IMPROVING ENVIRONMENTAL MANAGEMENT IN PIG FARMS BY IMPLEMENTING KNOWLEDGE-BASED SYSTEMS

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Introduction

Brittany, a region located in Western France about 500 km from Paris, has experienced for fifty years a unique growth of livestock farming and related activities. From 1955 to 1997, the value of the livestock production grew from 643 million up to 36 935 million of former francs (1995 basis). Among the various productions, pig production has experienced one of the deepest change, from a couple of backyard sows to large industrial-like specialised pig farms. Between 1955 and 1997, the number of pigs in Brittany increased from 1.1 million to 8.8 million. About 60% of the whole French pig production is located in Brittany. This growth in production has gone along with a significant decrease in the number of farms owning pigs, which means a strong concentration of the pig production. Between 1955 and 1997, the number of farms with pigs fell from about 135 000 to just 11 200. This trend still remains with less than 9 000 pig farms in 2001. The farrow-to-finish system strongly prevails in Brittany. In the meantime, the productivity in pig farm has increased both in terms of labour and in terms of production. For instance, in 1990, a pig farmer needed 25% less time than in 1980 to take care of one sow meanwhile this same sow produced one more weaned piglet.

This has been enabled by an efficient technical information system and by the fact that development projects were driven by people involved in defining and monitoring the orientations of agriculture. We call “technical information system” of a farming sector, here the pig sector, the set of players and procedures displaying information flows towards and from farmers. This systems includes extension agents, technical advisors, feed-mill salesmen and so on. Creation and control of information and knowledge (in other word information and knowledge management) have been key factors in the success-story of the pig sector in Brittany [Montel, 2001 ; Bourgeat, 2002]

By the way, one of the consequences of this evolution of livestock farming in Brittany has been an increase in nitrogen flows at farm scale but also at watershed scale, leading to a degradation of water quality which often does not comply with drinkability standard. As rural areas have socially changed for the last twenty years and environmental values have become part of the legitimacy frame for human activities and as treating water for consumption does have a high cost, this situation has not remained neutral regarding the course of intensive livestock farming activities. Several European and national public policies have been enforced, leading to a process of change within livestock farms, and particularly within pig farms. This changes appear through new techniques such as biphasic diets for fattened pigs or manure treatment devices [Montel, 2001].

In a first section, we will establish that, if one intends to achieve the objective of a true environmental management, the required changes, although seen as technical at a first glance, are much deeper. They are related to the decision-making process.

Therefore we have been led to consider Environmental management systems (EMS) as a potential frame to improve environmental management in pig farms. In a second section, we will present the main results of an *ex ante* reflection on the likely consequences of the implementation of an EMS in a conventional French pig farm (farrow-to-finish system).

In a third section, we will show how knowledge-based system (KBS) are necessary to facilitate environmental information and knowledge management and what characteristics an environmental management KBS should have to be successfully built and used.

1. Where does the environmental problem of pig farms lie ?

1.1. Conceptual frame

First, we will consider all along this reflection that pig farms are open and controlled systems setting up their own projects. Using Le Moigne's systemic approach [1984], such systems are made of a decision-making sub-system, of an informational sub-system and of an operating sub-system. Regarding agricultural activities, the latter can be divided into two other systems. The first one gathers the labour force, the technological and financial resources. We call it the resources system. The second one is the set of biological processes controlled by the farmer. It is the bio-technical system [Landais & Deffontaines, 1991]. The decision-making process can be represented by Simon's IMC (Intelligence-Modelling-Choice) model [Le Moigne, 1974].

Farmer's actions can be represented by a set of practices which are basically the use of a technique to modify the state of one or several elements of the whole system in order to fulfil an objective. We will more precisely define a practice as a set of co-ordinated actions according to space and time, aimed at modifying the state of one or several elements of the whole system in order to fulfil an objective by using information and resources [Montel, 2001].

1.2. Beyond technical change, environment and decision-making in pig farms

A pig farm is linked to its natural environment by, among other things, various flows : organic matter, nitrates, phosphates, ammonia. As long as a kind of balance is maintained, these flows do not alter the integrity of the natural environment. Hence, one may consider there is no change in the natural environment. But, as soon as these flows modify its integrity, there is pollution. In the case of pig farming in Brittany, the increase of animal density has implied an increase of N amount to be spread per area unit. Because the cleansing capacity of the soil has been overstepped, nitrates and phosphates leaching has occurred and created modifications of the continental water ecosystem such as eutrophisation. But this pollution has an other consequence. Indeed, continental water is used as a source of drinkable water. In Brittany, one may note that some sources are closed because the nitrate drinkability standard (50 mg/l of NO_3^-) is exceeded. At that point, the ecological problem becomes an health problem and thus comes into the social environment of pig farms, challenging their legitimacy.

When we look at the process leading to this pollution [Capillon, 1992], it appears it results from an interaction between the natural ecosystem of the field (air-water-soil-plant) and the amount of nitrates and phosphates spread. The latter is resulting from the implementation of spreading practices which come after a decision-making process. At this point of our paper, we ought to conclude that pig farming systems need at least to deeply change their decision-making system to solve their environmental problems. According to Llerena [1996], this shows an organisational failure of the system.

We need now to assess how deeply the decision-making system must be changed in pig farms as to enable better environmental management which primarily means controlling nitrogen and phosphorus flows. We will accordingly use the Intelligence-Modelling-Choice frame.

Besides, we previously mentioned that the legitimacy of pig farms is also at stake, i.e. this activity has now to comply with the prevailing social values. Le Menestrel and Panes [1996] have proposed to distinguish three level of legitimacy for the decision-making process : the consequential legitimacy, the procedural legitimacy and the cognitive legitimacy. We will also use this pattern for understanding how the decision-making system is environmentally oriented.

1.3. Environment and decision-making in pig farms : an assessment.

The following statements are based on a field work made with nine pig farmers located in Brittany [Montel, 2001].

The lack of environmental intelligence

The intelligence stage of decision-making aims, in our perspective of improving environmental management, at providing the elements necessary to build a representation of the environmental state of the farm. Environmental intelligence was almost non-existent until the early 90's. Indeed, the only tool enabling the farmer to assess one's environmental impacts was the fertilisation balance which is not environmentally designed and is not whole-farm wide.

At the end of 1993, French authorities and farmers unions concluded an agreement to support a national plan for agricultural pollution control (PMPOA). Among the various measures, there was an environmental diagnosis of the farm, the DeXeL® [Dockès et al, 1995]. But this diagnosis method is partial for it deals only with nitrates and phosphates pollution due to farm wastes (animal excrements , dirty water). Moreover, in the PMPOA frame, this diagnosis has to be made by an accredited extension agent which does not favour its direct implementation by the farmer.

The intelligence step of the decision-making process remains mainly focused on technical and economic sides. Consequently, cognitive legitimacy is lacking. Besides, use of DeXeL is linked to PMPOA which is to last until 2001. One may fear once the plan is achieved DeXeL will not be used anymore, at least not widely.

Modelling and choice have almost excluded environmental issues

The modelling step is from a general point of view barely implemented by the farmer oneself [Bourgeat, 2002]. This step is often not formally made in regulation and control decision for the farmer gives greater place to « routine procedures », using Cerf and Sebillotte's words [1997]. One must note that these procedures have not been greened yet because few references are existing. They are under construction. For planning decisions, the modelling of the various alternatives is seldom environmentally sound. As these decisions bind the farm for a long time, say at least five years, pig farms may remain in a controversial situation because they cannot reach their procedural legitimacy.

Regarding the final step of decision-making, we have noticed that environmental issues do not usually determine the choice, except in the case of an external pressure (regulations, neighbours' complains, and so on) whose intensity may vary. The technical and economic dimensions are still prevailing and we think that being unable to provide sound economic assessment of environmentally-oriented choices is a great obstacle in greening the decision-

making process. We are indeed persuaded that improving environmental management may lead to better cost control in pig farms, especially through nitrogen, phosphorus and energy flows management.

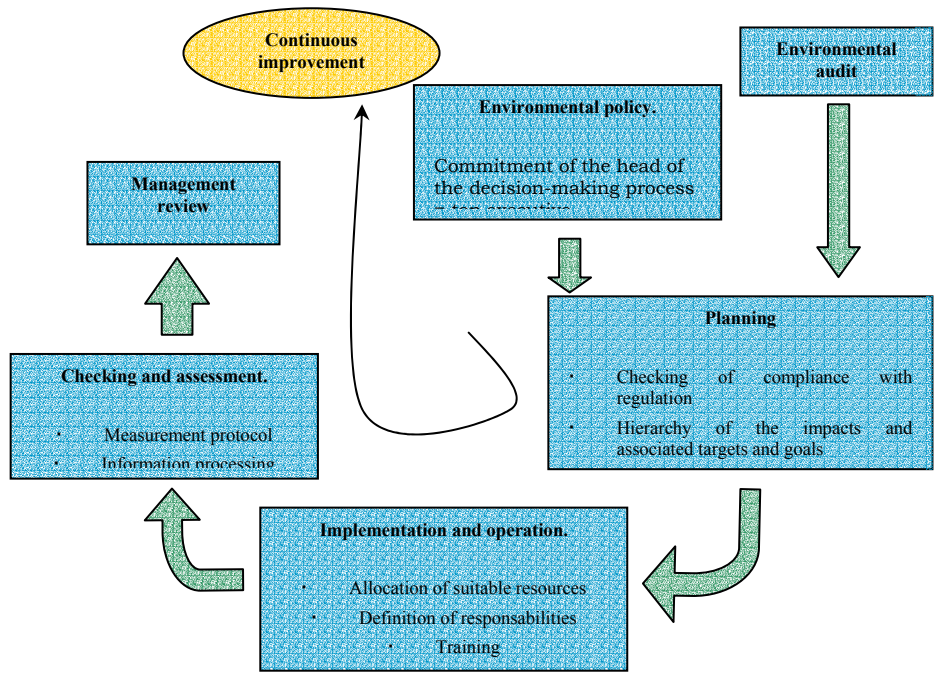
Improving environmental management requires to set up a set of management procedures targeted at the elements of the pig farming system associated with environmental risks and whose goals are to better their environmental performances. This leads us to environmental management systems (EMSs) as a frame to support the changes we have just written about.

2. An environment management system in a pig farm : an *ex ante* analysis

2.1. What is an environmental management system ?

According to the ISO 14001 standard [AFNOR, 1996a and 1996b], an EMS is a set of procedures whose aim is to enable a firm to achieve its environmental goals. The primacy is given here to the more satisfying method to build an environmentally sound decision over the best *ex ante* alternative. This is justified by the complexity and singularity of environmental issues [Llerena, 1996]. As shown in Figure 1, an EMS relies on an environmental audit and five points and is driven by continuous improvement.

Figure 1. Principles of an environmental management system.



We will now address the possible consequences of the implementation of an EMS in a pig farm. We will stay at the level of possible consequences for in France only one pig farm has fully and successfully implemented an ISO 14001 EMS so far. Nonetheless, discussions with the advisors of this pig farm seems to confirm our results.

2.2. Implementing an EMS in a pig farm. What could it mean ?

Boundaries and goals of the EMS

First of all, the system in which the EMS will be implemented has to be determined, in particular the decision-making system. At a first glance, it is quite simple : the farm seems to fit. But if we are interested in subcontracting fattening we ought to reconsider our position for decision power does lie in the hands of both contractors. So, in that case, it is not easy to tell where is the head of the decision-making system. It may depend on the sort of contract.

Once the head of the decision-making system is identified, an EMS can be implemented only if there is an actual environmental commitment. This is the very first condition to achieve it [Bezou, 1997, p.197 ; AFNOR, 1996a and 1996b ; IISD, 1996]. Such a commitment involves the farmer must change one's system of values by including environmental concern. This asks for environmental information and education being provided to pig farmers.

Intelligence and planning

Afterwards, the farmer has to ask for a comprehensive environmental diagnosis in order to draw the list and the hierarchy (according to intensity, danger and frequency) of the environmental impacts of the pig farm. Such a diagnosis can currently only be carried out by an external player : extension agent, private consultant. Nevertheless, using its results to build an EMS will require basic environmental knowledge that many pig farmers do not currently have. This diagnosis goes along with a juridical audit of the farm checking its compliance with environmental regulations, adding a new field of information and knowledge.

Planning is the next stage. This is the first step from commitment stated in environment policy towards the very implementation of EMS. Then, according to the results of the complete diagnosis, the farmer must choose the environmental impacts that the EMS will address and the corresponding targets and goals according to the environmental policy of the farm.

Building an environmental information system

In order to follow up the functioning of the EMS and to assess environmental performances, specific indicators have to be created. This means, in the current state-of-the-art, a specific research and extension work for these indicators must be designed for making decisions [Montel, 2001] :

i) they have to represent relevant elements of the systems according to both their involvement in environmental risks and the control the farmer can have on them ;

ii) they have to be measurable by technically and economically sound devices ;

iii)they have to be understandable by pig farmers.

These indicators will be the basis of an environmental information system. This information systems will be fed through a set of measurements protocols. For instance, to actually balance fertilisation, the farmer has to know how much nitrates remain in the soil. Therefore, soil analysis are required according to a sampling scheme relevant to the farmer's fertilisation goals.

Towards labour division

The very implementation of the EMS requires that the various resources (labour force, money, technologies) are adequately allocated. A formal investment plan ought to be designed, what is not a so widespread practice among pig farmers as shown by E.Bourgeat [2002]. Each

worker's responsibilities (from head-farmer to part-time wage-earner) must be defined. This demands a kind of formalisation of the labour organisation in the farm. Such a change is likely to involve an increasing functional specialisation but not a taylorian labour organisation. The question of decision-making autonomy is arising at this point : « to what extent each person is autonomous, and then responsible, in the decision-making process ? » According to the answer at the previous question, a training program for all pig workers within the farms may be necessary.

2.3. Information and knowledge management as a key for success

Besides, we have shown in other writings that implementing an ISO 14001 EMS in a pig farm may be very costly, especially for small and medium-sized pig farms [Montel, 2000 & 2001]. Therefore, we do think that the interest of such management system can only be highlighted by proving the economic interest of improving environmental management. To bring such evidences, environmental management accounting systems (EMASs) [EPA, 1995] may be suitable [Montel, 2000]. These EMASs aim at valuing environmental performances from an economic point of view and thus pointing out where environmental mismanagement prevents savings or creation of value. Here again an huge amount of information and knowledge is needed.

It seems nowadays difficult for pig farmers to extend quickly their knowledge to the environmental field at the same level than their current technical and economic expertise. Therefore, expert knowledge must be brought at pig farmers' disposal in a form requiring only basic environmental knowledge to be understood.

Information and knowledge management appears to be a key issue for improving environmental management in pig farms. Information and knowledge management in a farm relies both on a proper internal information system (see above) and on the technical information system of the pig sector. About the former, we think that it may enhance the need for a certain level of labour division within pig farms between managerial and operational tasks. Concerning the latter, an historical overview shows that between 1975 and 1990 environmental issues were largely ignored [Montel, 2001]. The new challenge faced by pig farmers is also faced by the players involved in the technical information system.

Keβeler and Schiefer [1997] have proposed to design an environmental information operational system which leads us to address the potential role for expert knowledge-based system in the implementation of environmental management systems.

3. Knowledge-bases systems (KBS) : the key for the success of the environmental management ?

As we said before, environmental management is a very new, complex an moving question that requires a new field of knowledge and information. One cannot seriously think that pig farmers will instantaneously acquire it. Therefore, a media is necessary to bring usable expert knowledge to farmers.

Looking back to recent history, we can observe that advisors, the extension officers, have successfully brought the technical and economic knowledge through the technical information system. But they generally do lack of environmental knowledge themselves. We think that a KBS designed for them could be a first step towards environmental information and knowledge management in pig farms.

Indeed, such a system could provide them with the correct (experts one), up-to-date (legislation changes rapidly) formalised methodology to analyse the environmental practices of the farmers and help them to improve their situation.

As a means of sharing knowledge, the building of a KBS involves a specific step, namely knowledge acquisition. During this step, a knowledge engineer 1. identifies the knowledge required to create the KBS (knowledge elicitation), 2. analyses it, elaborates a model to represent it and records it (knowledge documentation) [Enting et al, 1995].

Several experts should be involved in the knowledge acquisition. The aim of a KBS is actually frequently the diffusion of the knowledge of a few overbooked experts.

3.1. Knowledge based systems and decisions support systems (DSS) for pig farms : the state of the art

The analysis of the research publications presenting various systems of DSS specifically intended for the pig farmers or their advisors shows a wide variety of softwares [Bourgeat, 2002, p.182-184]. These publications are becoming more and more numerous and are concerning different components of the pig farm : pathology, growing, genetics, breeding, quality,…

Numerous data processing methods are used : dynamic linear modelling, multiple regression modelling, Markov decision process, risk functions generation,… Knowledge-based systems are also used, in addition with other components. They are sometimes interpreting raw data, and sometimes working on data produced by the other techniques.

At the same time, integrated systems start appearing on the market. They are composed of several modules, that can be purchased separately or as an integrated suit. Nevertheless, the modules based on sophisticated data processing methods do not seem to be available yet. Moreover, these systems only concern the pig unit.

So, if there are many research programs that work on the application of sophisticated data processing methods in pig farms management, the on-fields softwares available on the market still rely on basic programming. We observe a real gap between the research and the field.

However, over the past few years, they have at least integrated two innovations : Windows and the Palm Pilot Technology. Today, a new possibility is offered by the arrival of electronic chips on the market. They will permit to ease the data recording [Jon, 2001].

3.2. Characteristics of a knowledge-based system for the environmental management of a pig farm

Our own experience of KBS development in agriculture and the numerous ones related in research publications give us elements of the characteristics that an EM KBS should respect in order to be successfully used.

A environmental management knowledge-based system must be part of a wider management information system of the farm

In the future, the whole management information system of the pig farms will have to evolve toward the integration of all the components which are today separated. In fact, these components are not independent. For example, there are evident links between the pig unit and the crop system, or between the pig unit and the accounts of the whole farm. Also, if specific management information systems can help solving very short term problems, only wide integrated management information systems will support the farmer in his long term strategic decisions.

On today's DSS for pig farms, each system is based on a particular data base. The presence of various data bases is time consuming (when an information is to be present in 2 bases) and errors generating [Bourgeat and al, 1997]. An integrated MIS also is the only possible answer to that kind of problems.

We believe that integrated systems are the key to face the complexity of the management of a pig farm. Therefore, tomorrow's MIS will have to take into account all the components of the farm : technical and economic aspects, accounting problems, and others that are poorly taken into account today : management of the quality, the environmental aspects, the sanitary problems,…

All the farmers will not need a MIS that covers all the kind of decisions that a pig farmer is supposed to take once or a while. Therefore, it has to be built in a modular way. Around a common standard centre, the farmer would have the possibility to put several decision support systems (DSS) on top of it. An EM KBS could be one of these modules.

Complexity level ?

Simple or moderately complex KBS have generally known a reasonable level of success, as far as we consider their utilisation as advising tools. At the opposite, more elaborated systems have sometimes been criticised. In Great-Britain, the complexity of the model that underlies the KBS Grasplan has generated difficulties in the comprehension and the interpretation of the results by people ignoring this model [Mainland and Doyle, 1992]. Enevoldsen and al (1995) made the same observations after the development of a diagnostic and prognostic tool for dairy herd health management. This system is deliberately very large, complex and flexible. A major barrier to the adoption of this tool has been the considerable time required to understand and use it properly.

In France, a survey of 6 DSS in agriculture conducted in 1992 showed that the advisors want tools that propose reasonings that convince the farmers. The advisors consider that the existing DSS are conceptually interesting but too much time consuming and therefore hard to use in their professional activity [Desjeux and Taponnier, 1994].

In fact, as far as we consider the future adoption of the KBS, the main factor is the ratio between the cost and the benefits. The successful KBS i) were easy and rapid to use (low cost), and/or ii) had high and easy to measure benefits [Kamp, 1999].

Nevertheless, considering the evolution of the farms, it is fairly obvious that the systems used by the advisory services will have to be more and more complex. To be so, they will have to be provided with numerous and accurate information. But their development will be slow, because the advisory services are limited in their innovations by financial considerations (recurrent in agriculture) and human ones (education level of both the advisors and the farmers).

An advisor's oriented KBS

We consider that most of the DSS, including KBS, must be advisor's oriented, while much of them are initially farmer's oriented. Two kind of reasons justify this position :

- Giving to the farmer better management tools that to the advisor is not very judicious. Indeed, the advisors are afraid that their own competences and social position are disputed [Albaladejo, 1998]. They are also afraid to be pushed into second position by KBS. Fortunately, their fear is fading away when they realise than their technical role is confirmed and even renewed [Bourgeat, 2002].
- The example of a DSS of replacement and insemination strategies in pig and dairy herd [Kamp, 1999] leads us to consider that advisors should be, in fact, the end-users of many

DSS. Combined with a low frequency for use by an individual farmers, the fairly complex interpretation of results made this DSS difficult to use. Complex tools being used for other kind of decisions that short term repeated ones should be kept for the advisors.

Conclusion

We have shown how information and knowledge management is a key issue for the improvement of environmental management in pig farms mainly because environmental issues cannot be properly addressed by the decision making system : lack of environmental intelligence and modelling. We assume that this situation could be bettered through the building of environmentally-oriented KBS for i) this is a means for sharing expert knowledge ; ii) it could be a structuring project to support change in the technical information system which, as we already said, is also facing the environmental challenge.

We consider that these points are of major importance in a view of future development of the pig sector in Brittany for at least two reasons.

First, because of price pressure and accordingly the need for cost control, we think that flow management (especially nitrogen, phosphorus, energy) is an interesting approach to increase pig farm competitiveness. Meanwhile, this is the basis of managing the main environmental impacts of pig farming.

Secondly, to overstep the constraints risen by environmental issues, i.e. improving management beyond the sole compliance with environmental regulations, pig farmers need to be able to set up original production system which means i) to increase decision-making autonomy through a minimum control on environmental information and knowledge ; ii) to be given support by the technical information system and the whole pig sector [AREAR, 1997; Montel, 2001].

References

- AFNOR, , 1996a. NF EN ISO 14001. *Systèmes de management environnemental. Spécifications et lignes directrices pour son utilisation*. pp. 15
- AFNOR, , 1996b. NF ISO 14004. *Systèmes de management environnemental. Lignes directrices générales concernant les principes, les systèmes et les techniques de mise en œuvre*. pp.31
- Albaladejo C., 1998. Organisations sociotechniques locales : un potentiel de développement pour les petites exploitations agricoles de la frontière agraire de Misiones (Argentine). Pairs et experts dans l'agriculture, Technologies / idéologies / pratiques vol 12 n°1, 173-202.
- AREAR – Bretagne, 1997. *L'industrie agro-alimentaire bretonne et l'environnement. Le chaînon manquant*. Ss dir. G. Premel, AREAR, Rennes, 119 pp.
- Bezou, E., 1997. *Système de management environnemental*. AFNOR, Paris, pp.294
- Bourgeat E., Ghilardi B., Gontier V., Lapierre O., 1997. Swinytec', un système expert d'audit d'élevages porcins. Interfaces 1997, 6th International Conference of La Lettre de l'IA, Montpellier, 28-30 mai, Ed. EC2 & Développement, Paris, 87-89.
- Bourgeat E., Le Vezouet T. et Serain ME., 1992. *Etat actuel et persepctives d'évolution des pratiques d'encadrement technique et économique des élevages porcins*. CEREOPA, Paris, 91 pp.
- Bourgeat, 2002. *Systèmes d'information et de décision en élevage : contribution au développement de systèmes experts pour l'aide au conseil en élevage porcin*. PhD thesis Institut National Agronomique Paris-Grignon. 205 p.
- Capillon, A., 1992. Utilité et spécificité de l'approche de l'environnement par l'agronome. Cahiers

Agricultures, 1:113-122

- Cerf, M., Sebillotte, M., 1997. Approche cognitive des décisions de production dans l'exploitation agricole. Econ.rurale, 239:11-18
- Desjeux D., Taponnier S., 1994. L'informatique pour l'aide à la décision. B.T.I. (Bulletin Technique d'Information), Ministère de l'Agriculture et de la Pêche, 1994, 14, 32-36.
- Dockès, A.C., Capdeville, J., Farrugia, A., 1995. Diagnostic des risques de pollution des eaux dans les élevages : la méthode DeXeL. Renc.Rech.Ruminants, 2:362.
- Enevoldsen C., Sorensen J.T., Thysen I., Guard C., Grohn Y.T., 1995. A diagnostic and prognostic tool for epidemiologic and economic analyses of dairy herd health management. Journal of Dairy Science Vol 78, No 4, 947-961.
- Enting J., Huirne R.B.M., Tielen M.J.M., Dijkhuizen A.A., 1995. ZOVEX : an expert system to help solving health and production problems on pig farms. 2nd IFAC/IFIP/EurAgEng Workshop on AI in Agriculture, Wageningen, 29-31 May, 1995, 397-402.
- EPA, 1995. *An introduction to environmental accounting as a business management tool*. EPA 742-R-95-001, Washington DC, USA, pp 49.
- IISD, 1996. *Global Green Standards*. IISD, Winnipeg, Canada, pp 97.
- Jon G., 2001. *Etude des technologies (information et électronique) développées au service de la traçabilité dans les filières animales*. MSc Thesis Institut National Agronomique Paris-Grignon. 46 p.
- Kamp J.A.L.M., 1999. Knowledge based systems : from research to practical application : pitfalls and critical success factors. Computers and Electronics in Agriculture, 22, 243-250.
- Keβeler T., Schiefer G., 1997. Computer aided environmental control to support environmental management systems in agricultural and food-indutrial production chains. 1st European conference for information technology in agriculture, Copenhagen, 15-18 june 1997.
- Landais E., Deffontaines JP, 1990. Les pratiques des agriculteurs. In *Modélisation systémique et système agraire*. INRA, Paris: 31-64.
- Le Menestrel, M., Planes, F., 1996. Rationality and legitimacy. Legitimacy requirements for collective decision-making based on instrumental rationality,. actes du colloque *Ecologie, Economie et Société*, Université de Versailles Saint-Quentin en Yvelines - 23/25 mai 1996 - tome2
- Le Moigne, J.L., 1974. *Les systèmes de décision ans les organisations*. PUF, Paris, pp 244.
- Le Moigne, J.L., 1984. *La théorie du système général*. PUF, Paris, pp 320 .
- Llerena, D., 1996. Integration of environmental issues in the firm : learning processes and coordination. Working paper du BETA, n°9608
- Mainland D.D., Doyle C.J., 1992. Problèmes posés par l'introduction réussie de modèles laitiers en tant qu'outils de conseil. 4th International Conference on Computers in Agriculture. Paris-Versailles 1-3 june 1992. Société des Agriculteurs de France, Paris, 84-87.
- Montel B., 2000. Prospective analysis for implementing an environmental management system in pig farms. Likely role of an environmental management accounting system. Presented at the 4th annual conference of the Environmental Management Accounting Network, Rotterdam 13&14 December 2000. 10pp.
- Montel B., 2001. *Environnement et changement des pratiques dans des élevages bretons : intérêt des systèmes de management environnemental*. PhD thesis Institut National Agronomique Paris-Grignon. 184 p.