or were protected for a long time (Brereton et al., 2002; Peter and Walter, 2001). In the same context, European Union has recently reinforced a new regulation (EU No 485/2013), thus imposing the total ban of three Neonicotinoids **(**responsible for the loss of bees and other pollinators) for two years concerning a specified set of crops (sunflower, rapeseed, maize and cotton) from the 1st of December 2013. This is all part of the European Commission's continued program of review for all active substances used in plant protection products within the EU and stems from the recent legislative framework established by the Regulation (EC) No 1107/2009[2].

Taken as given that the services of wild and commercial bees are in a complementary relationship (Greenleaf and Kremen 2006; Klein et al. 2003), we are trying to examine the dynamic relationships that evolve between production (especially oilseeds) in crop rotation systems and bee pollination services. Inside these relationships, we focus on the negative effects of pesticides on bee pollination while considering the links between the yield and the bee pollination. Higher level of bee pollination in the case of oilseed production offers better yield results. Unfortunately, a low level of bee population may lead to extremely low yield production or even to a collapse. (Greenleaf et al., 2006; Jivan et al., 2012; Oz et al., 2009; Parker, 1981)

To assess the effects of the above policy changes on farm incomes and pollination services, we develop an ecological-economic model displaying farmers' decisions under the assumption that both pesticides and pollination are essential inputs.

Modelling Framework

The model is based on two components: An ecological model describing the ecosystem production function offering wild bees and a farmer's decision model which decides quantity of inputs including pollination services (wild and / or commercial bees) and pest control and calculates the potential revenues (Acs et al., 2008; Hazel & Norton, 1986). We assume that beekeepers' supply is perfectly elastic. The general framework we use here is a single-period optimization problem. Indeed, although we start describing the dynamic relationship between production and pollination services as they interact with the pesticides, the assumption that within-season dynamic is fast allows us to assume instantaneous response of the bees to pesticide levels and of bees to yield levels. (Kleczkowski et al., 2013).

[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:309:0001:0050:EN:PDF

A. *Ecological model*

In order to calculate the pollination supply we have to take into account the abundance of bees in the examined area, the composition of the bee species (commercial bees and wild bees), the negative effect of pests on pollinators as well as the positive effect of the crops on these populations as far as these crops can feed them and serve as natural habitats. For example, as sunflower is one of the essential bee plants, the interaction level of pollination/sunflower is higher and as a result, the pollination supply is higher.

The wild bee population is measured by their density W, a number of bees pollinating the area. The evolution of W satisfies a decreasing function from a given level of pesticides use on. This signifies that the use of pesticides has a negative effect on the wild bee population given their toxicity characteristics but that this negative effect appears only after a certain known threshold of their use $\bar{C}$ (Rortais et al. 2005). We introduce in this function an indicator that measures the capacity of the farmer to reduce the toxicity of pesticides on the wild bee population. We suppose that this capacity depends on the chemical characteristics of the pesticides having a more or less important impact on insect pollinators, the application methods and technology used for them and the farmer's knowledge concerning their application. Thus, we define i this indicator of improvement.

The wild bee population function is defined by the following a non-linear equation:

$$W = \begin{cases} \frac{\bar{w}}{\frac{C*\beta}{g}}, \ C > \bar{C} \\ \bar{w}, \ C \leq \bar{C} \end{cases} \tag{1}$$

Where:

$\bar{w}$ is the initial density of wild bees;

C is the quantity of pesticides (litters) applied during the period;

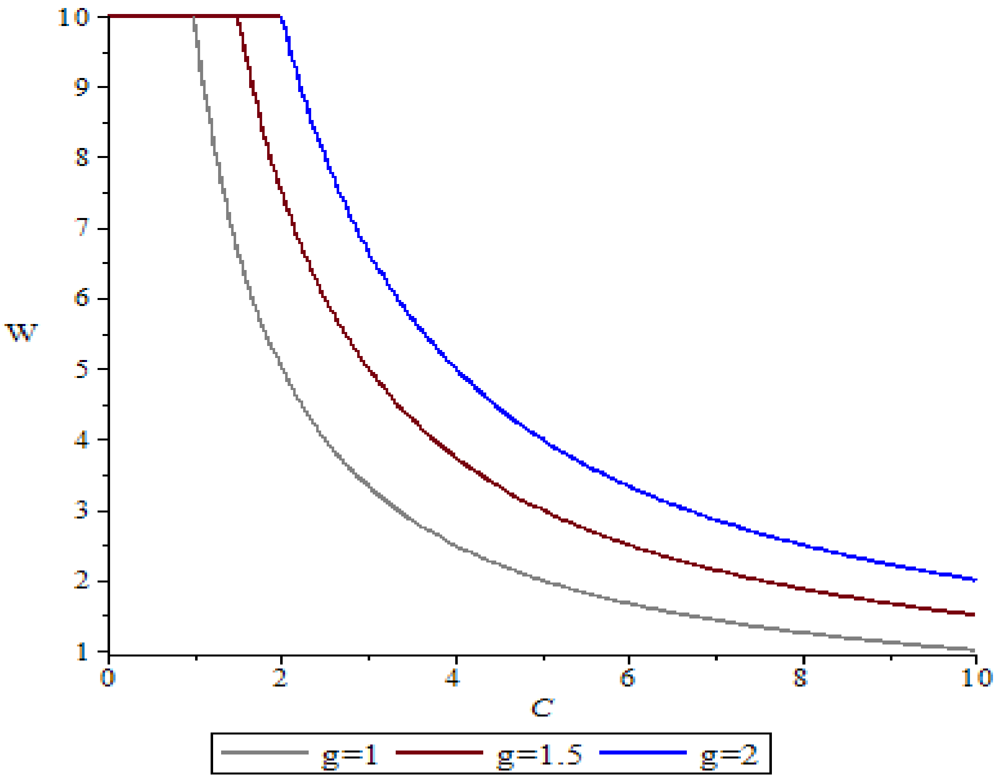
β is the toxicity index of the pesticides per litter;

$g = 1 + i$. This coefficient g takes values equal or superior to 1, with 1 to signify the initial level of toxicity of the applied pesticides. Due to potential improvements (in characteristics, application methods and knowledge) g may increase by a ratio i.

In order to simplify the calculus, we assume that $\beta = 1$.

Thus, the graph for equation (1) is as in Fig 1.

Figure 1.The negative effect of pesticides on wild pollinators



For a given density of the commercial bees, a level of pesticides and a β, we suppose that the pollination supply function has the following form:

$$P(B,W) = d_1 * W + d_2 * B + d_3 * \alpha W * B \quad (2)$$

P: the pollination service (defined as pollen transferred by bees);

B: the density of commercial bees (it is assumed perfectly elastic);

W: the density of wild bees (depending on the use of pesticides) ;

d_i: the pollen transferred per bee;

α: a production coefficient of pollen transferred for one honeybee due to the presence of one wild bee;

αW: the pollen transferred by one honeybee due the presence of W wild bees;

$\alpha W * B$: the total supplementary pollen transferred by B honeybees due to the existence on the same area of a number W wild bees;

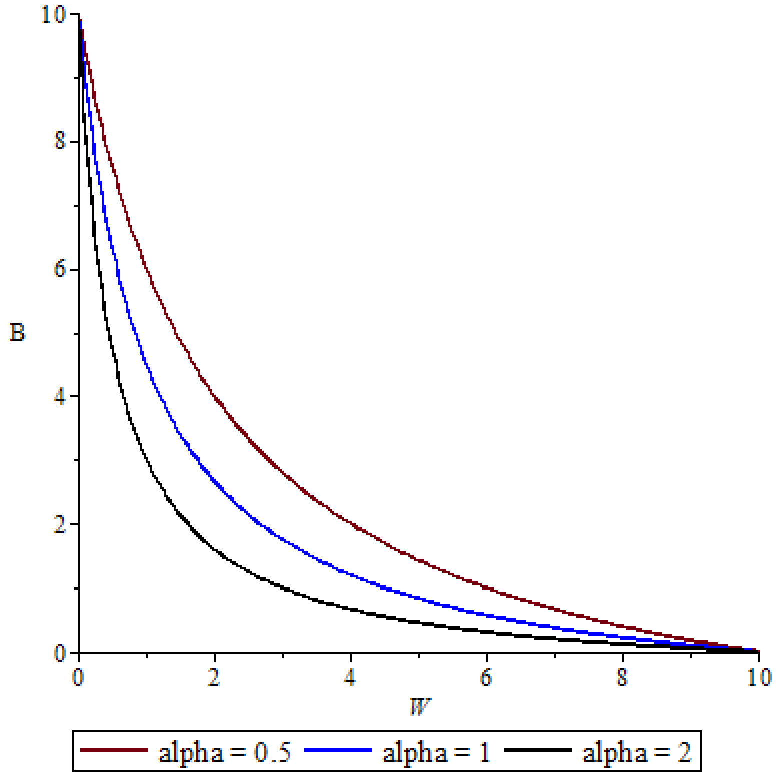
In order to simplify the calculus, we assume that $d_i = d_1 = d_2 = d_3 = 1$,

Thus we can re-write the function:

$$P(W, B) = W + B * (1 + \alpha * W) \tag{3}$$

The equation (2) suggests that this relationship is double sense: the pollination service of wild bees is also improved by the presence of commercial ones.

Figure 2 Pollination Function



B. *Traditional farmer's decision model*

The traditional farmer's decision model takes into account two elements the production function and the prices of the output (yield) and of the production factors including the pollination service providing by the commercial bees only. In order to simplify we assume that the output follows a Cobb-Douglas production function with two inputs: pollination services and pest control. (The other factors contributing to the production activity are represented here by a constant K). However, ecological interactions between bees and pesticides provide a key modification to the standard Cobb-Douglas model by including interactions between inputs. The Cobb-Douglas production function was selected because it represents the need for both pesticides and pollination in agricultural production; we assume that the output is zero if either of the inputs is zero that is both pollination (from commercial or wild bees) and pest control are assumed to be essential. Thus,

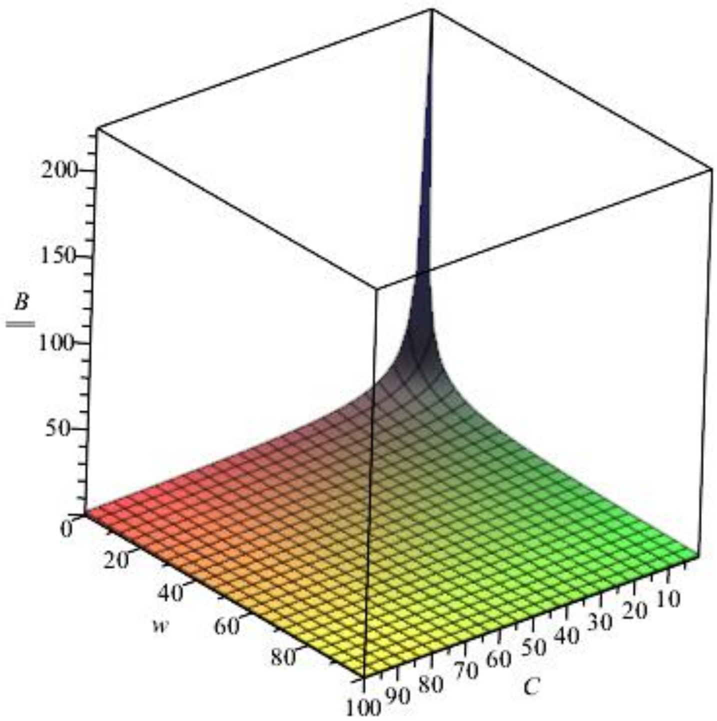
$$F = K * C^{l} * P^{1-l} \qquad (4)$$

Where, l is the output elasticity of pest control and $1 - l$ is the output elasticity of pollination services, we assume $l = 1/2$; K represents a total factor productivity, and without loss of generality we assume K=1.

We integrate the function representing the provision of the pollination service on the farm level, (1) in the production function (4). Then,

$$F = (C)^{\frac{1}{2}} * \left(B + \frac{\overline{w}*g}{C} + \frac{a*\overline{w}*g*B}{C}\right)^{\frac{1}{2}} \qquad (5)$$

Figure 4. A perspective plot



The total cost function takes into account only the marketed inputs, pesticides and commercial bees, as wild pollination service comes free, even if it is assumed to be productive. Thus, the total cost function on the farm level takes the form:

$$c(cc, cb) = cc * C + cb * B \quad (6)$$

Where, cc represents the unit cost of pesticides and cb represents the unit cost of commercial bees. These unit costs are assumed to be constant.

In a first step, let us assume that the farmer minimizes his cost for a given output $\bar{y}$ defined by

$$F(C, P) = \bar{y} \quad (7)$$

Thus, given $\bar{y}$ and cc, cb, the solution of this minimization problem will give us the optimal levels of pesticides C^*, of commercial bees B^* and wild bees pollinators W^* and of course the resulting P^*.

Optimization Results

We assume that the farmer wants to achieve the target level of output, $\bar{y}$, and hence the constraint becomes

$$F(C, P) = \bar{y}$$

The cost function to minimize is:

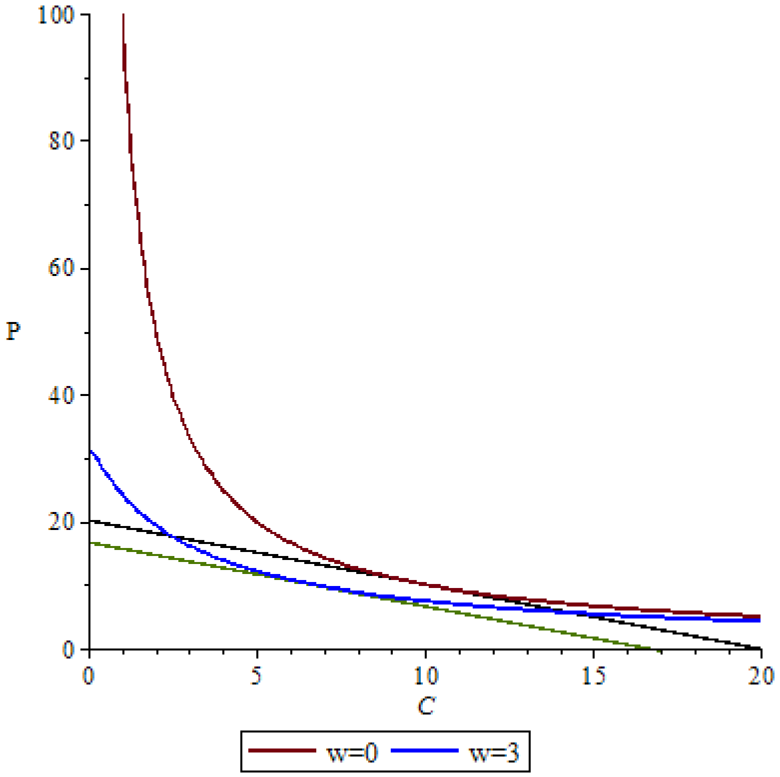
$$c = cc * C + cb * B \quad (8)$$

A pair (C^*, P^*) represents a management strategy that he can choose to achieve this. It is useful to propose first a graphical representation of the optimization results (see graph 4) before entering in the more general mathematical resolution of the optimization problem.

The cost function is represented by a straight line corresponding to $cc * C + cb * B = const$ with negative slope, $-\frac{cc}{cb}$, see Fig 4.

The procedure for optimizing Eqn(5), can be interpreted as finding a minimal value of total cost, c, such that the isocost line is tangent to the isoquant curve corresponding to the target value of $\bar{y}$, see Fig 4. If more than one such line exists (representing local minima), the one with the smallest value of c is chosen. Figure 4 represents two optimal factor combinations corresponding to two different values of $\overline{w}$.

Figure 4 Optimal factors combination



In this graph, the farm's output isoquant is drawn for $\bar{y} = 10$, $g = 1$, $a = 1$. For these values, two different isoquants are depicted, each one corresponding to $\overline{w} = 0$ (red) and $\overline{w} = 3$ (blue). Other parameters: cb = 1 and cc = 1.

As the total cost is linear in C and B, following standard microeconomic theory (Gravelle & Rees, 2004), the conditional factor demands $\hat{C}$ and $\hat{P}$ that minimize the total costs of producing $\bar{y}$ units of output are derived from:

$$\frac{\frac{\partial F}{\partial C}}{\frac{\partial F}{\partial B}} = \frac{F'_C}{F'_B} = \frac{cc}{cb} \quad (9)$$

$$F(C, P) = \bar{y}$$

The conditional demand functions of inputs: pesticides use, wild bee population and commercial bee population are respectively:

$$C = \frac{-cc*g*\bar{w}*a+\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cc} \qquad (10)$$

$$W = \frac{\bar{w}*cc*g}{-cc*g*\bar{w}*a+\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}} \qquad (11)$$

$$B = \frac{\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cb} \qquad (12)$$

We noticed that as the complementarity (α) increases the values of pesticides (C) and wild pollinators (W) increase as well. That is normal as in the high complementarity more W is needed for the production. Moreover, the use of pesticides decreases as α increase. This is happening because the high complementarity indicates the combination of wild and commercial bees. As a result the use of pesticide should decrease in order to reduce the loss of wild pollinators and to achieve the optimal output.

When the price ratio $\frac{cc}{cb}$ decreases the commercial bees become more expensive and as a result, the demand of B decreases. This means that the farmer would like to preserve wild bees knowing that at the same time he is obliged to increase the use of pesticides for a higher output.

Comparative statics

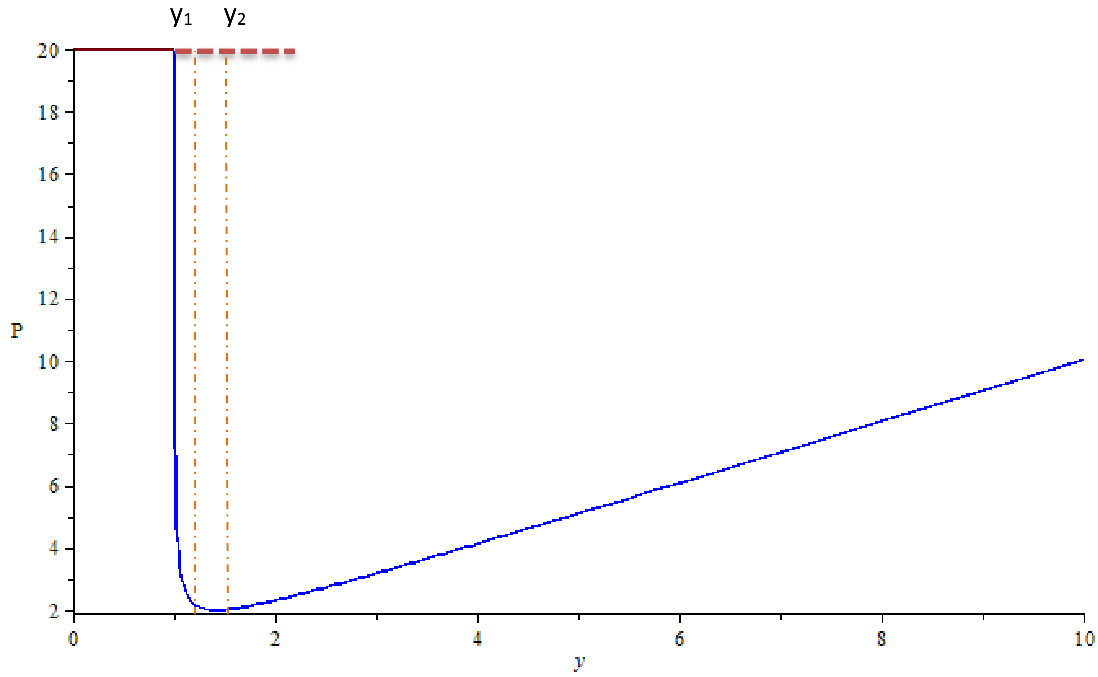
a. No complementarity between commercial bees and wild bees (α = 0). This is the case in the article of Kleczkowski et al., 2013. The equations (10) and (11) become:

$$C = \frac{\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cc} \qquad (13)$$

$$B = \frac{\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cb} \qquad (14)$$

In the case where there is no complementarity between the wild and the commercial bees, the commercial bees are an alternative to wild pollinators. The farmer in order to increase the output $\bar{y}$ starts to use commercial bees in order to compensate the loss of wild pollinators by the increase of pesticide use. As we can see in Fig 5 when the target output level, $\bar{y}$, approaches a certain amount y_1, it becomes economically more interesting to introduce commercial bees to replace the destroyed wild bees. (For a given g in order to increase $\bar{y}$ the farmer prefers to increase the use of pesticides and rely on commercial bees for the associated necessary pollination service.) As a result, commercial bees become an economically attractive option, even though the remained wild bees still provide corresponding pollination services. From y_2 on the wild bees population is zero, all the pollination services are provided by commercial bees only.

Figure 5. Total pollination services as function of the targeted output $\bar{y}$ for $\alpha = 0$



Other parameters: cb = 1, cc = 1, g = 1, w = 1.

When the output level is $y_1 \leq \bar{y} \leq y_2$ the pollination provided to the farmer is a combination between wild and commercial bees. From any targeted output superior to y¯ the pollination depend only on the commercial bees, as the wild bees have been eliminated due to the high use of pesticides, results the increase of the total cost.

Proposition 1

If pollination is provided by wild bees only, there is a limited output that can be achieved. This output is determined by the ecology of wild bees and their interaction with pesticides.

Proof

The mechanism for this behavior is related to the balance between pesticides use (g) and wild pollinators. If the farmer wants to increase the level of output, he needs to increase the level of pesticide use, which in turn effects the wild bee population. The coefficient g plays a very important role as from its value depends the level of production that we can have without the use of commercial bees. This result is given by analyzing the value $cc * cb * (\bar{y} - g * \bar{w}) \geq 0$.

If $\frac{\bar{y}^2}{\bar{w}} \geq g$, any further increase of $\bar{y}$ must be followed by increase of commercial bee populations.

If $\frac{\bar{y}^2}{\bar{w}} \geq g$, the targeted production $\bar{y}$ can be realized by the use of wild bees only.

As a result, we can see that a potential decrease of toxicity effect of the pesticides on the wild bees by increasing the coefficient g gives to the farmers the opportunity to increase the output $\bar{y}$ by the use of wild bees only. This improvement of g by innovation gives to the farmer the opportunity to increase the production without to increase the cost by the use of commercial bees.

b. Medium complementarity (α = 0.5)

$$C = \frac{-cc*g*\bar{w}*0.5+\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cc} \quad (15)$$

$$W = \frac{w*cc*g}{-cc*g*\bar{w}*0.5+\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}} \quad (16)$$

$$B = \frac{\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cb} \quad (17)$$

In the case of a medium complementarity between wild and commercial bees we noticed the following results. Firstly, the value $y_1'$is much more higher than the y_1. As a result the farmer in this system is capable to produce higher production than the previous one only by the use of wild pollinators. Secondly, the value of $y_2' > y_2$ giving to the farmer the opportunity to product higher output by keeping the cost at minimum as the range of collaboration between wild and commercial bees is significant at this system. (Fig 6)

c. High complementarity (α = 1)

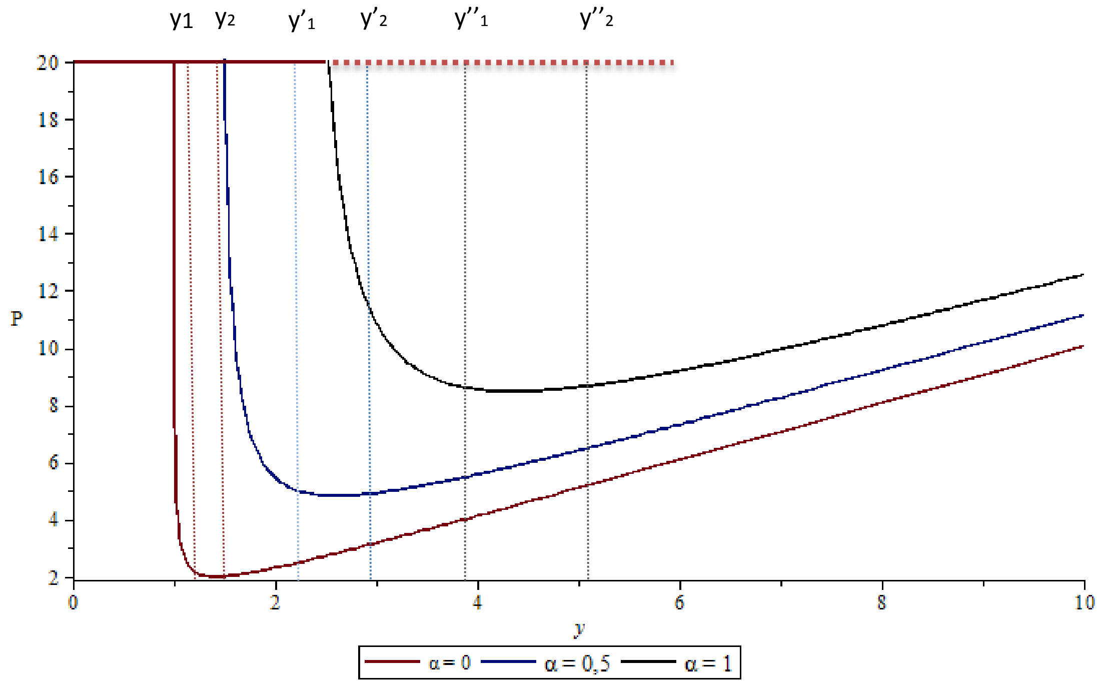
$$C = \frac{-cc*g*\bar{w}+\sqrt{cc*cb*(\bar{y}^2-g*\bar{w})}}{cc} \quad (18)$$

$$W = \frac{w*cc*g}{-cc*g*\overline{w}+\sqrt{cc*cb*(\overline{y}^2-g*\overline{w})}} \qquad (19)$$

$$B = \frac{\sqrt{cc*cb*(\overline{y}^2-g*\overline{w})}}{cb} \qquad (20)$$

In the case of high complementarity (oilseed crops) between the two groups of pollinators the stoke of wild pollinators $\overline{w}$ can contribute to a much more higher production $y_1'' > y_1' > y_1$ than in the other two systems (Fig 6). Moreover, the range y_1'', y_2'' is much higher than in the previous systems. As a result, the collaboration between wild and commercial bees is much more effective here and we can achieve a high output $\overline{q}$ with a minimum cost. Any desire for output higher than y_2'' leads to an extinction of wild bee populations and this output can be achieved only by the increase of pesticide use and the corresponding increase in the total pollination services (only by commercial bees).

Figure 6. Total pollination services as function of the targeted output $\overline{y}$ for different values of α



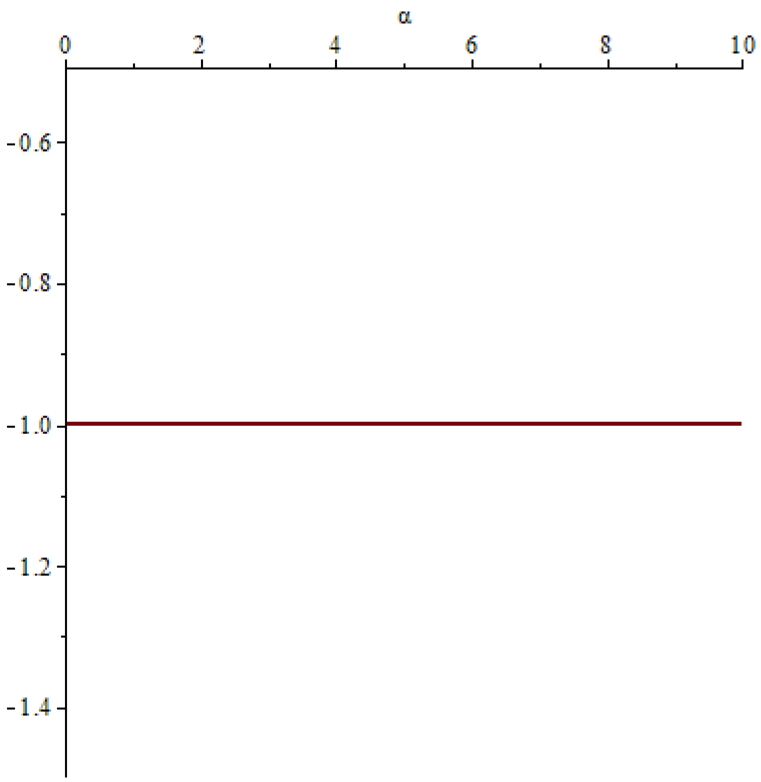
Other parameters: cb = 1, cc = 1, g = 1, w = 1.

Proposition 2

The level of complementarity between wild and commercial bees defines the level of the applied pesticides. As the level of complementarity (α) increases the need of wild pollinators increases too and as a result the level of pesticides decreases.

Proof

The conditional factor demand function of C regarding α is negative positive and perfectly elastic. This is happening because the conditional demand function of C regarding α depends only on g and wild bees stock $\overline{w}$. When α is zero, $\frac{dC}{d\alpha}$ is zero as well. In the case that α≥0 means that the constant output $\bar{y}$ depends on the complementarity between wild and commercial bees and as a result, the existence of wild bees is essential. That's why the conditional factor demand function of C regarding α depends directly to the wild bee stock and on the capacity of the farmer to reduce the toxicity of pesticides on the wild bee population value (coefficient g).



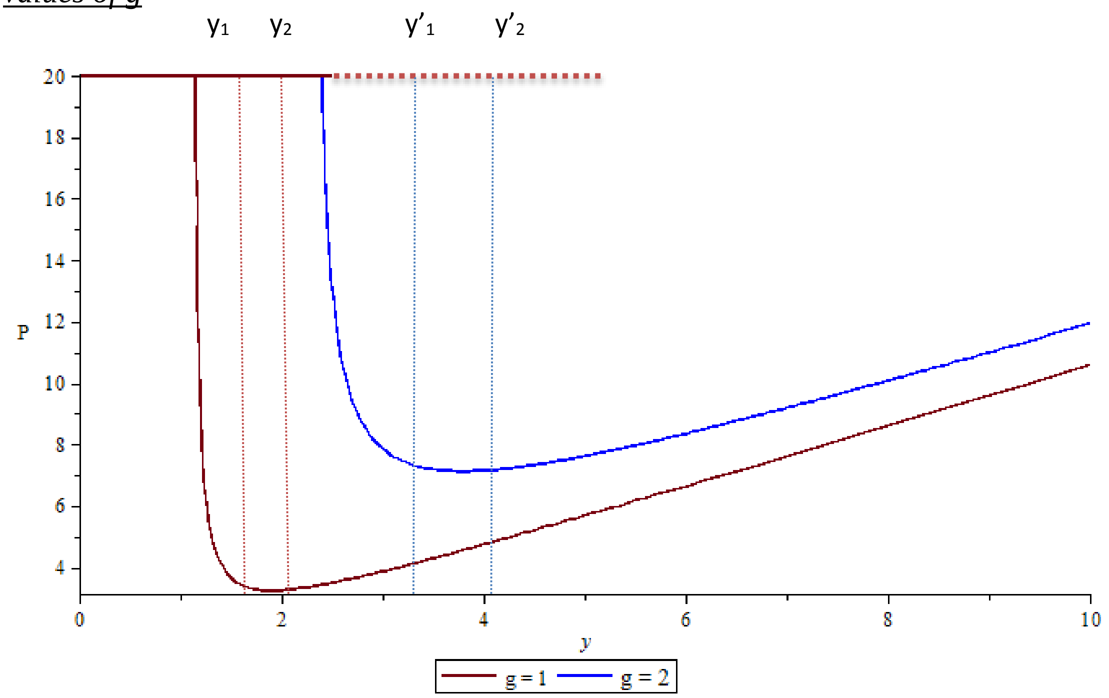
Other parameters: g = 1, $\overline{w}$ = 1, cb = 1, cc = 1, $\bar{y} = 10$.

Sensitivity analysis

1. *Sensitivity to changes of coefficient g*

As we have already said g is a coefficient measuring the capacity of the farmer to reduce the toxicity of pesticides on the wild bee population. The amelioration of g by the innovation gives to the farmers the opportunity to product higher output $\bar{y}$ depending more to the wild pollinators.

Figure 7 <u>*Total pollination services as function of the targeted output $\bar{y}$ for different values of g*</u>



Other parameters: α = 0.5, cc = 1, cb = 1, w = 1.

The dependence of threshold values y_1, y_2 and y'_1, y'_2 describing the effect of pesticides on wild bees. As g increases the system can support the wild pollinators for higher output. Moreover, the range where the wild bees co-exist with the commercial ones increases as the coefficient g increases. In addition, the point where the commercial bees become economically viable increases as g increases $y_1 < y'_1$.

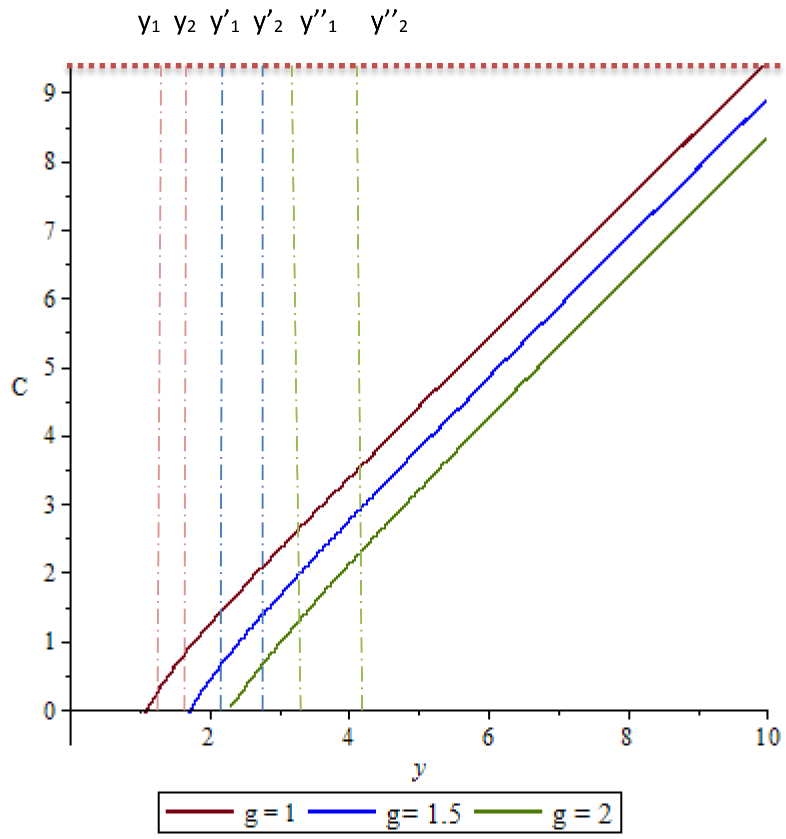
In the case of pesticides use, as g increases the level of pesticides needed for the same amount of production decreases. As a result with better g the farmer has the opportunity to produce at the optimum with an "ecologically safer" strategy. Fig(8)

These results can be summarized as:

Proposition 3

The shift to a less damaging pesticide or to better application methods (increasing g) should give to the farmer the opportunity to produce the same output $\bar{y}$ by decreasing the use of pesticides due to the increasing of wild pollinators.

Figure 8. Pesticide use as function of the targeted output $\bar{y}$ for different values of g



Other parameters: α = 0.5, cc = 1, cb = 1, w = 1.

2. *Sensitivity to chances of wild bees stock $\overline{w}$*

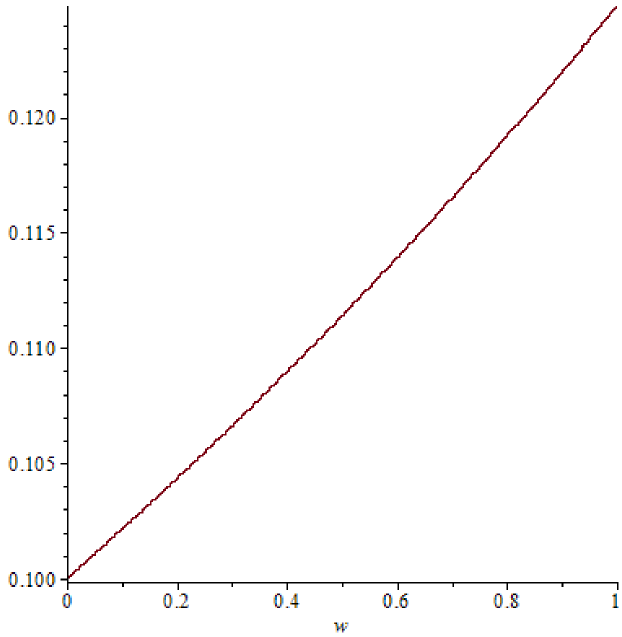
As the wild bees stock $\overline{w}$ increases, wild bees are able to provide most of the pollination services with a given g. As a result, the threshold output y_1 increases to y_1'. An increase of $\overline{w}$ should be effected by expanding field margins of by protecting refugia for wild bees, for instance. In this way, increased $\overline{w}$ implies less use of pesticides and less commercial bees, hence leading to the reduction of total cost.

Proposition 4

An increase on the wild bees stock ($\overline{w}$) signifies a direct increase on the wild pollination density (W).

Proof

The conditional factor demand function of W regarding $\overline{w}$ $\left(\frac{dW}{d\overline{w}}\right)$ is always positive and can be zero only when the wild bees stock $\overline{w}$ is zero. As the wild bees density depends directly on the wild bees stock is normal that when the $\overline{w}$ increase the conditional factor demand of W increase as well. An increase of $\overline{w}$ should be effected by expanding field margins of by protecting refugia for wild bees, for instance. In this way, increased $\overline{w}$ implies less use of pesticides and less commercial bees, hence leading to the reduction of total cost.



Other parameters: α = 1, cb = 1, cc = 1, $\bar{y}$ = 10, g = 1.

Mathematical Programming (MP) modelling

1. Simple MP model for two crops

The first step in this work is to create a simple bio-economic model in order to analyze the relationship between pollination and farm decisions. This analytical model gives to the farmer the choice to cultivate sunflower or maize. We choose these two crops in order to highlight the difference between an oilseed (which depends on bee pollination) and maize (whose yield is less dependent of pollination). Moreover, in order to link in a relatively dynamic way the production's decisions and their impact on pollinators (wild bees), we introduce a two period framework. In the first year we start with a given level of wild pollinators. This initial level may be affected by the use of pesticides at the end of the first period so that the existing level of wild bees in the second period may be reduced. This two period farmer's decision model decides each period's quantity of inputs including pest control and related pollination services (wild and / or commercial bees) and calculates the corresponding net revenues.

The wild bees density $W = \overline{w}$ is given for the first year, while in the second period the wild bee density is calculated according to the use of pesticides.

Pollination Function

The ecological regression model was integrated into the economic model by adding it as a separate equation that provides the relationships between pollination and farm management variables.

$$P_t = \sum_{s,m} [x_t(W_t + B_t + A_t)]$$

Where:

P_t: the total pollen transferred by bees in the area;

W_t: density of wild pollinators in the area under crop management;

B_t: density of honey bees in the area crop management;

A_t: the total supplementary pollen transferred by B honeybees due to the existence on the same area of a number W wild bees, in the area under crop management. This expresses the complementarity component $\alpha W * B$ of the equation 2. The α takes different prices for each crop;

In order to differentiate between the two crops, we suppose that this complementarity effect is very important for the sunflower crop and close to zero for maize.

The production function of the two crops is a Cobb-Douglas function taking the general following form

$$y = K * C^{l} * P^{1-l}$$

Where C is the total use of pesticides.

The expected farmer's income comes from the following equation:

$$R_t = \sum_{s,m} [(x_t(y_{s,m} p_{s,m} - w_{s,m}) - FC)]$$

Where,

x_t is the annual area under each crop management;

y is the annual yield per crop;

w_s represents the annual variable costs of sunflower;

w_m represents the annual variable costs of maize;

p_s represents the price of sunflower per ton;

p_m represents the price of maize per ton;

FC represents the annual fixed costs;

Constraints of the analytical model

- Land

$$\sum_{s,m} x_t \leq LAND$$

- Labor: The labor is composed by the family workers and possible extra seasonal workers according to the needs of the farms

$$\sum_{s,m} x_t \, L_{s,m} \leq \bar{L}$$

Where, $L_{s,m}$ is the labor needed for each crop and $\bar{L}$ is the available labor of the farm;

- Pollination: The bees number (wild and commercial) in the area at the end of the first period should not be lower than the initial wild bees stock:

$$\bar{w} \leq \sum_{s,m} x_{t1}(W_{t1} + B_{t1})$$

- For the second period the level of the initial stock of wild bees will be equal to Wt1 so that the constraint will be:

$$W_{t1} \leq \sum_{s,m} x_{t2}(W_{t2} + B_{t2})$$

- Pesticides use : A low level of pesticides should be used in order to guarantee the crop production

$$\sum_{s,m} x_t C_{s,m} \geq \bar{C}$$

Where, $C_{s,m}$ is the pest control for the each crop and $\bar{C}$ the lowest level of pesticides in order to a guarantee the crop production;

We run simulations for different levels of initial wild bees stock in order to examine the farmer's decisions on crops management, pesticides use and pollination.

Results

The results of this simple analytical model indicate that the farmer's decision is sensitive to the wild bees stock. When $\bar{w}$ is high, the farmer prefers to cultivate only sunflower in the first period as the variable costs are lower due to the lower pesticides use and to the low need for beehives. During the second period, the production capacities for sunflower are improved because of the previous low pesticides use and the consequent higher wild bees population. Thus, the optimality criterion results to an even higher sunflower surface for the same reasons. On the contrary, when $\bar{w}$ is low, the farmer turns to maize as the former crop's yield is much less dependent on pollination. Of course, during the second period the W is going to be even lower and because of the pollination constraint the farmer's variable costs increase due to the purchase of beehives. This increase has a certain negative impact on the maize surface whose level depends on the price of beehives, other things been equal.

In the following section we are going to present simulations performed with a more complete MP model. The production decisions and the farmer's expected revenue are calculated based on a real life context under yield risk in South-Western France.

2. The structure of the MP model

This model enables us to depict the farmer's production decision through an optimisation choice among several crops, techniques, variable inputs and pollination activity. Thus different existing and novel practices with different levels of inputs are competing and technical changes are explicitly modelled. This approach also takes into account the existing policy tools of CAP as well as the farmers' possibility contract agri-environmental measures by their will. The choice of contracting is endogenous thanks to the use of binary variables. These kinds of methods have been applied for a major number of studies on farm or territorial level by embracing mixed ecological-economic analyses (De Koeijer et al, 1999; Falconer and Hodge, 2001; Mosnier et al, 2009; Havlik et al. 2005).

The objective function

The optimization model maximizes the expected utility of income over one period. The model considers the yield variability depending on climate conditions, pollination levels, and soil types. The yield distribution is discrete and depicted through states of nature *k*. We considered that farmers opposed to the new practices (risk aversion) and the expected utility model is retained. The expected utility of income is the arithmetic mean of the utilities obtained for the various states of nature of the observed yields. Generally, it is supposed that for every state of nature (good or bad) the farmers allot the same weight. According to the literature the farmers give generally more weight to the bad seasons than the good ones (following equation).

$$EU(\tilde{R}) = \sum_{k} U(R_k) \times \pi_\kappa$$

EU(R) : expected utility of the risky income;

$U(R_k)$: utility or income per state of nature k;

π_k : probability of each state of nature;

We suppose here that these new farming practices use fewer pesticides than the conventional ones which thus imply better pollination levels as well as variations in the obtained yield and its variability. However, the model does not ignore the unpredictable increases or decreases of the crops prices.

To obtain the optimal solution for the MP model, CONOPT and SBB solvers were used in GAMS software, in 100 states of nature according to these distributions. As we have already mentioned above the article assumed that the yield variability increases under the use of the tree novel practices (General Algebraic Modelling System).

Considering that yield variability is the only source of risk, the vector of net incomes by state of nature *k*, R_k is calculated and $U(R_k)$ is a vector of utilities weighted by w_k the probability per state of nature (Lambert and Mac Carl, 1985; Lien and Hardaker, 2001). The utility function is CRRA type:

$$U(R_k) = \left(\frac{1}{1-r}\right) * (R_k)^{(1-r)} \qquad \text{When r > 0 and r} \neq 1$$

$$U(R_k) = \ln(R_k) \qquad \text{When r = 1}$$

R_k is the expected income for state of nature k;

r is the coefficient of relative risk aversion

The net income is divided in two parts: market returns and subsidies,

$$R_k = \sum_{c,n} \left[x_c \left(y_{c,k} p_c - w_c + s \right) + x_n (y_{n,k} p_c - w_n + s + AEM) \right] + \bar{S}D - FC$$

Where,

p is the vector market price of crops; w is the variable cost per hectare of crop.

x_c represents the area under conventional crop management;

x_n is the area under novel crop management;

$y_{c,n}$ is the yield per crop for every state of nature k. In this version of the model, we have related the yield of every crop under conventional and novel practices with different pollination levels in the following simplified way. Three pollination levels, low, medium and high, are supposed to be obtained following respectively the existing use of pesticides (conventional practices), a 50% reduction of pesticide use in new practices and a total absence of pesticides in new practices. For every such pollination/pesticides combination, the yield of every crop and its variability has been defined according to information obtained from existing literature. (Bartomeus et al., 2014)

Fixed costs are noted FC. The subsidies from CAP first pillar are introduced; the coupled subsidy per hectare of arable crop is noted s and decoupled Single Farm Payment is noted D. It is distributed to the whole farming area $\bar{S}$. Also, an Agri Environmental Measure (AEM) is allocated to areas cropped under novel practices x_n.

The constraints of the MP extended model

The main constraints of the model are related to agronomic, environmental, and economic resources related as well on the existing public policy:

- Land: The composition of the soil type is different for both types of farms
- Irrigation: The irrigated land is limited for each farm type
- Rotation: The rotation of each crop is identified and the share of area of each crop is limited by the total area of its previous crop

$$X_{c,\text{"}previous-crop\text{"}} \leq \sum_{previous-crop} X_{\text{crop},pc}$$

- Labor: The labor in each farm type is composed by the family workers and possible extra seasonal workers according to the needs of the farms
- CAP cross compliance: In order for farmers to receive the entire amount of Single Farm Payment
- Set-aside constraint: A rate of 10% set aside of the surface in cereals, oilseeds and proteins crops is imposed according to former CAP regulation

- Buffer strip constraint: A rate of 3% of surface allocated for cereals, oilseeds and proteins crops has to be converted into buffer strips.

Area study and farm typology

Farm types

The expected income in this model calculated in two farm types with two different cropping systems, in the river basin called "Gers Amont", belonging to the Adour-Garonne watershed located in the Midi- Pyrénées region. The program has been tested to 700 farmers on a total area of 37 000ha.

Farm-type 1: specialized in "dry cereals"

The farm-type 1 is specialized in dry cereals, located in the driest and most hilly areas of the river basin and where the main crop rotation is durum wheat followed by sunflower and represents about 35% of the total area. Six different crops can be grown on this type of farms type: durum wheat, soft wheat, maize, rapeseed, sunflower and soya. The initial wild pollination level in this area are higher than in farm-type 2 as this farm-type is located in hilly areas and close to natural habitats.

Farm-type 2: predominance of irrigated maize

The farm-type 2 is specialized in irrigated maize and located in valleys where the main rotations are maize/maize or maize/soft-wheat or maize/soybean and it represents 17% of the total area. The wild pollination levels in this area are lower than in previous farm-type. As farm-type 2 is located in valleys with high agricultural activity and small number of natural habitats the initial wild bees stock ($\overline{w}$) is lower than in farm-type 1.

Assumptions of the simulation scenarios

We tested the following new scenarios in the examined area in order to highlight the set of conditions under which the pollination sensitive crops such as oilseeds (sunflower, rapeseed and soya) can be included in the rotations of farms, given the local as well as the market and public policy context.

- Scenario 1: Following the EcoPhyto[3] program in France, we impose a decrease by 50% on the pesticides use for the different crops. This decrease is replaced by an increase by three times of all the mechanical operations. Furthermore, this scenario allows a subsidy for the adoption of this new measure by the farm-types. It is assumed that a decrease in pesticides by 50% reduces yield by only 10%. Other such heavier yield reductions could be considered.

- Scenario 2: It represents the new regulation of the European Union banning the pesticides linked to bees (and other insects) decline (see above). In this scenario, we proposed a 100% decrease in the pests by imposing penalties for their use under the common techniques. This decrease is replaced by a five times increase in all the mechanical operations costs while we assumed that a 100% decrease in the pesticides reduces yield by 20%.

- Scenario 3: The last scenario is exactly like the scenario 2 but instead of a penalty for cultivating under the traditional practices, we propose an AEM subsidy for the adoption of the new practices for rapeseed, maize and sunflower.

The results of these scenarios are compared with the baseline scenario used for calibration and corresponding to the situation of 2013 for prices and the CAP regulations at the examined area. The main outputs of the simulations we report here are: i) the crop patterns and the surface converted under new farming practises, ii) pesticides use and bee populations, iii) the expenses in AEM subsidies or penalties.

<u>Results and sensitivity analysis</u>

The following section reports the results of the three scenarios performed for year 2013. The results of these scenarios are compared with the baseline scenario before setting up agri-environmental measures.

i) Crop patterns and the crop patterns and the surface converted under new farming practises

[3] http://agriculture.gouv.fr/Ecophyto-in-English-1571

The results in **Scenario 1** show some changes in the crop pattern of the two farm-types (figure 1, 2). In farm-type 1 the surface of oilseeds (sunflower and rapeseed) increases due to the existence of an AEM subsidy. However, there are some other complementary reasons for that. The total surface of sweet wheat and durum wheat decreases. In this scenario, we noticed a strong increase of barley due to the low yield variability of this crop contrarily to that of soft and durum wheat. In addition, the total surface of the maize slightly increases because maize has better relative price and smaller yield variability than soft and durum wheat. In farm-type 2, we noticed that the maize/maize rotation is very favorable due to the high price and low yield variability. As a result, the farmers start to cultivate oilseeds only in very high values of AEM subsidy. As sunflower and maize are competing crops the farmers prefer to keep high level of maize and to introduce rapeseed in their rotation systems. Moreover, the yield variability of rapeseed is lower than the sunflowers. However, the sunflower appears in this farm-type the second year in the rotation with the soft wheat.

The results obtained in **Scenario 2**, for farm-type 1 show that the farmers has no will to cultivate oilseeds with low use of inputs even if the yield variability remain at the same levels. They prefer to change their rotation systems to more stable and profitable crops such as the soft wheat and maize. In the case of farm-type 2 the results show that is affected more severely under the new measures of the European Union. The farmers increase the total surface of soft wheat because of its lower yield variability and of the penalties that strike the other crops. The level of maize under the conventional practices remains almost at the same level as in scenario 1 because of the low yield variability, the high price and the irrigation systems.

The results of **Scenario 3 -**reducing pesticides by 100% with an AEM subsidy show a major change in crop patterns in farm-type 1. The soft wheat and maize surfaces fall while the surface with rapeseed and sunflower increases considerably. The AEM subsidy gives again to the farmers the motivation to introduce once more the oilseeds. In farm-type 2, as expected, a much higher subsidy is necessary in this case as oilseed crops are competing with maize cultivation in the irrigated area. Instead of oilseed crops the farmer increase the cultivation of soft wheat and keeps the surface of maize almost in the same levels. Finally, a very interesting point is that the farmer chooses to cultivate a small surface of soya instead of sunflower.

Figure 9.

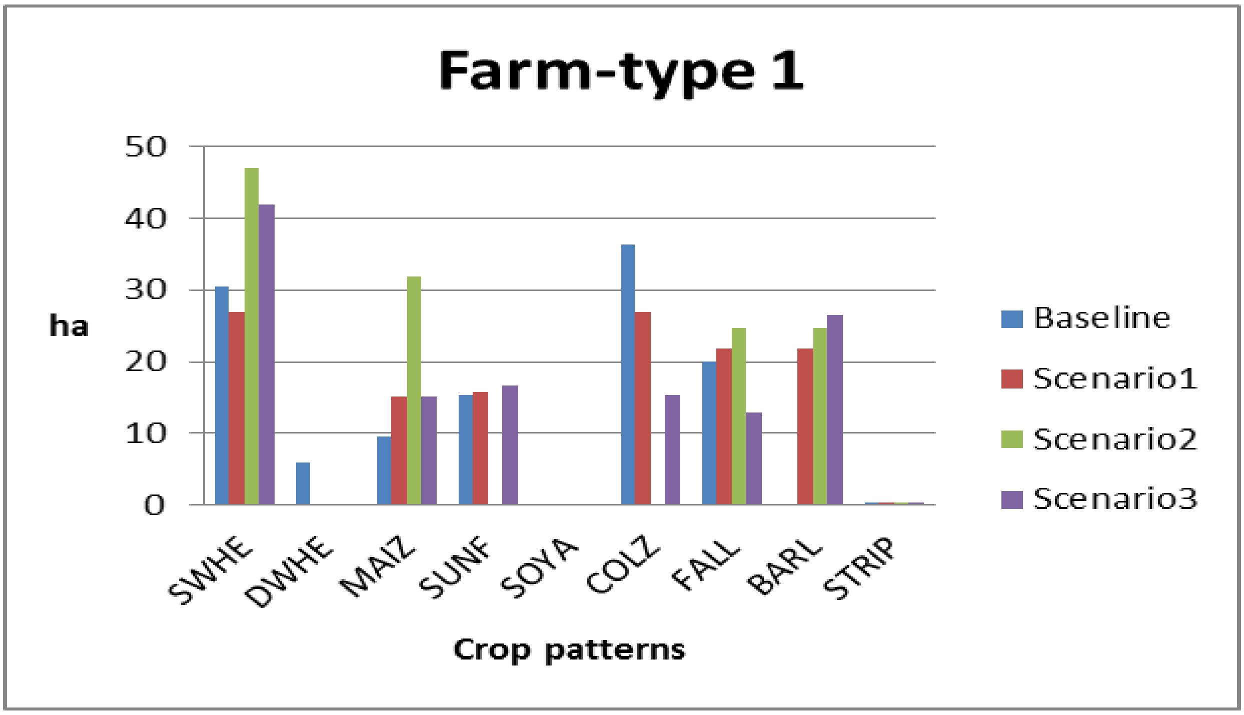
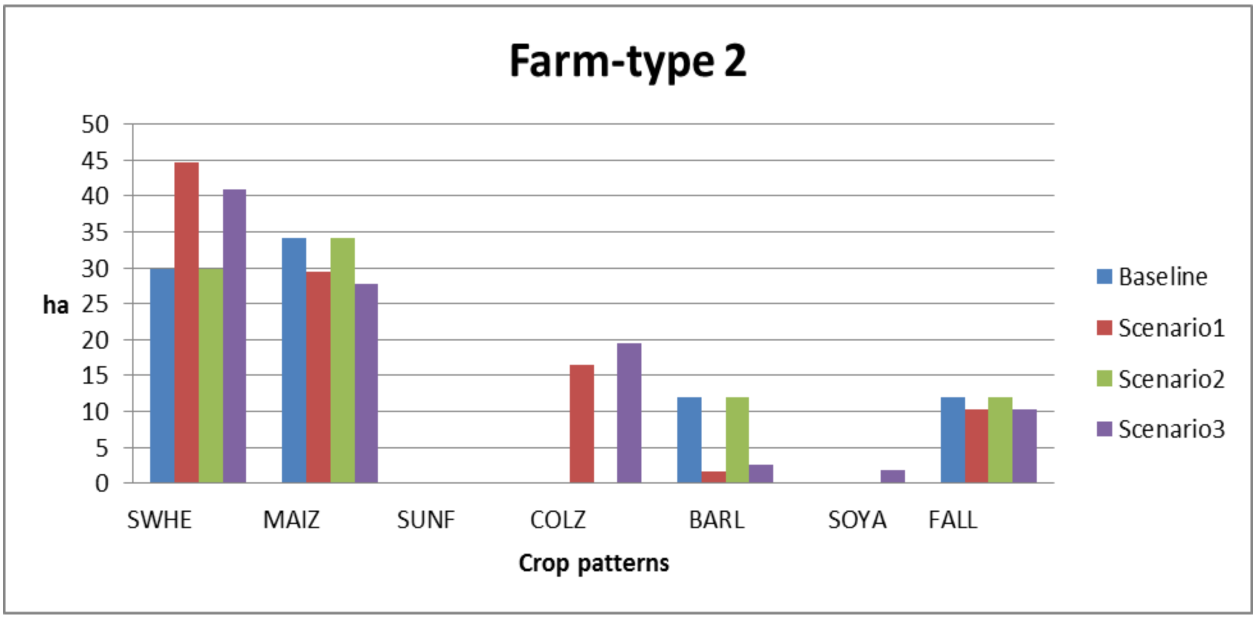


Figure 10.



ii) Pesticides use and bee populations

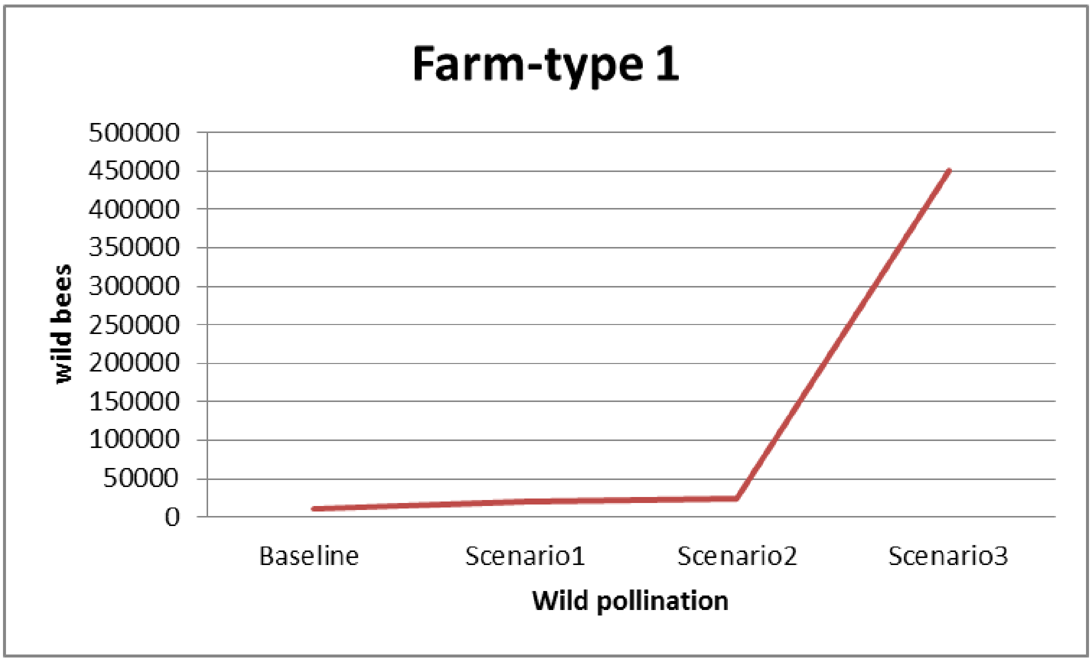
Farm-type 1

Concerning **Scenario 1**, the pesticides use decreases by 50% in the surfaces of rapeseed and sunflower due to the AEM measure. Concerning pollination, the wild pollination in this scenario has a significant increase accompanied by reduction of the farm's expenses for beehives. This is happening firstly because of the increase in the oilseed surfaces which necessitate less pesticides treatment. Secondly, the adopted rotation systems of soft-wheat/sunflower and fallow/sunflower guarantee a 50% reduction in the pesticides use over soft-wheat surface because the sunflower is going to follow the next year. In other terms, the level of pollination has to remain in sufficient levels in order to secure the sunflower yield during the following year. The wild pollination levels increase also because of the augmented place of fallows and the consequent absence of pesticides on them. Finally, an extra increase on wild pollinators is provided by the use of buffer strips which provide natural habitats and nesting spaces.

In the **Scenario 2**, the pesticide use decreases by 100% for the oilseed crops. Unfortunately, there is no surface of them in the current year something that we interpret in the following way. With uncertain yields and the increase of labour needs due to the reduction of pesticides use, farmers will try to concentrate their efforts and time availability on crops having the strongest gross margins. However, in this scenario we noticed a slight increase on the wild bee populations. This is happening because of the penalty on the cultivation of crops under the conventional practices. As a result, with no cultivation of oilseeds and cultivation of maize with medium pesticides use (they prefer to pay the penalty than to stop using pesticides) the use of neonicotinoids decrease and we noticed a slight increase in the population of wild bees. Finally, the surface in fallow and the buffer strips play a role for their increase.

In **Scenario 3**, the AEM subsidy motivates farmers to cultivate oilseed crops under the novel practices (pesticides decrease by 100%). The absence of pesticides and the cultivation of oilseeds (especially sunflower) in significant surfaces increase the wild bees population in the area. However, as the fallow surface decreases, this wild bee population is mitigated. The soft-wheat/sunflower rotation is again used by the farmers in this scenario as in scenario 1, and consequently the wild bees population increases more. Finally, as in the previous scenarios, the buffer strips increase the wild bees population. The figure 11 displays the evolution of the wild bees and the corresponding commercial bees and their cost throughout the three scenarios.

Figure 11.



Farm-type 2

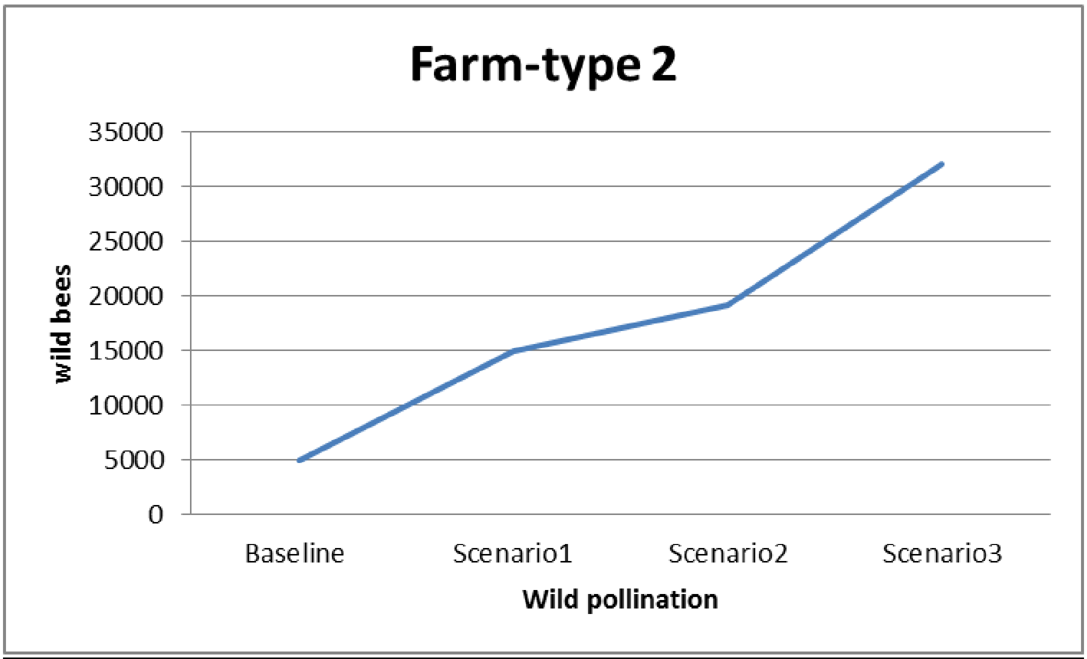
The pollination levels in Farm-type 2 are lower than in Farm-type 1. This is because this farm-type is located in valleys with less natural habitats than in farm-type one which is located near to forests. Moreover, the agriculture activity is more intense in this farm type area and the oilseed production (which is linked to pollination) is relatively not profitable for farmers.

The results of the **Scenario 1** show an increase in the wild bees population. This is due to the cultivation of rapeseed in a significant surface under the novel practices (50% decrease of pesticide use). Moreover, the sunflower is going to appear the next year in the rotation with soft-wheat. This rotation means lower chemical use in the soft-wheat surface in order to preserve the highest amount of wild pollinators for the sunflower production. Finally, the fallow levels in this farm-type are lower in every scenario and as a result they are offering less natural habitats for the wild pollinators.

In the **Scenario 2**, the oilseed crops are totally absent as in farm-type 1. The wild pollinators show a slight increase for the same reasons as in farm-type 1. The absence of oilseed crops and the cultivation of maize under low pesticides use decrease the neonicotinoid insecticides. Thus, there is no toxicity for the wild pollinators and with the help of the fallow surface and the buffer strips we notice this slight increase.

The results obtained in **Scenario 3** show a high increase on the wild bee populations due to the cultivation of rapeseed and soya under the novel practices (100% decrease on pesticide use). Furthermore, the traditional soft-wheat/sunflower rotation increases more the wild pollinators. Finally, as before, the fallow and the buffer strips contribute to the increase of pollinators.

Figure 12.



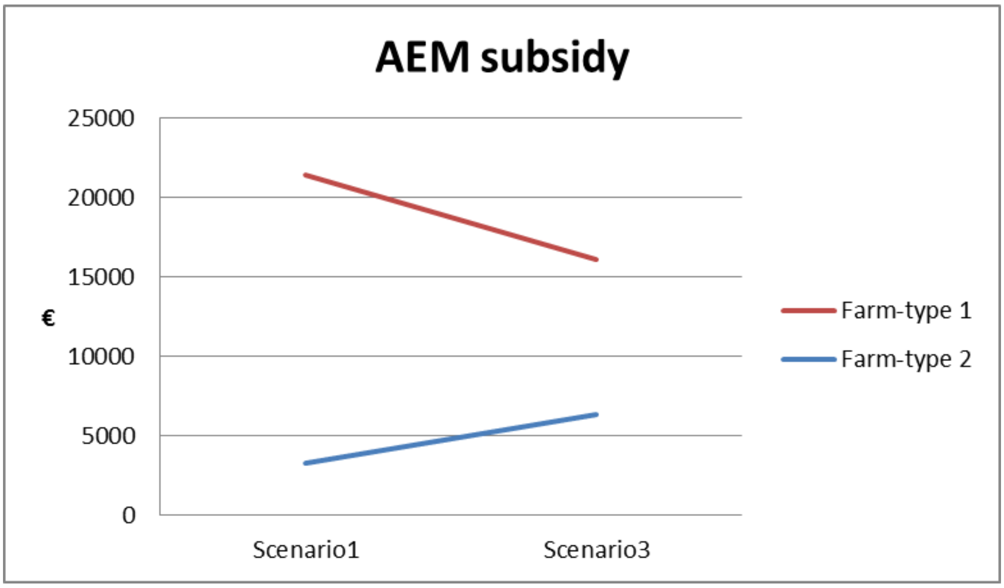
iii) The costs in AEM subsidies or penalties

The result obtained in **Scenario 1** show us that in farm-type 1 an AEM subsidy of 100 €/ha is enough to convince the farmers to adapt rapeseed under the novel practices. In the case of sunflower an amount of 500 €/ha is needed. In farm-type 2 a subsidy of 200 €/ha is needed in order to adapt the rapeseed under the novel practices. However, sunflower can be adapted only for extremely high prices.

In **Scenario 2**, the penalty measure gives the same result in both farm times. There is no cultivation of oilseed crops neither in novel or conventional practices. In farm-type 1 the farmers prefer to change the sunflower surfaces to fallow and maize. In farm-type 2 the crop patterns return in the baseline scenario with absence of oilseeds.

Scenario 3 shows us some very interesting results. We found that a subsidy of 500 € per ha in both farm-types is enough in order to convince farmers to shift from traditional crops into rapeseed and sunflower under the new practices.

Figure 13.



Conclusion

In this paper, we tried to analyse the dynamic relationships that evolve between agricultural production and bee pollination services. We considered the specific place of oilseed and especially sunflower production inside crop rotation systems as the former crops display specific dependence and even interdependence with insect pollinators. For this analysis, we constructed three linked models, one analytical and two others by using MP methods. Even if the three options are focusing at the same subject, they are complementary in the sense that each one of them tries to highlight specific relationships.

In the analytical model, we analyse the importance of the complementarity between wild and commercial bees in the production from the economic point of view. We examined the effects of a possible amelioration of the pesticides toxicity on the bees population as well as on the yield under the economic optimality criteria. In the first MP framework, we proposed to distinguish between two specific crops each one differentiated by its dependence on pollination services. In order to enter more deeply into the analysis we constructed a two periods decision model. Among other data, the farmer’s decision about the type of crop grown up depends here on the initial wild bees population available. This MP framework was extended in the third option in order to focus at the choice between practices available for a large number of crops. Based on a real life data, each practice and the related crop yield have been linked to a specific pesticides treatment and the associated impact on the bee populations.

Our results highlight that, depending on different agronomic contexts, and in presence of public policy incentives, the implementation of new farming practices can be an opportunity for farmers to re-consider their options towards more profitable crops and ecological projects.

The key results in this paper are: Firstly, by the combined use of commercial bees and wild bees the farmers can achieve better sunflower seed yield than relaying only on pesticides use, while maximizing their revenue and thus keeping the cost at minimum. Secondly, the extended model displays a tradeoff between the farm yields (by increasing the pesticides use) and the local decline in the wild bee population. Thus, a decrease in the use of pesticides might lead to an increase in the bee population and to better and more stable sunflower yields. The model is able to evaluate the cost of farmers' need in commercial bees, which may be compelling and thus expensive. Thirdly, by the tested scenarios we highlight the set of conditions under which the sunflower as a food (seed, sunflower oil, confection markets etc.) and as energy crop can be included in the rotation of farms, given the local as well as the market and public policy context.

This research tries to extend some already existing published work (Ridier et al, 2013) and allows some interesting new propositions, as it attempts to introduce some complementarity between the two kind of bees, wild ones and commercial ones. Another proposed innovation consists in the integration of agricultural practices varieties and their links with the pollination population and corresponding services. There is a lot to do in order to produce more consistent arguments particularly by means of more homogenous hypotheses across the three presented models. Relatively to the realism of our modeled context, even if we tried to base our findings on a real field context, it is necessary to update our data and simulations in order to follow the new regulations and public schemes carried out through the implementation of the new CAP.

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