Agricultural Land Design Modelling: a methodological proposal

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1 - Introduction

Sixty years after its launching through the «Marshall Plan», the European agriculture revolution is up again, but with some strong contradictions: water pollution, landscape uniformization, ethical crisis (Fresco, 2000). These harmful side-effects of agriculture could be aggravated if the evolution of agricultural practices continues following the current trends towards greater concentration, intensification and technicality. We focus our paper on agricultural practices, from their choice by farmers decisions to their effects, as they continuously remodel our agricultural landscapes. The approach of farming systems as landscapes "builders" is a new one, but its background is the vision of land as resource for agriculture (de Wit, 1992; Lardon et al, 1990).

In spite of some encouraging results in reducing pollution through rationalisation of the use of fertilizers and pesticides (Baudoux et al, 1998; Benoît, Papy, 1998; Küng-Benoit, 1992; Le Houerou, 1994), the European experience shows that the optimisation of practices from the sole agricultural point of view is not sufficient to ensure sustainability, but will rather lead to increased environmental damage.

Agronomic measures specifically designed to maintain soil, water and air quality are necessary, including more severe regulations restricting intensification and the agricultural use of chemicals. For instance, keeping the nitrate content of drainage water to less than 50 $mg.l^{-1}$ requires not only an optimized and reduced application of fertilizers, but also the planting of catch crops during the winter. Parts of the hydrological basins in many areas should be withdrawn from arable cropping and turned into grasslands or forests (several authors in Lemaire and Nicolardot, 1997). Preventing runoff erosion and the associated pollution of surface water (especially by pesticides) needs grassland strips, ditches, or other structures placed in suitable strategic locations in a catchment. Again, similar conclusions could be drawn about many other environmental targets, such as biodiversity, or landscape quality and accessibility (Boiffin et al., 2000).

The farmer practices are the focus point of researchers who built tools to help their changes (Benoît et al, 1990). In this paper we propose a methodogical approach of farmer practices involved in the land designing through land uses and land pattern changes.

2 - The double bind (in reference to Bateson works) between landscape and agriculture

In accord with the Bateson works, we want to focuse on the mutual relationship between land and farmer practices: on the one hand, the current state of the land is a result of farming practices and changes in landscapes could not be decided without farmers participation, but on the other hand, the choice and location of cropping and grassland systems by farmers all over the world takes into account their own land characteristics.

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2.1 - Land as a result of farming practices

A number of farming systems researchers have shown the central role played by landuse patterns and farmer's practices in the evolution of soil erosion, surface and ground water quality as well as of animal diversity.

Example A.: Agricultural intensification, landscape changes and runoff in Kraichgau (Germany) (Herrmann *et al.*, 2003 ; Dabbert *et al.*, 1999 ; Dabbert *et al.*, 2002)

The Kraichgau region extends in the north-western part of Baden-Württemberg. As a result of a combination of relatively high average annual temperature (9° C), an average rainfall of 700 mm per year and extremely fertile soils (Loess), this area has had a long tradition of agricultural use. In most communities of the Kraichgau region, land consolidation and modern agricultural techniques have led to a change of the former landscape structure (e.g. terracing).

Despite the hilly topography, most areas are now characterised by large arable fields, with significant volumes of row crops and only a few remaining landscape elements such as hedges and ridges. Under these conditions, run-off of water causing erosion and consequent flooding are increasingly problematic. Nutrient inputs by erosion to the remaining biotopes cause degradation of the formerly oligotrophic plant communities. Additionally, recent rainfall events have been giving rise to rapid water runoff from arable fields either directly into residential areas or into river systems that subsequently flood downstream.

A recently started research project tries to tackle these problems of water management through agricultural measures that will 'hold water up on the land' and so avoid or reduce the need for expensive (and intrusive) engineering solutions. Further on, the landscape impacts of different agricultural management options should be presented to local residents and other interested stakeholders. Such communication and participatory activities are regarded as central to ensuring the long-term implementation of the relevant measures and, therefore, the project intends to use a combination of GIS and virtual reality display techniques to help engage farmers and other interested parties in decisions regarding the planning of agricultural measures on a landscape scale.

Example B. Landscape changes and runoff, in Rhin watershed-Central Europe (Van Dijk et al, 1996a; Van Dijk et al, 1996b) and in Danube watershed (Vogel et al, 2002):

The key problem to be addressed is that of surface water runoff and soil erosion leading to flood damage. In Central Europe, the problems with recent rainfall events giving rise to rapid water runoff from arable fields either directly into residential areas or into river systems that subsequently flood downstream. The levels of runoff have also contributed to soil erosion that reduces agricultural productivity and in some cases brings soil onto roads and into residential areas. Current predictions of climate change suggest that the frequency of such intense rainfall events is likely to increase in the future.

Our approach is to tackle these problems of water management through agricultural measures that will 'hold water up on the land' and so avoid or reduce the need for expensive (and intrusive) engineering solutions. We feel that through a carefully designed comparison of different measures in these areas we can gain important insights into the effectiveness of different approaches and by working together with farmers demonstrate the practical application of such technique to those involved in the formulation of agri-environmental policies.

The final issue concerns the integration of the research findings into planning and policy frameworks. We anticipate that this will need to take different forms in particular countries, but envisage that it will occur through input into the formulation of landscape and regional plans, agricultural subsidy programs or agri-environmental schemes like the MEKA program in Baden.

These examples show that in many instances environmental issues may be converted into farming systems questions in which the activities of farmers and their changing location from the new picture is the focus point of problem solving (Gaury, 1992; Benoît, Papy, 1998). A number of new research tools such as remote-sensing data and Geographical Information Systems are now available to address this type of research (Benoît *et al*., 1997).

2.2 - Land as a factor of farmers practices.

In most cases, farmers are seen to take into account the properties and layout of their land in deciding about the location of their cropping and grassland systems (Morlon & Benoît, 1990). This relationship between farmers and their territory could be an individual or a collective one (Le Gal, Papy, 1998) The role of land characteristics and environmental constraints on land use is illustrated by the following example:

Example C - Rules of field use and pasture practices in the French Atlantic marshes (Espalieu, 2003, poster Pons *et al*. In IFSA-2004-workshop 3):

Most farms in the French Atlantic marshes have fields both in and out of the mashes, some quite far apart. The main land constraints on field use and practices are related to water excess in some fields preventing machine work or cattle access at given periods of the year, clay sodicity causing soil structural instability, again hindering field work and access, and distance from farm buildings. As these factors vary largely over farmland, they determine the patterns of land use and practices over the farms.

In short, best fields, i.e. the fields that are the less sodic, inundated and far away, are dedicated to the highest return crops (usually maize in the context), whereas the worst fields are pastures. So a direct relationship is shown between land characteristics and use (ALMS). However this simple relation should be corrected for other factors (field relative dispositions, slopes) and may be suppressed when work organization takes priority, as when the farmer has a herd. Similar rules of use can be also found in the management of pastures (hay or grazing, types of animals).

It is interesting to note that in the marshes, the water factor is subject to a collective management occurring at the scale of a small region. The rules of this management and its interaction with individual farm management should provide a model of interaction at different scales.

Example D - Landscape changes and types of farming systems in the Vosges mountains-France (INRA-ENSSAA, 1977).

Location of farm fields is related to farm type. Crossing a farm typology with farm field location in each type shows the role played by small farms (part-time farmers) in slope management. The continuing decrease in the number of these farms has a major impact on landscape evolution in the Vosges mountains. A main consequence on Vosges landscape is the increasing place of planting forest. The actual state of these new forests (planted from 1830 until now) depends on the fertility level during the plantation. So, the agricultural past of the actual forests is a major factor of forest declining in these zones (Koerner, 1993)

Example E. Management of farmyard manure (FYM) and groundwater pollution in Lorraine-France (Kung-Benoit, 1992; Le Houérou, 1993; Teilhard de Chardin, 1990).

The location of FYM spreading has an effect on groundwater quality. When farmers choose to spread all their organic manure on soils with good trafficability, they make a logical decision with regard to management of their agricultural production but a disastrous one for water quality. If soils are trafficable, then they are also permeable and the issue of water quality under such soils is a major one. A vicious circle ensues. Soils permeable to water are also trafficable for heavy machinery (silage, FYM spreading in winter). The only solution at present would be to spread FYM elsewhere or in another form. For this it is proposed to replace FYM by an alternative form of manure that may be spread on grasslands in spring «and summer. This involves working with the farmers on farmyard manure composting.

3- A methodological approach for the study of agricultural land use / environment relations: the Agricultural Land Management System (ALMS)

Whether we want to study the effect of agriculture on landscape or its dependence on land characteristics, a precise knowledge and description of agricultural practices is a necessary preamble. Our aim is to advance on this way by proposing a model of farmer's management of their land focussed on the relations between farmer's practices and agricultural landscape. This model built at farm scale should be extensible to discuss processes at regional scale.

Three steps are necessary for this modelling: (1) the identification of land parts, as conceived by farmers, (2) the identification of farmer's practices, for each crop rotation or grassland management, (3) the identification of rules indicting how the practices are applied to the farm's particular land, with the farmers decision rules as background.

3.1 - The identification of land pattern with the farmers definitions

It is important that fields be defined by the farmer's rules, because if the aim is to understand (and foresee or influence) their reasons, logics and strategies, then we have to consider the objects on which these rules apply, which would be different from fields defined by other means, administrative divisions or else.

All over the world, "the farmers have good reasons to do what they do". This primitive hypothesis of SAD research department in INRA, needs researches on the modelling of farmer practices. For our purpose, the first practices to identify are the patterning of land created by the farmers. We identify these practices with the farmers definitions, their own characteristics, their own land qualification.

3.2 - The identification of crop or grassland practices of the farmers

The practice here is intended as including the choice of crops by the farmers, as well as the operations that are applied to the plots to cultivate these crops.

One central point is that in Europe, the farmer decisions are not taken "crop per crop" but on a crop/grassland rotation series, that is, on a multi-plot and multi-year scale. For example, if we can see a wheat field in a landscape, it is not obey the same logic rules if this wheat is in the first or the third rotation we described above.

So it is important that the description includes not only the result (list of crops and pastures and operations) but the rationale behind them.

a- Definition of Agricultural Land Management System:

The land used by agriculture can be modelled as a complex and dynamic pattern of fields, including tilled plots and pastures. M. Sebillotte, in the 1st European Society of Agronomy Congress, defined the "cropping system" as a set of crop management procedures used on a homogeneously treated space inside a farm, which can be a field, or a part of field, or several fields. According to this definition, a given cropping system is a component of a farming system, and is identified (characterised) by the sequence of crops and corresponding technical operations (Sebillotte, 1990a).

The cropping system is a tool to characterize land use on the tilled part of farms (Sebillotte, 1990b). However many farms have not only tilled crops but comprise also pastures. So if we want to reason at farm scale, it is necessary to generalize the concept of cropping system by including grasslands.

So we propose to name **Agricultural Land Management System (ALMS) the system of crop and grassland management procedures used on an portion of land** (which can be a field, or a part of field including its the boundaries, or several fields). According to this definition, a given ALMS is a component of a farming system, and is identified (characterised) by the choices of the rotation of crops or grassland uses and the farmland structure.

This definition should be completed by including also common items such as hedges, fences etc. that are components of the landscape and play a role in farm management (Burel, Baudry, 1990; Baudry et al, 1998).

The position of ALMS in a framework of farming system research is illustrated in figure 1.

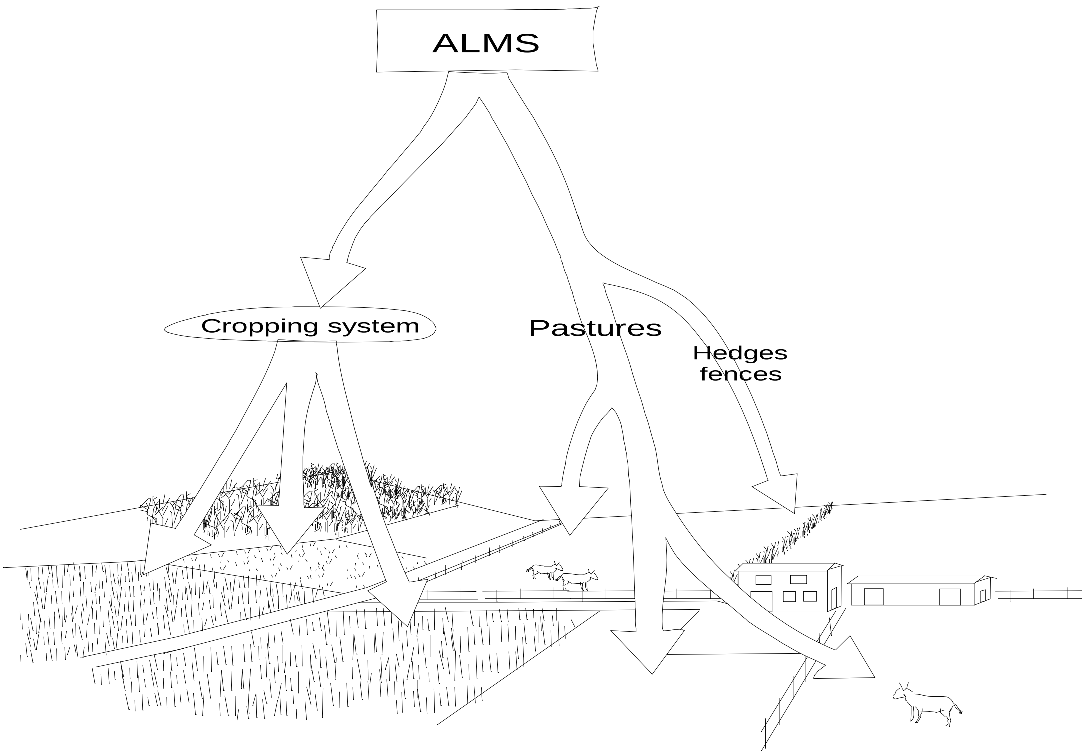

Figure 1. Agricultural Land Management System, a framework of farming system research on Land designing

For us, the ALMS is the basic unit of landscape design at farm scale. At a regional scale, other land uses and actors outside farms should be taken into account (forests, waters, “wild” areas), according to the aims of the models (environment, leisure …) as well as collective farmers’ organizations.

b - A proposal of European notation for crop rotations and grassland management:

As a tool of representation and understanding of the interactions between agriculture, land and environment, ALMS could be used as well for research as for management and negotiations in agroenvironmental policies. Especially in this respect, is would be important to speak a common language. Although the agricultural practices we are familiar with are far from covering the whole range of existing systems, we shall propose a method for establishing a nomenclature of ALMS, that could be used in other cases as well as in the examples given.

The origin of these proposals lies in a number of monographs done for a large diversities of farms in a European research project ("Regional Guidelines to Support Sustainable Land Use by EC-Agri-environmental Programmes (EAP)", AIR 3 CT94-1296). These monographs covered parts the Netherlands, Germany, France. This first large range of landscape building monographs meet the works of Pierre Morlon (Morlon, Benoît, 1990), and the French project FORTE ("Formes d'ORganisation Territoriales à finalités Environnementales": Land Mangement to Preserve Natural Resources; managed by Jacques Baudry) as illustrated by Thenail et al., in IFSA-2004Congress-workshop3.

So, we propose a common notation of land use descriptions (figure 2) with two characteristics (i) description of the land uses as they are described, managed and decided by the actors, (ii) account of time scales as first organisational factor (Mari&Napoli, 1997).

All over Europe, the farmers have each year to allocate their crops and grassland uses in their territory. This annual adjustment between chosen crops and field plots results in different perennial rotations of crops and grassland use types (Kareln et al, 1994). Examples are:

- in Denmark : maize/ maize / winter Wheat/Barley
- in south west France without irrigation : sunflower/ winter Wheat/ barley
- in the East region of France : oil rapes-winter wheat
- in the plain of Rhein in Vorarlberg (Austria): maize/maize/temporary grassland for mowing (3 years).

These notations describe yearly sequence of crops or pasture use as they are conceived by farmers: this has the advantages of corresponding to the planning structure of the farmer, which reasons rotations over several years, and to allow a stability of land use descriptions over years, whereas crop by crop descriptions would vary each year.

However they lack the account of the logic behind the simple crop rotation description, although some hints may be given (such as maize for silage vs maize for sale) which complete the raw fact description, so these notations cannot yet be fully counted as ALMS nomenclature. In the future, our aim is to contribute to build a framework of farmer rules used to build rotations. The first work done by Aubry et al (1998) shows the importance of delay between two crops, sowing and harvesting dates, machinery choices.

Examples of use of the proposed European cropping/grassland management systems are given in Figure 2.

For crops:

M / wW / wB..ic /

= Maïs/ winter wheat / winter barley with intermediary crops in automn after harvesting.

For grassland:

.../ hC – tPH2 /...

.../ /... = each year the uses are the same

hC = mowing for hay making

tPH2 = turning Pasture For Heifers 2 years old

Figure 2: Nomenclature of crops and grassland uses sequencies

3.3 - The building of logic rules with the farmers decision rules as background

With a comprehensive survey, we can reach the decisions taken by farmers concerning their land. A lot of factors are described by European farmers: land tenure, accessibility (roads, ways), field soil, slope, boundaries (forests, roads, rivers), distance from the farmstead, size of this field, proximity of other fields, irrigation suitability, ... All of them have a specific local weight.

We propose to use the Artificial Intelligence capabilities to modelize these rules (Le Ber, Benoît, 1998). For example, the simulation system MOSTAR is built on three modules:

- determination of homogeneous regions of land (soil criterias, slope, distance of building) (Figure 3),
- choice of a production system and calculation of crops and grassland need for this system. Three types of system are actually discribed for mixed farming in Europe (extensive milk – hay - cereals; intensive milk –maïs; intensive crops- intensive milk),
- affectation of land uses in the farm territory. The rules are kepted by qualitative surveys with farmers.

The MOSTAR system allows to observe the succesive application of land uses on the farm territory. So, we can evaluate the current competitions between land uses. The figure 4 presents the final result of the simulation in the case of intensive milk – maïs system on the territory illustrated in figure 3.

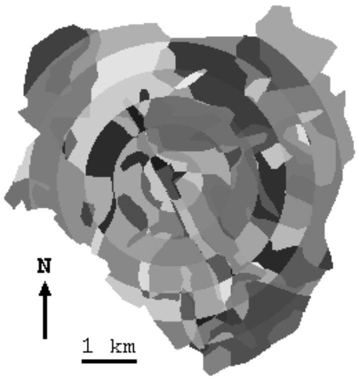

Figure 3. Homogeneous regions in Lignéville territory (Vosges, France): segmentation on farmer classification (soils, slopes, distances between fields and building).

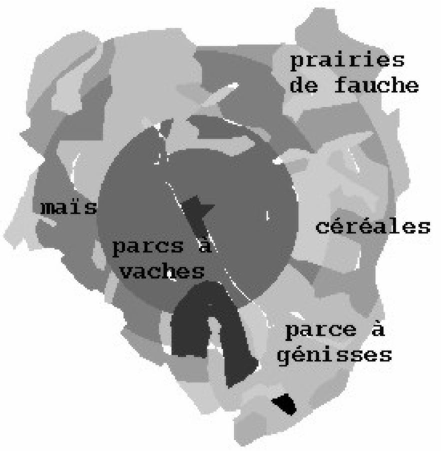

Figure 4 . Map of land uses locations simulated for an intensive milk-maïs system with 420 milk cows in the Lignéville village (Vosges, France).

Conclusion

1 The concept of ALMS that we propose is a generalization of the cropping system concept to meadows, field boundaries when they are tended by the farmers and other areas managed by the farmers. We want to focuse on the logical dimension of this system which is man managed, man thinked, and man evaluated. For us, farmers are land designers, as for other researchers they are food producers.

2 we think that this concept is relevant and can be useful :

- it will help research on agriculture/environment relations by providing types of land use that convey the farmer’s strategy, independently of year to year changes that characterise crop rotations; these types of land use are stable over several years and can be related, on one side to field characteristics and constraints, and on the other side to environmental effects.
- it will facilitate discussions between farmers and other actors of rural territories by setting a common language and allowing an objective description of agricultural land use types.
- the concept of ALMS, by considering the middle-term strategy of the farmer, frees itself from the infinite diversity of actual crop successions and facilitates the comparison between fields similarly managed in different farms, and hence facilitates the extension of cropping system research to the territorial and multi-year scales, which are relevant to environmental questions.

3 The concept of agricultural land use system is a first step towards the precise description and classifications of all types of land uses intervening in a region. In order to understand and manage the evolution of landscapes, it will be necessary to include non agricultural uses: forests, waters (in marshes, waters are subject to a particular type of collective management), roads and roadsides etc. ALMS should then give place to the more general LMS (Land Use Systems).

4 Are landscape problems an effect or a consequence of farmer practices? This question is not merely semantic; it is also a social one. If we take "effect" as meaning "the future result of a voluntary action", and "consequence" as meaning "a sideline, involuntary result of an action", then landscape problems are almost always the consequences and not the effects of the farmers' practices. Therefore, the "actors" must be enlightened about the links between their objectives, their practices and the consequences of their practices (Gras *et al.*, 1989). To be more precise, this means that as partners investigating this type of issue we must not set out from the assumption that a farmer has voluntarily deteriorated the landscape parameter that is being investigated.

5 How can we test different scenarios for the actors? Two types of scenarios may be developed based on the following argumentation: "What.... if...", and "How....to....". Research methods to address these two types of scenarios taking into account the analysis of farmer practices and modelling of decision making are to be developped (Attonaty et al, 1999; Affholder et al, 1998)).

The model-building process serves as a tool to construct and discuss scenarios with the actors (Cox, 1996). In our work with farmers, two approaches are used: farmers are taken as "research objects" and as "research subjects". Two main model-building procedures are used: mathematical ones involving methods used in landscape ecology and linear programming, and graphic ones. We shall elaborate on the second procedure, since the first one is well known.

Drawing may be viewed as an interactive form of research: the ability of most people to understand a drawing is used in discussing research results. One research approach developed by geographers (Brunet, 1986) is to represent spatial problems using a dictionary of graphic symbols or "choremes". Using this form of qualitative modelling proves most useful in discussions with a wide number of people: drawing is a universal language. This enables us to build models of farmer practices in their spatial dimension. A potential further development in this direction is the use of 3D visualisation to facilitate the understanding of the land use and landscape changes. Lovett et al. (2003) show an example of using such technique to visualise landscape changes caused by introducing new management techniques (mulch seeding) or additional landscape structures (hedges) to the farmers involved in the procedure.

6 LMS is a pragmatic research object useful to explain land use changes, and we propose to apply our fisrt modelling processes to understand the recent changes and to propose for the future new land uses (Fresco, 1993; Benoît & Muhar, 1993) . So, logically, our works will take place in the international project LUCC (Land Use and Cover Changes) and we invite our communauty to participate to this worldwide research project (Lambin et al, 1999). The challenges for land uses changes are not only european localised, as we show in this paper, but they are also worldwide to manage (Lambin et al, 2003).

7 To end with an ethical posture (Jonas, 1990), we propose a new researcher behaviour: investigating this type of issue we must not set out from the assumption that a farmer has voluntarily deteriorated the landscape parameter that is being investigated. This corresponds to the development of a «decision agriculture» (Miflin, 1997) that is increasingly knowledge-based, and increasingly rooted in the information and communication sciences and technologies and to a sustainability trend with a new weight of land capabilities (Vereijken, 1992; Jordan et al., 1997). We agree with Boiffin *et al.* (2000): “This does not, however, mean a technology-driven process of innovation, but on the contrary increased feedback of action and decision into the design of innovation”...mainly on land design management innovation!

References

Affholder, F., Bonnal, P., Jourdain, D. and Scopel, E. (1998) Small scale farming diversity and bioeconomic variability : a modelling approach. Proceedings of the 15th International Symposium of the association for farming systems research-extension. Pretoria, pp. 952-959.

Attonaty, J.M., Chatelin, M.H. and Garcia, F. (1999) Interactive simulation modelling in farm decision-making. Computers and Electronics in Agriculture 22, 157-170.

Aubry, C., Papy, F. and Capillon, A. (1998) Modelling decision-making processes for annual crop management. Agricultural systems 56, pp. 45-65.

Baudoux P., Kazenwadel G., Doluschitz R., 1998. On-farm effects and farmer attitudes towards agri-environmental programmes : a case study in Baden-Wüttemberg. In : Brossier J., Dent B. (eds) : Gestion des exploitations et des ressources rurales. Entreprendre, négocier, évaluer. Farm and Rural Management. New context, new constraints, new opportunities. Etud. Rech. Syst. Agraires Dév., 1998: 333-356.

Baudry J., Jouin A., Thenail C., 1998. La diversité des bordures de champ dans les exploitations agricoles de pays de bocage. In : Brossier J., Dent B. (eds): Gestion des exploitations et des ressources rurales. Entreprendre, négocier, évaluer. Farm and Rural Management. New context, new constraints, new opportunities. Etud. Rech. Syst. Agraires Dév., 1998: 117-135.

Benoît, M., Fiorelli, J.L., Morlon, P., & Pons, Y. (1990). Technical management: a central point for agronomy challenge. First European Congress of Agronomy, Session V-01. Paris. European Society of Agronomy.

Benoît, M., & Muhar, M.C. (1993). Farmers, landuse and groundwater quality: an interdisciplinary approach. Congress "Future of the Land", Wageningen.

Benoît M., Deffontaines J.P., Gras F., Bienaimé E., Cosserat R., 1997. Agriculture et qualité de l'eau. Une approche interdisciplinaire de la pollution par les nitrates d'un bassin d'alimentation. Cahiers Agricultures, 6: 97-105.

Benoît M., Papy F., 1998. La place de l'agronomie dans la problématique environnementale. *Les dossiers de l'environnement de l'INRA*. 17 : 53-62.

Boiffin J., Malézieux E., Picard D., 2000. Cropping systems for the future. 3rd International crop science congress.17-22 august 2000. Hambourg (Germany). 13p.

Brunet R.,1986. « La carte-modèle et les chorèmes », Mappemonde, n° 86/4, 1986 : 3-6.

Burel F., Baudry J., 1990. Hedgerow network patterns and processes in France. In: Zonneveld & Forman (eds), Changing Landscape : an ecological perspective. Springer, NY: 99-120.

Dabbert, S., Herrmann, S., Vogel, T., Winter, T. and Schuster, H., 2002. Socio-economic analysis and modelling of agricultural water demands and land use. In: German Programme on Global Change in Hydrological Cycle Status Report 2002 (Phase I, 2000-2003). Hrsg.: BMBF.nnb:nnb, 2002, 55p.

Dabbert, S; Herrmann, S.; Kaule, G. & M. Sommer (Hrsg.) (1999): Landschaftsmodellierung für die Umweltplanung. Springer Verlag, 260p.

Cox, P.G. (1996) Some issues in the design of agricultural decision support systems. Agricultural systems 52, 355-381.

Espalieu D., 2003. Modélisation de la localisation des pratiques agricoles en Marais de l'Ouest. Mémoire DAA INAPG-INRA SAD Saint-Laurent-de-la-Prée.

Fresco L., (ed.), 1993. Future of the land. Wageningen.

Fresco, L., 2000. Crop science: scientific and ethical challenge to meet human need.3rd International crop science congress.17-22 august 2000. Hambourg (Germany). 11p.

Gaury F., « Systèmes de culture et teneurs en nitrates des eaux souterraines : Dynamique passée et actuelle en région de polyculture élevage sur le périmètre d'un gîte hydrominéral », Doctorat de l'Ecole Nationale Supérieure Agronomique de Rennes, 1992.

Gras, R., Benoît, M., Deffontaine J.P., Duru, M., Lagarde, M., Langlet, A., & Osty, P.L. (1989). Le fait technique en agronomie. Activité agricole, concepts et méthodes d'étude. Paris, co-éd. INRA-L'Harmattan. 160 p.

Herrmann, S., Dabbert, S. & H.-G. Schwarz-von Raumer (2003): Ecological threshold values as indicators for biodiversity – economic and ecological consequences. Agriculture, Ecosystems and Environment: 493 – 506.

INRA-ENSSAA (1977). Pays, paysans, paysages dans les Vosges du Sud. Paris. INRA. 167 p.

Jonas, H. (1990). Le principe de responsabilité. Une éthique pour la civilisation technologique. Paris. Editions du Cerf. 336 p.

Jordan, V.W.L., Hutcheon, J.A. and Donaldson, G.V. (1997) The role of integrated arable production systems in reducing synthetic inputs. Aspects of Applied Biology 50, 419-429.

Karlen, D.L., Varvel, G.E., Bullock, D.G. and Cruise, R.M. (1994) Crop rotations for the 21st century. Advances in Agronomy 53, 1-45.

Koener W., (1993.) L'histoire de l'utilisation du sol et le dépérissement de la forêt vosgienne à l'échelle locale ou parcellaire. Mémoire de Maîtrise de Géographie. Université Panthéon-Sorbonne.106 pages + annexes.

Küng-Benoît, Annie (1992). Réduction de la pollution nitrique : exemple d'un diagnostic en Lorraine. Fourrages, 131, 235-250.

Lardon S, Deffontaines JP, Baudry J, Benoît M, 1990. L'espace est aussi ailleurs. In : Brossier J, Vissac B, Le Moigne JL, éd. Modélisation systémique et système agraire. Décision et organisation. Paris : INRA, 321-37.

Lambin E.F., Baulies X., Bockstael N., Fischer G., Krug T., *et al.*, 1999. Land-use and land-cover change (LUCC): implementation strategy. *IGBP Rep. 48, IHDP Rep. 1*0, Int. Geosph.-Biosph. Program., Int. Hum. Dimens. Glob. Environ. Change Program., Stockholm/Bonn.

Lambin E.F., Geist H. J., Lepers E., 2003. Dynamics of land-use and land-cover change in tropical regions, *Annual Review of Environment and Resources*, 28:205–241.

Le Ber F., Benoît M., 1998. Modelling the spatial organization of land use in a farming territory. Example of a village in the Plateau Lorrain. Agronomie, 18, 103-115.

Le Gal, P.Y. and Papy, F. (1998) Coordination processes in a collectively managed cropping system : double cropping of irrigated rice in Senegal. Agricultural systems 57, 135-159

Le Houerou B., « Transfert du fumier des cultures vers les prairies en Lorraine. Outils et méthode pour changer de pratiques », Fourrages, n° 140, 1994, p. 471-488.

Lemaire, G. and Nicolardot, B. (eds) (1997) Maîtrise de l'azote dans les agrosystèmes. INRA Editions, Paris, 333 p.

Lovett, A.; Herrmann, S.; Appleton, K. and T. Winter (2003): Landscape Modelling and Visualisation for Environmental Planning in Intensive Agricultural Areas. In: E. Buhmann, S. Ervin (eds.) Trends in Landscape Modeling, Wichmann, Heidelberg, pp.114-122

Mari J.-F., Napoli A., 1997. Modèles stochastiques pour la classification de signaux temporels. *Actes des cinquièmes rencontres de la société francophone de classification*, pages 51-54.

Miflin, B.J. (1997) Sugar beet production : strategies for the future. In : Proceedings of the 60th IIRB Congress, IIRB, Brussels, pp. 253-262.

Morlon P., Benoît M., 1990 - Etude méthodologique d'un parcellaire d'exploitation agricole en tant que système. Agronomie, 1990 (6) : 499-508.

Sebillotte, M. ,1990a. Some concepts for analysing farming and cropping systems and for understanding their different effects. In : Scaife, A. (ed) Proceedings of the first Congress of European Society of Agronomy, volume 5, European Society of Agronomy, Colmar, pp. 1-16.

Sebillotte M., 1990b. Système de culture, un concept opératoire pour les agronomes. In : Les systèmes de culture, L. Combe et D. Picard (eds.), INRA éditions, 165-196.

Teilhard de Chardin, B. (1990). Gestion des déjections de bovins et pollution par les nitrates. Diversité des pratiques dans les élevages laitiers du Plateau Lorrain. Etudes et Recherches sur les Systèmes agraires et le Développement, 18. Paris. INRA. 46 p.

Van Dijk, P.M., Van der Zijp,M. and Kwaad, F.J.P.M., 1996a. Soil erodibility parameters under various cropping systems of maize. Hydrological Processes, 10 (8), 1061-1067.

Van Dijk, P.M., Kwaad, F.J.P.M. and Klapwijk, 1996b. Retention of water and sediment by grass strips. Hydrological Processes, 10(8), 1069-1080.

Vereijken, P. (1992) A methodic way to more sustainable farming systems. Netherlands Journal of Agricultural Science 40, 209-223.

Vogel, T., Herrmann, S., Dabbert, S., Winter, T., and Schuster, H., 2002. Socio economic analysis of agricultural water and land use. Poster, X th Congresse of the European Association of Agricultural Economists (EAAE) "Exploring Diversity in the European Agri-Food System", Zaragoza, Spain, 28-31.08.2002.

WIT, C.T. de (1992). Resource use efficiency in agriculture. Agricultural Systems, 40, 125-151. Elsevier.