EVALUATING POLICY OPTIONS FOR MANAGEMENT OF LIVESTOCK EFFLUENTS IN THE RÉUNION ISLAND USING A MULTI-AGENT SYSTEM

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ABSTRACT

This study uses a multi-agent model to illustrate the behaviour of economic players in a context of rapidly evolving environmental policy. The area under study is represented by a sector of Réunion island with a high concentration of pig farms (Grand Ilet) in the upland region and extensive sugarcane plantations in the coastal zone. The pollution problems associated with pig rearing are being addressed by the public authorities, in choosing a set of environmental measures suited to the local context. After illustrating the approach and the results that can be obtained using multi-agent systems model, we couple multi-agent simulations and economic cost-benefit analysis. The advantages of the illustrated methods for the implementation of decision-making and negotiation tools are finally discussed.

Keywords: Environmental policy, decision-making, livestock effluents, Réunion island, multi-agent, cost-benefit analysis.

1 – INTRODUCTION

1.1 – Present policy context

Nitrogen and phosphorous rich effluents from intensive livestock production are generally considered good fertilisers, but can be a source of pollution if present in large quantities. In areas of high-density livestock production, the persistent accumulation of elements such as nitrogen is a widespread problem. These areas are referred to as structural excess zones.

In order to protect the environment, legislation has been established to regulate the spreading of these effluents on farm land (in France: Ministerial Orders of 1992, modified in 1999, Code of Good Farming Practice, 1994; in Europe: Nitrates Directive, 1991). Under French law, livestock farms are "environmentally sensitive installations" (cf. national law on environmentally sensitive installations -ICPE- of 1976 and subsequent modifications), and the new water law project (January 2002) provided for a pollution charge to be levied on livestock producers. This project of water law was approved after a first reading by the French Parliament the 10 January 2002, but the Government decided that it had not been sufficiently discussed and negotiated with all stakeholders, and therefore withdrew it. A new water law, which integrates the European Water Framework Directive (n.2000/60/CE), has now become essential.

Under the European "Nitrates" Directive of 12 December 1991, France launched a long negotiation process. On 8 October 1993 this resulted in an agreement between the French government and farmers' organization (the Agricultural Pollution Control Plan - PMPOA). The system eventually adopted can concisely be described as follows: in order to reduce pollution, livestock breeders must perform the necessary tasks to ensure that their facilities comply with regulations covering environmentally sensitive installations (law no. 76-663 of

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19 July 1976 and subsequent modifications). They must furthermore undertake to modify their farming practices. The central focus of this programme is the establishment of maximum spreading limits according to the vulnerability and degree of pollution of land on which spreading may be performed.

In structural excess zones, the authorized maximum nitrogen content in soil is 170 kg per hectare. This limit is raised to 200 kg of organic nitrogen/ha on crops and 350 kg/ha on meadows outside structural excess zones. The state, the local authorities and the water agencies have undertaken to make financial contributions towards the investments required implementing the applicable strategies. On the other hand, breeders entitled to financial aid are subject to a pollution charge levied by water agencies. The mentioned project of water law approved after a first reading by the French Parliament, and then withdrew by the Government, contained for the first time a specific charge for excess nitrogen. According to the French Ministry of the Environment, the charge would have been set at 1.5 francs (0.23 Euro) per kg of excess nitrogen (Dépêches du MATE, 2002).

In the context of rapidly evolving and increasingly stringent legal requirements, stock breeders are faced with a new system of constraints and, perhaps in the near future, economic instruments (taxes, subsidies) which will reform their approach to effluent management.

Réunion is a French overseas territory situated in the Indian Ocean, 700 Km east of Madagascar. Although the tropical climate and hence the cycle of nitrogen use by crops is very different from that of the French mainland (higher plant productivity, different mineralisation kinetics), the island is subject to French regulations.

Our study concerns the economic behaviour of livestock breeders in Grand Ilet, an area of Réunion Island with a high concentration of livestock farms, pig farmers in particular. These breeders face the problem of dealing with large quantities of excess slurry, which they cannot dispose of by spreading, as they do not have sufficient arable land. Moreover, they grow mainly fresh vegetables, on which slurry spreading is prohibited.

In response to the exorbitant quantities of nitrogen provided to crops by slurry spreading in Grand Ilet (more than 1.5 t/ha per year on each cultivated plot, according to Renault and Paillat, 1999) and the environmental problems associated with this practice, a number of solutions have been proposed. One involves exporting the liquid effluents outside the Grand Ilet zone, to crops such as sugarcane, which require large quantities of organic matter.

Another solution is to transform the liquid effluents into more manageable solid products for use on the crops of pig breeders, or by other farmers and vegetables/flowers growers outside the zone.

The public institution, for its part, defines the legal and economic instruments of environmental policy required to reach economic, social and ecological objectives. Here, emphasis is placed on the combination of economic instruments (pollution charges and investment subsidies) and regulatory instruments (maximum authorized organic nitrogen input per hectare).

1.2 – The choice of multi-agent systems

The patterns observed in social or economic systems at the global level, as well as at the local level like in the studied context, may be caused by the multiple and different behavioural patterns of individuals. The complexity of behaviour cannot be studied with neoclassical, differentially based economic modelling tools, since they only consider the "representative" agent. Economists therefore explore other modelling approaches, which will enable them to represent this complexity. Multi-agent systems in their simplest form consist of models of individuals. These individuals are often superimposed on an automated environment and are capable of observing their environment, analysing what they observe, and of modifying their behaviour accordingly (Ferber, 1995).

"Agent-based modelling takes a bottom-up approach to generating data comparable to that observable in the real system" (Deadman, 1999). This bottom-up approach consists of defining methods that correspond to the behaviour of individuals, which are part of the real world system analysed. These methods do not specify the overall behaviour of the simulations, which instead emerges as a result of the actions and interactions of the individual agents (Deadman, 1999).

Agents can be considered adaptive if they possess the following criteria: a) the outcome of the agent's actions within its environment can be assigned a value such as utility or fitness, and b) the agents change their behaviour so that they become suitable to a new situation. Agents may possess a number of mechanisms for adjusting their actions in an effort to improve their aptitude. Complex adaptive systems usually operate far from the global optimum (Holland and Miller, 1991).

Multi-agent systems therefore facilitate the "real-world" representation of actors within a system by taking into consideration the variation between individuals, and the effects of an individual's action in precipitating global patterns. Multi-agent systems assist the understanding of how global patterns in societies or economies emerge from an individual's behaviour (Epstein and Axtell, 1996). The flexibility of this type of modelling tools "enables to improve both action and research outcomes through a process of iteration" (Gummesson, 1991; Bunnimg, 1994). They have also been applied in economic studies of natural resource management in order to study possible processes of change (Balmann, 1997, Bousquet *et al*., 1999, Rouchier *et al*., 2000, Antona and Farolfi, 2001, Balmann *et al.*, 2003).

A multi-agent systems model, *Biomas*, has been developed to simulate farming practices and effluent management in Réunion (Guerrin *et al*., 1998). With the exception of transportation costs, however, it has neglected the costs associated with effluent management.

In this study, the cost of different options available to pig farmers has been incorporated into *Echos*, a multi-agent model of livestock effluent management in Réunion. It facilitates studying the impacts that potential environmental intervention policies and investments are likely to have on pig farmers' behaviour, as well as the economic viability and environmental desirability of such policy options. *Echos* was constructed to simulate the economic costs associated with environmental legal compliance, the effluent management choices made by pig farmers as a consequence, and the diffusion of nitrogen pollution in the environment.

The simulation system utilised in this study is *Cormas*, a multi-agent simulation platform developed at Cirad-Tera (Bousquet *et al*. 1998).

A description of the model's structure and dynamics is provided in the following section (2). Section 3 illustrates a selection of scenarios obtained by *Echos*, and shows the results of a cost-benefit analysis conducted on these scenarios. Results are discussed in section 4. Some concluding remarks and future developments are proposed in section 5.

2 - METHODS

An area of approximately 100 km^2 of Réunion was represented on a 75 by 150 automated cellular grid. Each cell represented one hectare. The grid was divided into three regions corresponding to the topography of Réunion, namely Grand Ilet (central island), the coastal zone in which sugarcane is cultivated, and an intermediate non-cultivated zone.

Agents were used to represent 56 pig farmers, 6 sugarcane farmers and a public authority responsible for defining environmental policy.

According to a direct survey conducted in the Réunion Island in 2001 (Farolfi, 2003), the size of pig breeding operations varies from 1 to 50 sows with litters per farm. Pig farmers in *Echos* were subdivided into three types. Each of these types manages its effluent differently, namely:

Type	Number	Effluent Management	Sows with litters
I	23	Do not own any spreading facility, rent spreading and transport services from other farmers.	< 15
II	30	Own spreading and transporting facilities for personal use.	16 - 42
III	3	Own spreading and transporting facilities that are also rented out to farmers of type I.	> 43

Annual effluent production by pig farmers was calculated as $19.7m^3$ per sow with litters per annum. Since effluents in Réunion contain approximately 4 kg nitrogen per m^3, this is equivalent to 78.8 kg of nitrogen per sow with litters per annum. Constant pig production was assumed throughout the analyses. According to Rainault and Paillat (1999), $1m^3$=1T of effluent[1].

Pig farmers were allocated farms within the Grand Ilet zone. The size of the farms was randomly selected within a predetermined range of 1 to 17 ha and was determined by the number of sows and litters. Pig farms consisted of a random combination of fallow (50% of cells) and cropped (50%) cells. The cropped cells were allocated a nitrogen absorption capacity of 387.6 kg/year (weighted average of the absorption capacity of current crops present, Renault and Paillat, 1999), and fallow cells an absorption capacity of zero. The actual absorption for fallow areas in Réunion is close to zero (Renault and Paillat, 1999).

Each of the sugarcane farmers was allocated a sugarcane plantation in the coastal zone. Farm size was based on a random value between 20 and 40 hectares.

Two hypothetical types of collective treatment plants have been introduced into the model. A compost station and a wastewater treatment plant called “Bio-Armor” (Farolfi, 2003). The decision on their location within the study area was based on technical reports published by local consulting companies (Cyathea, 1999). The assumption was made that these collective treatment plants have the capacity to treat the effluent of 850 sows and litters (the current pig population in Grand Ilet).

The legal limit for nitrogen spread per hectare of land was defined, and taxation per kilogram of nitrogen in excess of the legal limit per hectare was introduced as a potential management policy to decrease environmental pollution.

A basic time step of one month was selected. In order to simulate monthly nitrogen diffusion in the environment in accordance with the topology of Réunion, it was assumed that 10% of the nitrogen present in each cell spread to lower lying cells each month. Of this, 50% spread to the eastern cells and 25% to the north-eastern and south-eastern cells respectively. At this stage of the modelling process, a nitrogen assimilation rate of 0.3% per month was allocated to all cells, irrespective of land use.

[1] The data illustrated here were taken from a survey performed between 1995 and 1999 in Grand Ilet on Réunion (Cf. Reynaud, 1995 and Renault and Paillat, 1999) on a population of 56 pig breeders. This survey showed that the average farm size was 15.17 sows and litters, and that the average surface area of a farm was 3.76 ha, including 1.32 ha of cultivated land, 1.99 ha of fallows and 0.45 ha of buildings (including gardens) (Renault and Paillat, 1999).

Simulation of effluent management by pig breeders was based on the observations of, and data collected by, Aubry *et al.* (2001) and Renault and Paillat (1999). An effluent storage capacity was allocated to each pig farmer. The maximum storage capacity is reached approximately every four months, upon which the farmer empties his tanks, and spreads the effluent on his own farm, in quantities compliant with environmental legislation. Any remaining effluent is spread on farms legally available for effluent spreading within a 1km radius (fig.1).

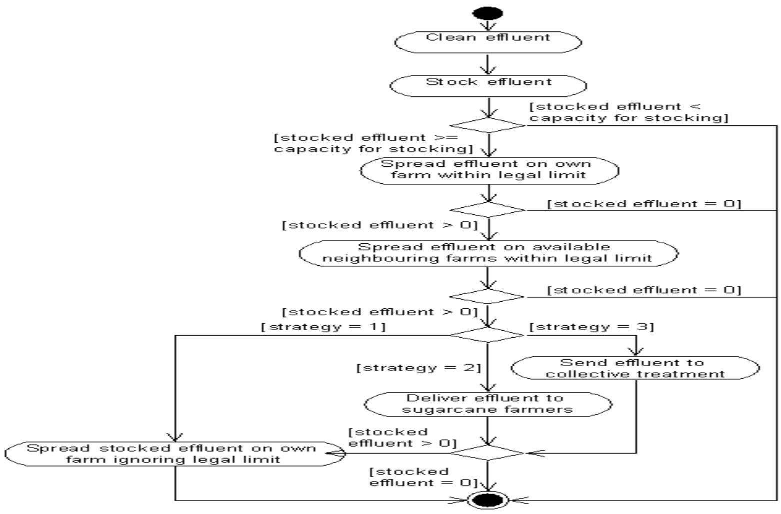

Figure 1. Activity diagram of a pig farmer's behaviour in disposing of excess effluent during a single time step (equivalent to one month) according to the strategy chosen

The farmer can then dispose of the remaining effluent by means of one of the following three strategies:

***Strategy 1*:** The farmer spreads the remaining effluent on his own land with no regard for environmental legislation.

***Strategy 2*:** The farmer transports the remaining effluent to the coastal sugarcane farmers, with preference for those closest to his farm. If there is no demand for effluent from sugarcane farmers, or if the effluent does not amount to a full transport load, the pig farmer spreads it on his own land. It is assumed that the only means of effluent transport is a tractor and a trailer with a load capacity determined by the simulation parameters, with a default capacity of $10m^3$. Due to the location of pig farmers and poor road conditions, this is the absolute maximum capacity of a transport load. The distance between the coastal zone and Grand Ilet (20 km), is used as the average distance between pig farmers and sugarcane farmers.

***Strategy 3*:** The farmer delivers remaining effluent to the collective treatment plant.

The pig farmers' generic annual cost function for slurry management can be represented as follows:

$$C_{ij} = f(CL_{ij}, ST_{ij}, SP_{ij}, TX_{ij}, TR_{ij}, CO_{ij}) \qquad [1]$$

Where:

C_{ij}	is the annual cost for the pig farmer of type *i* adopting the strategy *j*
CL_{ij}	is the cost of cleaning the stables
ST_{ij}	is the cost of stocking the slurry
SP_{ij}	is the spreading cost
TX_{ij}	is the tax to be paid for slurry spread in excess of the legal limit
TR_{ij}	is the cost of slurry transportation to the coastal area
CO_{ij}	is the cost of collective treatment
i	is the pig farmer type = I, II, or III
j	is the adopted strategy = 1, 2, or 3

The variables represented in the generic formula assume different values (positive, negative, or 0) according to the type of pig farmer and the strategy adopted.

A detailed illustration of the cost functions associated to each type of pig farmer and each adopted strategy is given in Appendix 1.

Echos analyses all costs incurred by the various strategies throughout the simulation. At the end of each simulated year, pig farmers are given the opportunity to adopt a more economic strategy, based on forecasts for the different strategies.

A parameter of inertia to change of strategy with a value between 0 and 1 was introduced. A value of 1 would indicate a 100% probability that a farmer would opt for a seemingly less expensive strategy. A value of 0 would represent a 0% probability that the farmer would switch strategies, even if another strategy would seem economically more feasible.

Sugarcane farmers annually spread nitrogen fertilizer on their sugarcane plantations according to the nitrogen requirements of sugarcane. The annual nitrogen requirement of 150 kilograms per hectare of sugarcane used in *Echos* was obtained from the Union of Farming Cooperatives in Réunion (Urcoopa). Other estimates of nitrogen requirements of sugarcane in Réunion vary from 100 (Baldoni and Giardini, 1982) to 200 (Reynaud, 1995) kilograms per hectare. In *Echos*, organic fertiliser supplied free of charge as effluent by pig farmers, is used when available. Additional mineral fertiliser is bought when effluent is not available in sufficient quantities.

The sugarcane farmers' generic cost function is represented as follows:

$$C_k = f(SP_k, ST_k, F_k) \qquad [2]$$

Where:

SP_k	is the cost of spreading mineral fertiliser (or slurry)
ST_k	is the cost of stocking the slurry imported from the pig farms
F_k	is the cost of buying mineral fertilisers
k	is the adopted strategy (4 = spreading mineral fertilisers; 5 = spreading slurry; 6 = spreading both)

The sugarcane farmers' cost functions according to the various strategies as well as the costs associated with the procurement of mineral fertiliser, and the spreading of both mineral and organic fertilisers, are given in Appendix 1.

3 - RESULTS

3.1 - Simulating policy options

20 variables (a complete list is included in Appendix 2) can be manipulated in order to run different simulations regarding slurry management in the Grand Ilet area with *Echos*. Since the main objective of this paper is the evaluation of environmental policy options, the results of simulations run with manipulation of the following variables[2] are shown: pollution charge at year 0; biennial increase in the pollution charge; proportion of variable transportation cost subsidised; load transportation capacity; price of compost (which, when subsidised, can reflect the level of public subsidy for a collective compost plant); and, only for some simulations, tariffs for renting out transporting facilities, as well as the size of sugarcane farmers.

The other variables are fixed at the levels indicated in Table 1.

All simulations are run over a period of 10 years, and all pig farmers initially adopt strategy 1. Analysed outputs are the choice of effluent management strategy by pig farmers, the cost of effluent management for both pig farmers and sugarcane farmers, and the total nitrogen accumulated in Grand Ilet and the coastal area.

Maintaining the legal limit for slurry spreading in the pig farming area at 170 KgN/ha, which corresponds to a structural excess zone, a number of combinations of "positive" and "negative" economic incentives - taxes and subsidies respectively, and their impact on the above mentioned outputs, are explored.

Variable	Value
Pig farmers initialised in strategy	1
Sugarcane farmers initialised in stragegy	5
Do the farmers change strategy during the simulation?	Yes
Likelihood change strategies	0.5
Collective treatment	Compost
Legal limit N (Kg/ha)	170
Proportion stocking cost subsidised	0
Rate utilisation machinery	0.2
Levy charged for transport services (%TR)	0.03
Price mineral N (F/Kg)	10

Table 1. Values of *Echos* fixed variables

In the two policy options illustrated below, a progressive introduction of environmental taxes, combined with different levels of subsidies, is simulated.

Policy option 1: Combining progressive tax and transportation subsidies
Pollution charge at year 0 = 0F; progressive pollution charge = 5 F/kg excess nitrogen every 2 years; proportion of variable transportation cost subsidised = 70%; load transportation capacity = 40KgN; price of compost = 250 F/T.

In this scenario, a progressive tax is introduced and combined with subsidised transportation cost, whilst the compost collective plant is not subsidised.

[2] Economic values are expressed in French Francs (F). 1 F = 0.1525 Euro – fixed exchange rate.

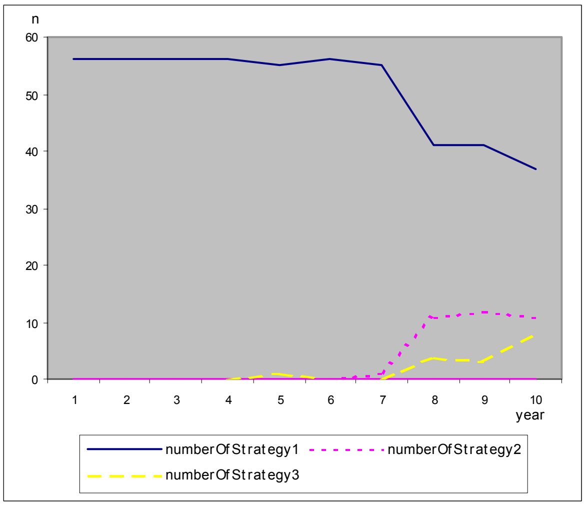

Figure 2. Policy option 1: Pig farmers strategies

Figure 2 illustrates the dynamics of strategy choices by pig farmers within this legal context.

Starting from year 5, some farmers (type I) shift from strategy 1 to 3, and starting from year 7, other pig farmers (type II first, then also type III) shift from strategy 1 to 2. Pig farmers in strategy 2 are more numerous than those in strategy 3, but at the end of the simulation 36 farmers (15 type I, 19 type II, and 2 type III) are still in strategy 1, whilst 11 (all type II and III) are in strategy 2, and 9 farmers (8 type I and 1 type II) are in strategy 3.

A higher progressively increasing pollution tax forces pig farmers to modify effluent management approach. Nevertheless, at the end of the simulation, a relatively large number of pig farmers opt to continue following the original strategy, despite strong economic incentives (pollution charge of 20 F/kgN, and a 70% variable transport cost subsidy) to change to one of the alternatives.

Starting from year 7, sugarcane farmers receive slurry from the pig farming area and consequently their annual cost pattern is affected (Fig. 3).

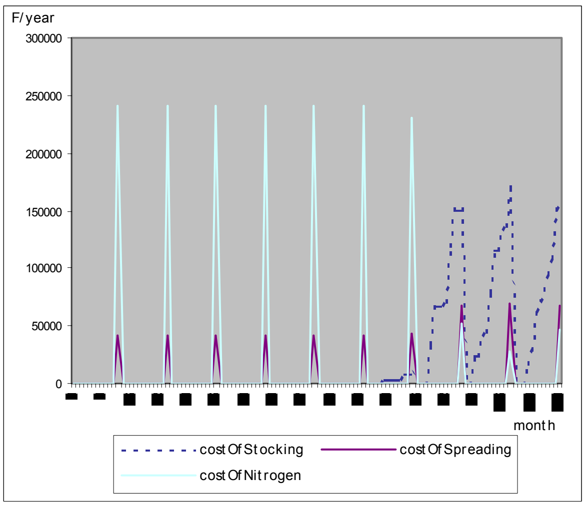

Figure 3. Policy option 1: Annual costs for sugarcane farmers

Expenditure on mineral nitrogen decreases, while spreading and stocking costs increase proportionally to the transfer of slurry from Grand Ilet to the coastal area. A limited positive effect on the accumulation of nitrogen in the soil is observed (from 550[3] to 500 T at year 10), due to the combined effects of transfer to the sugarcane farms and composting (Fig. 4).

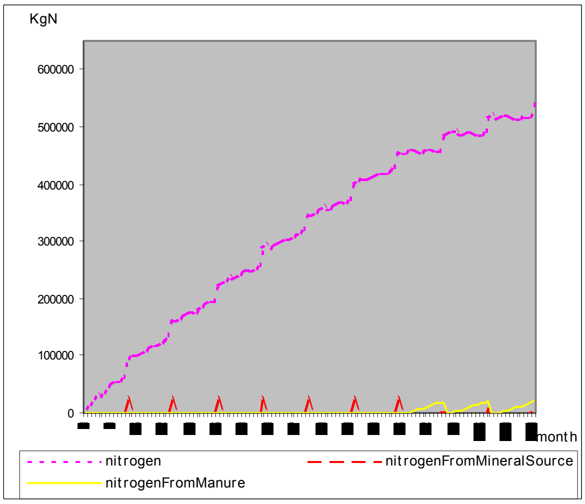

Figure 4. Policy option 1: Nitrogen dynamics

The problem represented by the technological and infrastructural limitations to the loading capacity of slurry transportation out of Grand Ilet was previously mentioned. One could then make the hypothesis that roads are improved which allows for the transit of trucks with a loading capacity of 200 kgN = 50 T of slurry per trip. Disregarding the costs associated with road construction work, as well as the capital investment in a new truck, some scenarios introducing the improved loading capacity in the previous context were run.

Simulations show that, *ceteris paribus*, the improved technology does not expedite the switch to strategy 2 among pig farmers. However, when doubling the tax progression (10 F/kg excess nitrogen every 2 years), a dramatic change in the pattern of strategy choice is observed (Fig. 5).

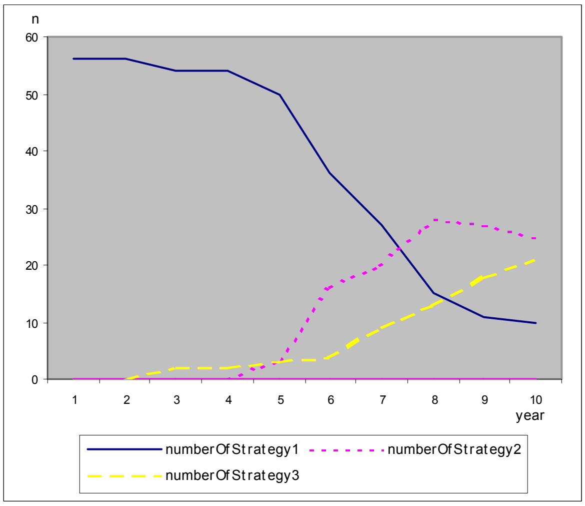

Figure 5. Policy option 1a: Pig farmers strategies

In this case, due to the limited surface area of sugarcane farms, the demand of slurry in the coastal area is saturated at year 8. In the following years, the pig farmers willing to abandon strategy 1 are obliged to choose strategy 3.

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[3] Quantity of nitrogen at year 10 if all pig farmers stay in strategy 1.

However, simulations run doubling the available sugarcane farm surface, show that at year 10 the nitrogen demand is not saturated. At this level of pollution tax (30 F/KgN at year 7 and 40 F/KgN at year 9) increasing numbers of pig farmers prefer the unsubsidised collective compost plant to heavily subsidised transportation to the coastal area.

Policy option 2: Combining progressive tax and subsidies for collective compost plant
Pollution charge at year 0 = 0F; progressive pollution charge = 2 F/kg excess nitrogen every 2 years; proportion of variable transportation cost subsidised = 0%; load transportation capacity = 40KgN; price of compost = 550 F/T.

A lower progressive tax (2 F/kg excess nitrogen every 2 years) combined with a subsidised price for the compost produced at the collective station (550 F/T, corresponding to 50% of the annual cost of the collective plant borne by the state, with a market price of 250 F/T) will induce the pig farmers to choose strategy 3 by year 10 (Fig. 6).

For this simulation the price for renting out spreading equipment was set at 10 F/kgN.

This behaviour by pig farmers would have a definite effect on the amount of nitrogen accumulated in the area, even though it does not exceed the 200T threshold (Fig 7).

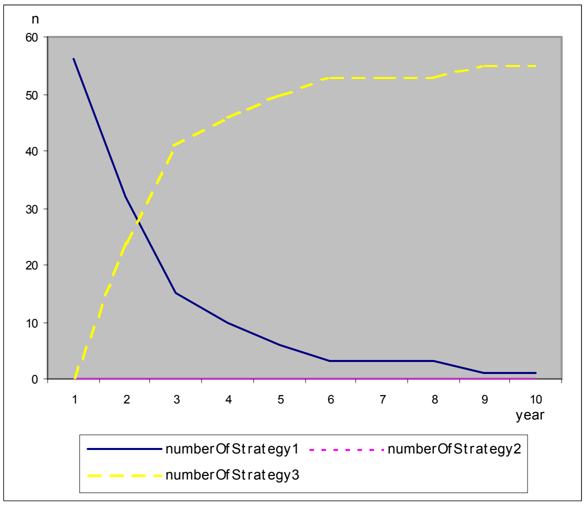

Figure 6. Policy option 2: Pig farmers strategies

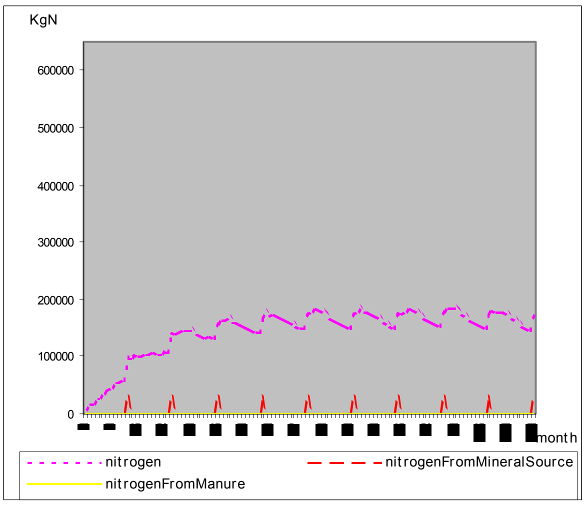

Figure 7. Policy option 2: Nitrogen dynamics

A compost price of 589 F/T corresponds to a state subsidy of 57% of the collective plant annual cost. At this level of subsidy, all pig farmers would adopt strategy 3 by year two without any pollution charge. The probability of strategy change is set at 1 in this case.

3.2. - Coupling multi-agent simulations (MAS) and cost-benefit analysis (CBA)

Multi-agent simulations enable the analysis of the dynamics of agents' behaviour under different hypothetical policy conditions. The costs associated with the adopted strategies are also calculated. Having said that, if precise economic indicators on the efficiency and effectiveness of the simulated policy option are sought, MAS analysis must be coupled with an economic approach of monetary valuation, such as CBA.

According to Layard and Glaister, in any cost-benefit exercise it is recommended that one proceeds in two stages: a) value the costs and benefits in each year of the project (in this case the policy option adopted); and b) obtain an aggregate 'present value' of the project by 'discounting' costs and benefits in future years to make them commensurate with present costs and benefits, and then adding them up (Layard and Glaister, 1994). The following costs resulting from the adoption of a policy option were considered: incremental cost for pig farmers[4] (with respect to the *status quo*), and annual subsidies to be paid by public institutions in order to cover transport or collective treatment costs.

The benefits are represented by the annual cost reduction for sugarcane farmers (resulting from the use of organic matter instead of mineral fertilisers), and the double dividend produced by the tax payment for the spread of excess organic matter.

The reduction of accumulated nitrogen in the soil at the final year of the simulation was then calculated, as this represents the environmental impact of the adopted policy. The analysis allows defining the discounted cost of the adopted policy, and expressing it in terms of cost per unit of reduced nitrogen in the soil.

Analyses were conducted over a period of ten years, using a discount rate of 6%, a higher value than the present inflation rate in Réunion. This discount rate accounts for the risk of the investments.

The following table (tab. 2) illustrates the results of this analysis applied to the policy option consisting of a high tax (20F/KgN) over the whole simulated period combined with 70% subsidy of transportation costs. The surface of sugarcane farms in the coastal area was randomly set between 20 and 40 hectares in the first scenario, and between 40 and 80 hectares in the second one.

Costs and benefits of this option were then compared with costs and benefits of the policy option consisting of a lower tax (5 F/KgN) over the whole period and a subsidy covering 42% of the annual cost of a collective compost plant. No subsidy for transportation costs is contemplated in this second option.

[4] Resulting from the pollution taxes plus the cost of transport, or the unsubsidised cost of collective treatment, according to the policy option analysed. The reduction of spreading costs contributes to the reduction of this incremental cost.

Subsidising transport (20 ha ->40 ha)

year	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Subsidy	0	1,093,400	1,484,000	1,484,000	1,484,000	1,484,000	1,484,000	1,484,000	1,484,000	1,484,000	**12,965,400**
Δ cost PF	1,504,000	1,444,600	1,396,000	1,415,000	1,299,000	1,499,000	1,459,000	1,369,000	1,439,000	1,286,000	***14,110,600***
Double dividend	1,504,000	1,074,000	907,000	910,000	820,000	990,000	950,000	890,000	930,000	807,000	***9,782,000***
Δ cost SF	0	20,800	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	***260,800***
Policy option costs	*0*	*1,443,200*	*1,943,000*	*1,959,000*	*1,933,000*	*1,963,000*	*1,963,000*	*1,933,000*	*1,963,000*	*1,933,000*	***17,033,200***
RESIDUAL N (Kg)	**483,853**									**PV 6%**	**12,055,391**
REDUCED N (Kg)	***95,047***								**PV/KgN reduced**		***127***

Subsidising transport (40 ha ->80 ha)

year	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Subsidy	0	1,302,000	1,570,333	1,591,333	2,030,000	2,361,333	2,776,667	1,997,333	2,212,000	1,946,000	**17,787,000**
Δ cost PF	1,440,000	1,474,000	1,315,000	1,307,000	1,245,000	1,418,000	1,453,000	1,297,000	1,391,000	1,258,000	***13,598,000***
Double dividend	1,440,000	1,004,000	795,000	782,000	578,000	597,000	486,000	644,000	646,000	627,000	**7,599,000**
Δ cost SF	0	80,290	94,360	124,060	127,460	146,960	172,860	124,760	137,760	121,060	***1,129,570***
Policy option costs	*0*	*1,691,710*	*1,995,973*	*1,992,273*	*2,569,540*	*3,035,373*	*3,570,807*	*2,525,573*	*2,819,240*	*2,455,940*	***22,656,430***
RESIDUAL N (Kg)	**403,216**									**PV 6%**	**15,818,923**
REDUCED N (Kg)	***175,684***								**PV/KgN reduced**		***90***

Subsidising compost collective treatment

year	1	2	3	4	5	6	7	8	9	10	**TOTAL**
Subsidy (disc.)	0	1,146,938	1,191,710	1,327,118	1,276,886	1,411,202	1,424,306	1,365,338	1,451,606	1,329,302	***11,924,403***
Δ PF Colletive syst.(disc)	0	106,000	70,000	158,000	65,000	151,000	167,000	108,000	193,000	82,000	***1,100,000***
PF Tax	687,000	342,000	213,000	71,453	4,500	2,500	1,300	5,500	5,500	5,200	***1,337,953***
Double dividend	687,000	342,000	213,000	71,453	4,500	2,500	1,300	5,500	5,500	5,200	***1,337,953***
Net Costs (but subs.)	*0*	*1,252,938*	*1,261,710*	*1,485,118*	*1,341,886*	*1,562,202*	*1,591,306*	*1,473,338*	*1,644,606*	*1,411,302*	***13,024,403***
RESIDUAL N (Kg)	**135,834**									**PV 6%**	***13,024,403***
REDUCED N (Kg)	***443,066***								**PV/KgN reduced**		***29***

Table 2. Present values (PV) in Francs (r=6%) and PV in F/KgN reduced of the total cost for three policy options over a ten year simulation. Comparison with the *status quo* situation.

Notes: 1) PF = Pig Farmer; SF = Sugarcane Farmer
2) annual values for collective system subsidy and pig farmer collective treatment cost are discounted in the simulation

Results clearly indicate that the policy option consisting of a lower tax combined with a subsidy for the compost collective treatment plant is the less expensive among those analysed. Furthermore, its impact in terms of pollution reduction is higher. Increasing the available surface in the coastal zone, only marginally improves the results of the policy option aimed at transferring effluent to the sugarcane plots. Finally, the feasibility of the second policy option is far higher when compared to the previous one. In particular, the high tax imposed on pig farmers in order to push them to adopt a strategy of transfer of effluent to the coastal zone, is not acceptable in the specific context, and does not reflect the general orientation of the environmental protection policy in France and in the EU.

The structural and technical constraints linked to the transfer of effluent to the coastal area, namely the poor quality of the roads and the consequent low capacity load for slurry were mentioned. An improvement of the road connections between Grand Ilet and the coastal area would correspond to high costs that are not considered in this analysis. In this simulation, a load capacity for transportation of 20T of slurry was taken into account, corresponding to 80KgN per trip. Actually, the present state of the roads in the studied area allows only a load capacity of 10T of slurry.

4 - DISCUSSION

The adoption of a multi-agent model for simulating the behaviour of pig farmers in Réunion Island under different sets of environmental policy measures allowed the identification of some general trends that are discussed hereafter.

The role of economic instruments (taxes and subsidies) as incentive tools aimed at modifying the attitude of polluters with regard to effluent management was first tested.

In the case study, a low level of economic instruments does not appear to be sufficient to induce the pig farmers toward a strategy of effluent management alternative to the present one, i.e. spreading all organic matter on the Grand Ilet plots. If the public authorities want to reduce the environmental impact created by the adoption of this strategy, they must introduce a set of relatively robust economic instruments.

Under the present French legal water framework, there are no taxes on agricultural pollution originating from livestock effluent. The new project of water law, still in a process of preparation, introduces a tax on these types of pollution. Its size is estimated at 1.5 to 2 F (0.23 to 0.3 Euro). Subsidies from water agencies are available up to a maximum of 42% of the investment cost. Local institutions can offer additional contributions.

The results of the presented simulations show clearly that a "stick and carrot" policy would be effective in the studied context, either through the adoption of a tax higher than 2F, or coupling it with a subsidy covering a significant share of the alternative strategy's annual cost.

In particular, at subsidy levels below 70% of the annual cost, the transfer of effluent to the coastal area does not seem to be attractive for the pig farmers (especially for those who do not own spreading and transport facilities).

A CBA was conducted on the two options that simulations indicated to be the most applicable to the studied context. The aim was to challenge the *status quo* by reducing pollution at the lowest possible cost to society (Baumol and Oates, 1975).

The CBA showed that a lower tax on effluent coupled with a subsidized collective treatment plant (compost) would be economically more viable, socially more acceptable, and environmentally more effective than an option aimed at facilitating the transfer of organic matter towards the sugarcane farms of the coastal area.

5 - CONCLUSION AND PERSPECTIVES

The main purpose of this exercise was to use a MAS to evaluate several options of environmental policy, by analysing the economic behaviour of pig farmers on Réunion island subsequent to the adoption of these policy options. In the multi-agent model *Echos*, the pig farmers and sugarcane growers are numerous, and distributed over a given area with specific characteristics (in this case, distance between agents and nitrogen assimilation capacities). Pig farmers own farms of different sizes and animal population, and have different characteristics in terms of the availability of spreading facilities.

The use of MAS enables the consideration of multiple components, thereby creating a representation of a complex reality. More specifically, it combines both economic and ecological dynamics in a spatial model. The agents studied may employ different strategies and may evolve during a simulation. In other words, multi-agent modelling enables the illustration of certain mechanisms that are difficult to pinpoint using standard economic modelling methods.

The agents of *Echos* are assumed to be rational and well informed. However, economic players who are not entirely rational or only partly informed can also be included in a MAS. These types of behaviour, not described in this paper, will be included in future project developments.

The model allows coupling the nitrogen produced, transported and assimilated by the soil with all economic simulations. This feature of the MAS is very useful for the construction of tools for decision-making and negotiation between players, since the environmental measures are tested not only in terms of economic efficiency and effectiveness, but also in terms of environmental sustainability.

In order to refine the economic analysis of the studied policy options, a cost-benefit analysis was conducted to some simulations produced by the MAS. Though the exercise remained at an experimental level, it showed the potential utility of combining a standard evaluation method such as CBA with multi-agent systems. In particular, the possibility to rank the different simulated scenarios through universally recognised economic criteria, such as net present value or internal rate of return, enlarges significantly the field of application for MAS as decision and negotiation support tools when policy options must be chosen.

Due to its specific features - dynamic illustration of simulations, simultaneous consideration of economic and ecological variables, spatialised representation of agents and the capacity to make them interact - MAS provides a sound basis for the creation of decision-making and negotiation-supporting tools to define environmental policy at a local level. Compared to economic models based on mathematical optimisation techniques, MAS are more capable of encompassing the complexity of the economic, ecological, social and ethical relations involved in the management of environmental impacts.

MAS allow environmental economists to be part of a process of action-research in close participation with local stakeholders. In the specific case of *Echos*, this process started in 2001 and contributed to provide the model with a far higher capacity to represent reality. At the same time, local stakeholders take advantage of the model’s outputs using them as a basis for the long and articulated discussion and decision-making process that is taking place in Réunion.

In future developments of the model, more complex behavioural patterns which differ from one agent to another will be introduced, since MAS provide a good means to represent agents possessing limited information and pursuing objectives other than profit maximization alone. The introduction of different strategies in a system of evolutionary games (Weibull, 1995) should allow illustrating the system's response to the introduction of technological or procedural innovations. Various forms of coordination between players will be analysed. Finally, since a great deal of importance is attached to the ecological dynamics simulated by a model which is basically economic in nature, the methods used to represent the behaviour of nitrogen in the soil (diffusion rates that vary according to the slope and nature of the soil, different types of soil leeching, crop assimilation capacities, etc.) will be improved.

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REFERENCES

ALLEN W., 2000. The role of action research in environmental management, working paper on the website : http://nrm.massey.ac.nz/changelinks/ar_working.html

ANTONA M., and FAROLFI S., 2001. Décision et négociation des politiques environnementales : l'application de la fiscalité dans les pays du nord et du sud. Colloque PIREE, Les instruments des politiques environnementales, Sophia Antipolis, 5-6 avril, 18 p. (www.idefi.cnrs.fr/ Colloques/PIREE2.html).

AUBRY C., PAILLAT J.M., and GUERRIN F., 2001. Modélisation conceptuelle de la gestion des effluents d'élevage à la Réunion. Rapport Cirad-Tera n°16/01, La Réunion, 58 p.

BALDONI R., and GIARDINI L., 1982. Coltivazioni erbacee, Pàtron, Bologna, 1024 p.

BALMANN A., 1997. Farm-based modelling of regional structural change: a cellular automata approach. European review of agricultural economics, 24 (1), 85-108.

BALMANN A., HAPPE K., KELLERMANN, K, and KLEINGARN, A., 2003, Adjustment costs of agri-environmental policy switchings. In: Janssen, M.A. (ed), Complexity and ecosystems management. The theory and practice of multi-agent systems. Edward Elgar, Cheltenham, UK, 127-157.

BAUMOL W.J., and OATES W.E., 1975, The theory of environmental policy, Cambridge University Press, New York, 299 p.

BOUSQUET F., BAKAM I., PROTON H., and LE PAGE C., 1998, Cormas: common-pool resources and multi-agent Systems. Lecture Notes in Artificial Intelligence 1416: 826-838.

BOUSQUET F., BARRETEAU O., LEPAGE C., MULLON C., and WEBER J., 1999. An environmental modelling approach: the use of multi-agent simulation. *In:* Blasco and Weill (Eds.), Advances in environmental modelling, Elsevier, p. 113-122.

BUNNING C., 1994. Action research: an emerging paradigm. Brisbane: Tertiary Education Institute, The University of Queensland. [Occasional paper series - No. 4]

CYATHEA (Bureau d'études), 1999. Etude préalable à la mise en place d'une station de traitement collectif des effluents d'élevage porcins à Grand Ilet. Groupement des éleveurs de Grand Ilet., 75 p.

DEADMAN P.J., 1999. Modelling individual behaviour and group performance in an intelligent agent-based simulation of the tragedy of the commons, Journal of Environmental Management, 56, p. 159-172.

DUPUY J.P., 1999. Aux origines des sciences cognitives. La Découverte, Paris, 188 p.

EPSTEIN, J.M., and AXTELL, R.L. 1996. Growing artificial societies : Social Science from the bottom up. MIT Press, Chicago

FAROLFI S., 2003. Coûts de gestion individuelle et collective d'effluents d'élevage à l'île de la Réunion, Research Report CIRAD-TERA n. 11/03, Montpellier, 50 p.

FAROLFI S., LE PAGE CH., TIDBALL M., and BOMMEL P., 2002. Management of livestock effluents in Réunion – Use of a multi-agent system to analyse the economic behaviour of players, in : Urban, Ch. (Ed.) « Proceedings Workshop 2002 : Agent-Based Simulation 3 », Ghent 2002, ISBN 3-936150-17-6, p 111-119 .

FEDERATION RÉUNIONNAISE DES COOPERATIVES AGRICOLES, 1999. Etude de marché du compost à la Réunion: état des lieux, tendances et commercialisation, 53p.

FERBER J., 1995. Les Systèmes multi-agents. Vers une intelligence collective, Inter-Editions, Paris, 522 p.

GUERRIN F., COURDIER R., CALDERONI S., PAILLAT J.-M., SOULIE J.C., and VALLY J.-D., 1998. Biomas : un modèle multi-agents pour aider à la gestion négociée d'effluents d'élevage. *In :* Modèles et systèmes multi-agents pour la gestion de l'environnement et des territoires (N. Ferrand, Ed.), Actes du colloque, Cemagref éditions, Clermont-Ferrand (F), 5-8 octobre, p. 359-378.

GUMMESSON E., 1991. Qualitative methods in management research. Newbury Park: Sage.

HOLLAND J.H., and MILLER J.H., 1991. Artificial adaptive agent in economic theory. American Economic Review, 81, p.365-370.

LAYARD R., and GLAISTER S.(ed.), 1994. Cost-Benefit analysis, Cambridge University Press, Cambridge, UK, 497 p.

MINISTÈRE DE L'AMÉNAGEMENT DU TERRITOIRE ET DE L'ENVIRONNEMENT, 2002. Lois sur l'eau : un texte amendé dans le bon sense, Dépêches du Mae, n.25, p.2.

NADEAU I., 2001. Les sept commandements de la nouvelle loi sur l'eau. Environnement Magazine, n° 1594, p. 28-29.

POLELLI M., and SALI, G., 1995. Attivazione di un mercato di permessi di inquinamento per il controllo ambientale dei reflui zootecnici. Rivista di Economia Agraria, n°2, Il Mulino, Bologna, p. 299-322.

POUX X., and BARBUT L., 1997. Etude sur l'insertion optimale des procédés de traitement dans les cantons en excédent structurel ; application des sciences de l'action. Agence de l'eau Loire-Bretagne, Ministère de l'environnement.

RAINELLI P., and VERMERSCH D., 2000. Gestion foncière des excédents azotés et marché implicite de droits à polluer : application aux élevages intensifs. Economie et Prévision, n°143-144, p. 91-100.

RENAULT D., and PAILLAT J.-M., 1999. Analyse de la production et de l'utilisation des effluents porcins à Grand-Ilet, localité de l'île de la Réunion (Cirque de Salazie). Rapport Cirad-Tera, La Réunion, n°16/99, 50 p. + annexes.

REYNAUD S., 1995. Diagnostic des pratiques agricoles pour une meilleure compréhension des transferts d'effluents d'élevage. Mémoire DAA Ina-PG, Paris, 59 p.+ annexes.

ROUCHIER J., 2000. La confiance à travers l'échange. Accès aux pâturages au Nord Cameroun et échanges non marchands : des simulations dans des SMA. Thèse de doctorat, Université d'Orléans, 372 p.

ROUCHIER J., BOUSQUET F., REQUIER-DESJARDINS M., and ANTONA M., 2000. A multi-agent model for transhumance in North Cameroon. Journal of Economic Dynamics and Control, 25, 3-4, p. 527-559.

WEIBULL J., 1995. Evolutionary game theory, MIT.

APPENDIX 1: Cost functions for pig farmers and sugarcane farmers according to the chosen strategy

The calculations contained in Farolfi (2003) and based on field surveys conducted in 2001, enabled the definition of average annual cost functions related to each strategy of slurry management in Grand Ilet (Réunion).

As for the individual management, the following basic operations have been identified: cleaning, stocking, and spreading. For each operation, the *average cost functions*[5] have been estimated according to the size of the pig farm (n. of sows and litters - SAL).

These cost functions, whose specific parameters have been calculated through regressions on field data, are of the form:

$$AC = aX^{-b} \quad ; \quad 0<b<1$$

Where:

AC = average cost
X = pig farm size (SAL)
a and b = parameters estimated for each operation (tab. A-1)

	Cleaning	Stocking*	Spreading (variable)	Spreading (fixed)
a	506.4	**66.33**	**304.87**	**379.93**
b	0.88	**0.43**	**0.96**	**0.74**
R^2	*0.40*	*0.97*	*0.93*	*0.89*

Table A-1. Average cost functions' parameters for individual management operations. Parameters in bold have significance levels > 95%
*** for sugarcane farmers: a = 102.68; b = 0.35**

Spreading for type I = e

$$e = \begin{cases} e_1 = 6.7 \\ e_2 = 20 \\ e_3 = 40 \end{cases}$$

Constant values for the average cost of collective treatment, as well as for transportation costs were calculated from various studies as indicated below.

A conversion rate allows using the same cost functions for both pig farmers and sugarcane farmers. If the nitrogen needs for sugarcane are considered to be 150 kgN/ha, since a sow and litters (SAL) produces 78.8 kgN/year (Rainault – Paillat, 1999), 1 hectare will require the equivalent of 1.9 SAL/year.

The average cost for the pig farmer that decides to use a collective station for treating the exceeding pollution is: C_{coll}. The hypothesis was made that a farmer who decides to use a collective station for treating the exceeding pollution is totally relieved of any responsibility with respect to that pollution. Therefore, the cost corresponds to a tariff that the breeder pays to the collective station's manager. This tariff, which must cover at least investment and operating costs of the collective station, is in F/kgN. Data corresponding to different types of collective stations are in: Farolfi (2003).

These average cost functions are crucial elements for building the annual total cost functions for each type of stockbreeder or sugarcane farmer, according to the chosen slurry management strategy.

[5] These functions give annual costs in F/m^3 of slurry. For the cost in F/KgN the cost should be divided by 4.

Pig farmers annual cost functions (referring to the generic cost function [1] in the text):

As illustrated in the text, for the pig farmers, the three possible strategies are:

1) Spreading all slurry in Grand Ilet;
2) Transporting the excess slurry in the coastal area;
3) Conveying the excess slurry to a collective station for treatment (here the cases of a compost station and « Bio-Armor » facility are illustrated).

The following formulas represent the total annual costs for each type of farmer and for each strategy of slurry management.

Terms :

Ca; Cb; Cc = Annual pig farmer's total cost for the three strategies (F/year)

Cfa; Cfb; Cfc = Component of the cost function common to the three types of pig farmers for a given strategy

p = Organic matter (OM) produced every year by the stockbreeder (KgN/year)[6]

Δp = Exceeding OM (KgN/year); $\Delta p = p-p^*.Sp$, where: p* = Norm for spreading (KgN/ha), and Sp = pig farm surface

p_1 = OM transported outside Grand Ilet, where: $0<p_1<\Delta p$ (KgN/year)

τ_p = Unitary pollution charge (F/KgN); it is applied to Δp

Cl = Average cleaning cost (F/KgN)

St = Average stocking cost (F/KgN)

Sp_f = Fixed average spreading cost (F/KgN)

Sp_v = Variable average spreading cost (F/KgN)

C_{coll} = Average cost for using a collective treatment facility (F/KgN)

TC_v= Variable transport cost (0.345/Km/KgN)

d = Distance between Grand Ilet and the coastal zone (Km)

S = Proportion of stocking cost not subsidized, where: 0<S<1

T = Use rate of spreading facilities, where 0<T<1

K = Constant cost for anti-smell products (1.55 F/KgN)

e = Fixed tariff paid by type I farmers to type 3 farmers for spreading, where: e_1=1.675 ; e_2= 5 ; e_3=10 (F/KgN)

TT = Fixed tariff for transport : proportion of TC_v that type 1 farmer pays to type 3 farmer in addition to TC_v for effluents transport, where: 0<TT<1

The formulas illustrated below are conceived to be introduced in the multi-agent model *Echos*. Therefore the effluent quantities that a type III pig farmer treats in addition to his effluent are represented by the quantities of p and p_1 that the type I pig farmers decide to make spread or transport by type III: $(\sum_{i=0}^{n}(p_i, p_{1i}))$. According to our field surveys, this formulation corresponds as an average to a coefficient equal to 1.225.

[6] To calculate p, we consider that a sow and her litters produce 19.7 tonnes/year of effluents and that the average size of a farm is 15.17 sows and litters. Hence, since one tonne of effluents corresponds to 4 kg of nitrogen, p = 1,195.39 Kg of nitrogen (cf. Renault and Paillat, 1999).

Spreading all in Grand Ilet (Strategy 1)

Type I

$$Ca = \tau_p.\Delta p + Cl.p + (St.S + K)p + e.p$$
$$= Cfa + e.p$$

Type II

$$Ca = Cfa + T.Sp_f.p + Sp_v.p$$

Type III

$$Ca = Cfa + T.Sp_f.p + Sp_v(p + \sum_{i=0}^{n} p_i) - e\sum_{i=0}^{n}(p_i - p_{1i})$$

Transporting p_1, where ($0 \leq p_1 \leq \Delta p$), in the coastal area (Strategy 2)

Type I

$$Cb = \tau_p(\Delta p - p_1) + Cl.p + (St.S + K)p + e(p - p_1) + TC_v.d.p_1(1 + TT)$$
$$= Cfb + e(p - p_1) + TC_v.d.p_1(1 + TT)$$

Type II

$$Cb = Cfb + T.Sp_f.p + Sp_v(p - p_1) + TC_v.d.p_1$$

Type III

$$Cb = Cfb + T.Sp_f.p + Sp_v[(p - p_1) + \sum_{i=0}^{n}(p_i - p_{1i})] - e\sum_{i=0}^{n}(p_i - p_{1i}) + TC_v.d(p_1 + \sum_{i=0}^{n} p_{1i}) +$$
$$-(TC_v.d\sum_{i=0}^{n} p_{1i})(1 + TT)$$

Using a collective system facility for treating the exceeding pollution (Strategy 3): $p_1 = \Delta p$

Type I

$$Cc = Cl.p + (St.S + K)p + e(p - p_1) + C_{Coll}\,p_1$$
$$= Cfc + e(p - p_1) + C_{Coll}\,p_1$$

Type II

$$Cc = Cfc + T.Sp_f.p + Sp_v(p - p_1) + C_{Coll}\,p_1$$

Type III

$$Cc = Cfc + T.Sp_f.p + Sp_v[(p - p_1) + \sum_{i=0}^{n}(p_i - p_{1i})] - e\sum_{i=0}^{n}(p_i - p_{1i}) + C_{Coll}\,p_1$$

Sugarcane farmers annual cost functions (referring to the generic cost function [2] in the text):

The following formulas represent the annual total cost related to nitrogen fertilising for the sugarcane farmers in the coastal area. 3 strategies are illustrated.

The following terms have been added to those employed in the previous formulas:

α = Sugarcane needs in nitrogen (Kg/ha ; here α =150)

S_s = Surface cultivated at sugarcane by the farmer (ha ; here $20<S_s<40$)

St_{sug} = Average stocking cost for sugarcane farmer (F/KgN)[7]

$Sp_{v\,min}$ = Variable average spreading cost for mineral fertilizers[8]

f = Price of mineral fertilizers (F/KgN ; here f =10)

Spreading mineral fertilizers[9]

$$C_{\min} = \alpha.S_s\,(T.Sp_f + Sp_{v\min} + f + St_{sug})$$

Spreading slurry from pig breeders

$$C_{org} = \alpha.S_s\,(T.Sp_f + Sp_v + St_{sug}.S + K)$$

Spreading both ***[10]***

$$C_{both} = T.Sp_f.\alpha.S_s + (Sp_{v\min} + f)(\alpha.S_s - p_1) + Sp_v.p_1 + (St_{sug}.S.\alpha.S_s) + K.p_1$$

[7] This average cost differs from the one calculated for pig breeders. In fact the tanks needed here are larger, and therefore the cost functions cannot be the same as in Grand Ilet.

[8] This cost (cf. Farolfi et al, 2002) is considered to be independed of the spreaded quantity of fertilizer (0.6 F/KgN). Due to the far higher nitrogen concentration in mineral fertilizers, this cost is much lower than the one we obtain through the function Sp_v.

[9] The last term of the function will exist only if the farmer decides at least once to spread slurry during the simulation time. He has therefore invested in stocking facilities. If he comes back to mineral fertilizers, he will continue to pay fixed stocking costs.

[10] This strategy is not considered in the present version of *Echos*.

APPENDIX 2: Simulation variables in *Echos*

Name	Values
Pig farmers initialised in strategy	1; 2; or 3
Sugarcane farmers initialised in stragegy	4 or 5
Do the farmers change strategy during the simulation?	Yes or No
Likelihood change stragegy 1	0 to 1
Likelihood change stragegy 2	0 to 1
Likelihood change stragegy 3	0 to 1
Collective treatment	Compost or Bio-Armor
Legal limit N (Kg/ha)	0 to 1000
Initial tax pollution (F/kg)	0 to 100
Increase every 2 years (F/kg)	0 to 20
Proportion variable TC subsidised	0 to 1
Proportion stocking cost subsidised	0 to 1
Rate utilisation machinery	0 to 1
Capacity transport N (kg)	0 to 200
Levy charged for transport services (%TR)	0 to 1
Price mineral N (F/Kg)	0 to 30
Minimum size of a sugarcane farm (ha)	20 to 40
Maximum size of a sugarcane farm (ha)	40 to 80
Price of compost (F/T)	0 to 585
Price for renting out spreading facilities (F/KgN)	1.675; 5; or 10